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Padova 15-17 September 2026

ABSTRACT BOOK

a cura della Società Geologica Italiana

SGI-SIMP 2026 PADOVA

Ter(r)ra: Risorse, Rischi, Rispetto

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Piazza delle Erbe, Padua, Italy (Photo courtesy of Lara Maritan)

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L’associazione Un Sasso per Leonardo ETS è stata fondata in ricordo di Leonardo Zanin, un bambino di Santa Caterina d’Este (Padova), mancato nel 2024 per una malattia incurabile.
Leonardo era un bambino meraviglioso e speciale, molto creativo, con un sorriso immenso e una grande forza e voglia di vivere.
L’associazione supporta iniziative rivolte a sostenere la ricerca scientifica sui tumori pediatrici, nonché le cure, l’assistenza e l’accoglienza ai piccoli malati oncologici del territorio della Bassa Padovana e alle loro famiglie.

L’idea di portare un **Sasso colorato in giro per il mondo** nasce dal desiderio di tenere vivo il ricordo di Leonardo e trasformare il dolore della sua perdita in un messaggio di speranza e solidarietà.

“Chiunque trovi un sasso è invitato a portarlo in un nuovo luogo e a diffondere il messaggio.
È un piccolo gesto che unisce le persone e le sensibilizza sull’importanza della ricerca, affinché un giorno nessun bambino debba più affrontare ciò che ha vissuto Leonardo”




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Scientific Drilling Town Hall Meeting

15 Settembre 2026

Sala Carraresi 18:30 – 19:30

SGI-SIMP 2026 - Padova Congress
Via N. Tommaseo, 59 Padova

Programma

Modera Ilaria Mazzini, *Istituto di Geoscienze CNR, Roma*

Partecipazione italiana a International Ocean Drilling Programme (IODP^3) e International Continental Scientific Drilling Program (ICDP)
Angelo Camerlenghi - Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, OGS, Trieste

Drilling Overdeepened Alpine Valleys (ICDP Project DOVE)
Giovanni Monegato - Istituto di Geoscienze CNR, Padova

Drilling the Ivrea-Verbano zone (ICDP Project DIVE)
Alberto Zanetti - Istituto di Geoscienze CNR, Pavia

New England Shelf Hydrogeology (IODP^3 Expedition 501)
Valentina Rossi - Istituto di Geoscienze CNR, Pavia

Impact of Petit-Spot Magmatism on Subduction Zone Seismicity and Global Geochemical Cycles (IODP^3 Expedition 502)
Francesco Narduzzi - Dipartimento di Scienze della Terra e dell'Ambiente, Università di Pavia

Hadal Trench Tsunamigenic Slip History (IODP^3 Expedition 503)
Claudio Robustelli Test - Dipartimento di Scienze della Terra, Università di Torino

L'evento, di carattere informale, è aperto ai partecipanti al Congresso Congiunto SGI-SIMP

Verrà offerto un rinfresco

Invitiamo inoltre i partecipanti a visitare lo spazio espositivo di IODP – Italia durante l'intera durata del congresso

ISTITUTO NAZIONALE
DI GEOFISICA E VULCANOLOGIA



L'Istituto Nazionale di Geofisica e Vulcanologia (INGV) è stato costituito con Decreto legislativo 29 settembre 1999, n. 381, dalla fusione di cinque istituti già operanti nell'ambito delle discipline geofisiche e vulcanologiche: l'Istituto Nazionale di Geofisica (ING), l'Osservatorio Vesuviano (OV), l'Istituto Internazionale di Vulcanologia di Catania (IIV), l'Istituto di Geochimica dei Fluidi di Palermo (IGF) e l'Istituto di Ricerca sul Rischio Sismico di Milano (IRRS).

Il mandato istituzionale dell'Ente comprende il perseguimento di obiettivi di osservazione dei fenomeni e di sviluppo delle conoscenze scientifiche sul Sistema Terra nel suo complesso, in forte interazione con l'attività tecnologica, la gestione e lo sviluppo delle infrastrutture di ricerca e la realizzazione di attività con potenziale significativo impatto sulla popolazione e sulle diverse componenti della Società. Tutte le suddette attività necessitano di un'azione amministrativa che è di supporto e facilitazione ai ricercatori e tecnologi INGV.

In quanto struttura operativa del Servizio Nazionale di Protezione Civile, ai sensi del proprio decreto legislativo 381/1999 e del decreto Legislativo 1/2018, all'INGV sono affidati il monitoraggio e la sorveglianza della sismicità dell'intero territorio nazionale e dell'attività dei vulcani attivi italiani, nonché dei maremoti nell'area mediterranea attraverso la gestione di reti osservazionali con strumentazioni tecnologicamente avanzate e distribuite sul territorio nazionale, o concentrate intorno ai vulcani attivi tramite il presidio h24 di tre Sale operative a Roma, Napoli e Catania.

Obiettivo primario dell'INGV è contribuire alla comprensione della dinamica del Sistema Terra, nelle sue diverse fenomenologie e componenti solida e fluida, e alla mitigazione dei rischi naturali associati.

In particolare, le attività dell'Ente possono suddividersi in tre grandi categorie:

- Attività di ricerca scientifica e tecnologica nell'ambito delle Geoscienze, con particolare riguardo alla Sismologia, Vulcanologia e alle tematiche ambientali.
- Attività di ricerca istituzionale e di servizio per la Società, per le Pubbliche amministrazioni e l'Industria; in particolare, si mettono in evidenza le attività svolte in Convenzione annuale, nell'ambito di un Accordo Quadro decennale con il Dipartimento della Protezione Civile, relativamente al rischio sismico, vulcanico e da maremoto, e le attività di monitoraggio sismico e delle deformazioni del suolo in aree sede di sfruttamento di georisorse, per conto del Ministero dello Sviluppo Economico. Le attività di ricerca istituzionale comprendono, inoltre, quelle relative alla progettazione, sviluppo e mantenimento delle Infrastrutture di ricerca, alcune delle quali di prestigio internazionale e di dimensione europea.
- Attività di Terza Missione, comprendenti la formazione, la divulgazione, il trasferimento tecnologico, gli spin-off e i brevetti, i poli museali e il public engagement.

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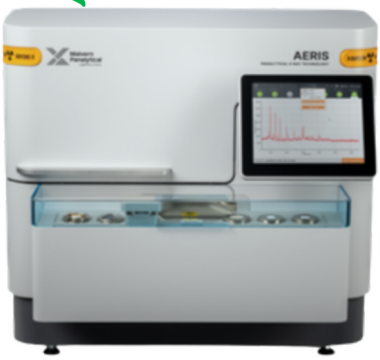
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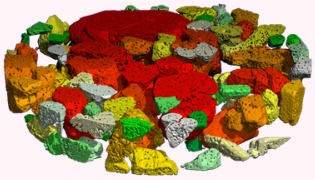
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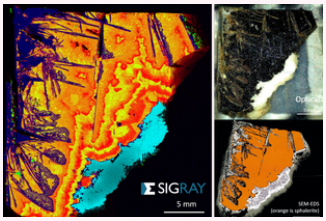


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- Microtomografia computerizzata a raggi X
- Microscopia a Forza Atomica

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Analisi mineralogica e geochimica per la caratterizzazione di composizione, struttura cristallina e trasformazioni dei campioni geologici.

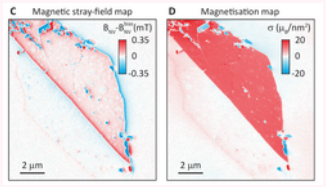


TECNOLOGIE

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- Imaging Raman confocale

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Studio delle proprietà magnetiche di minerali e campioni geologici per comprendere processi naturali.

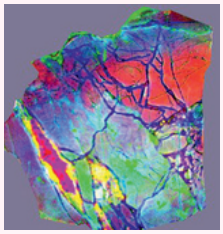


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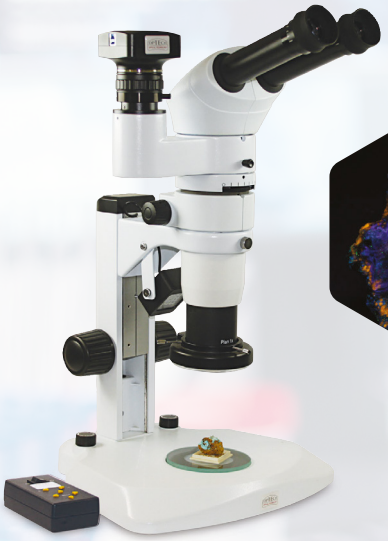
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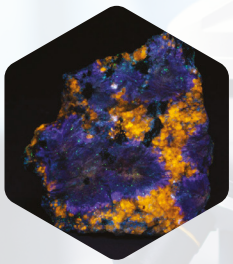


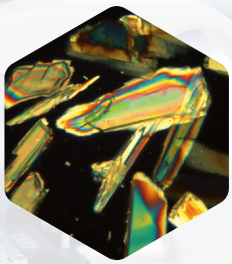
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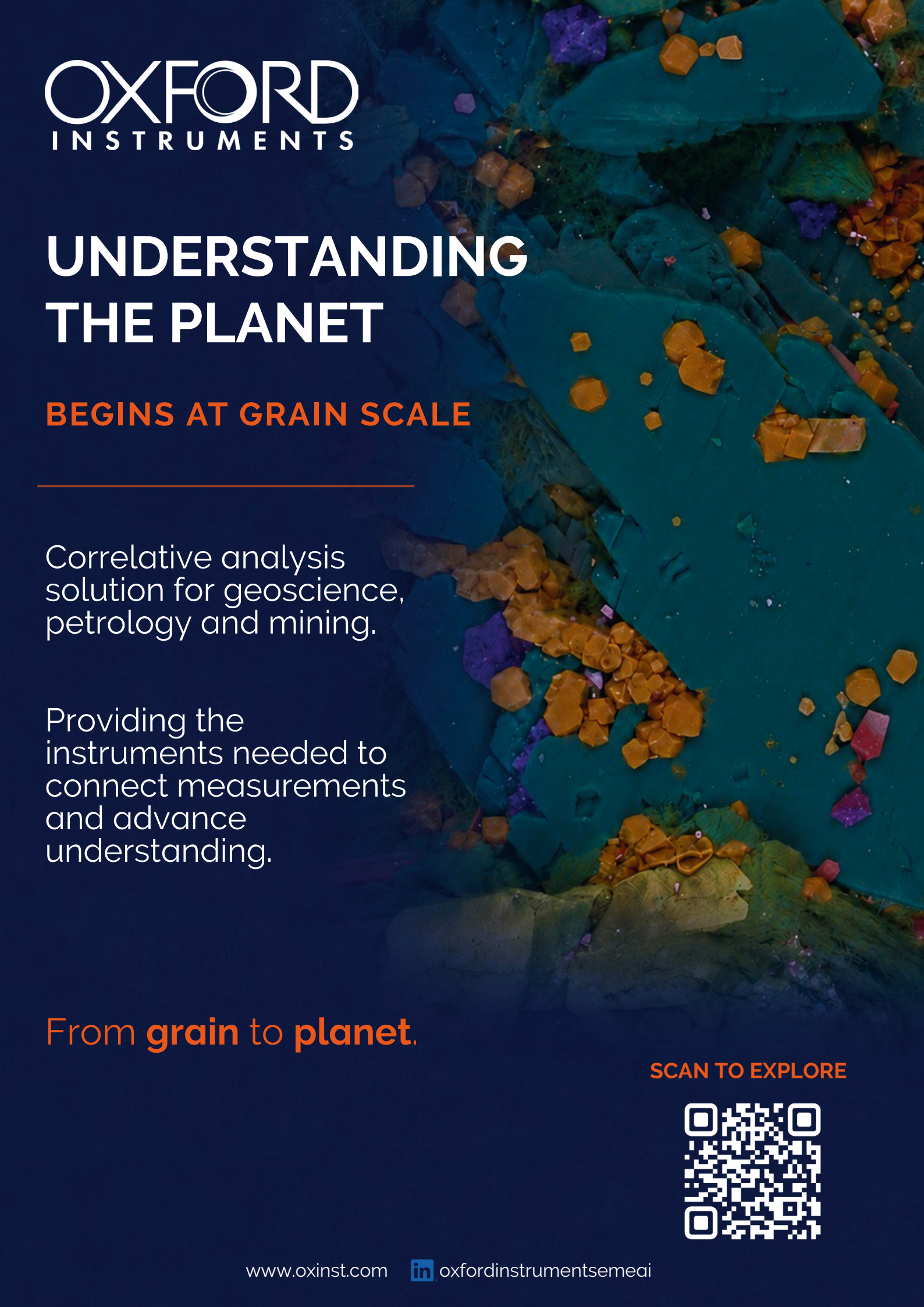
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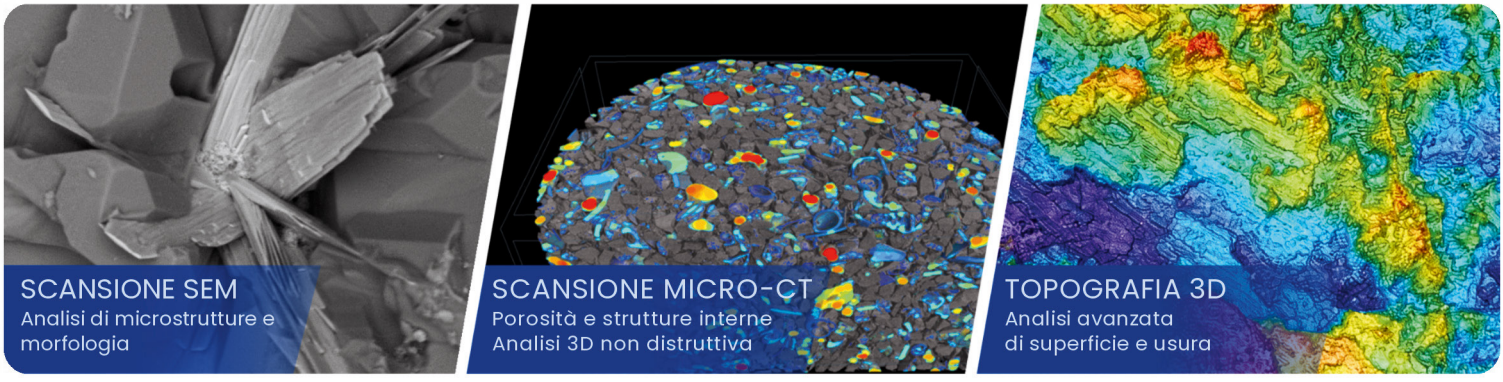
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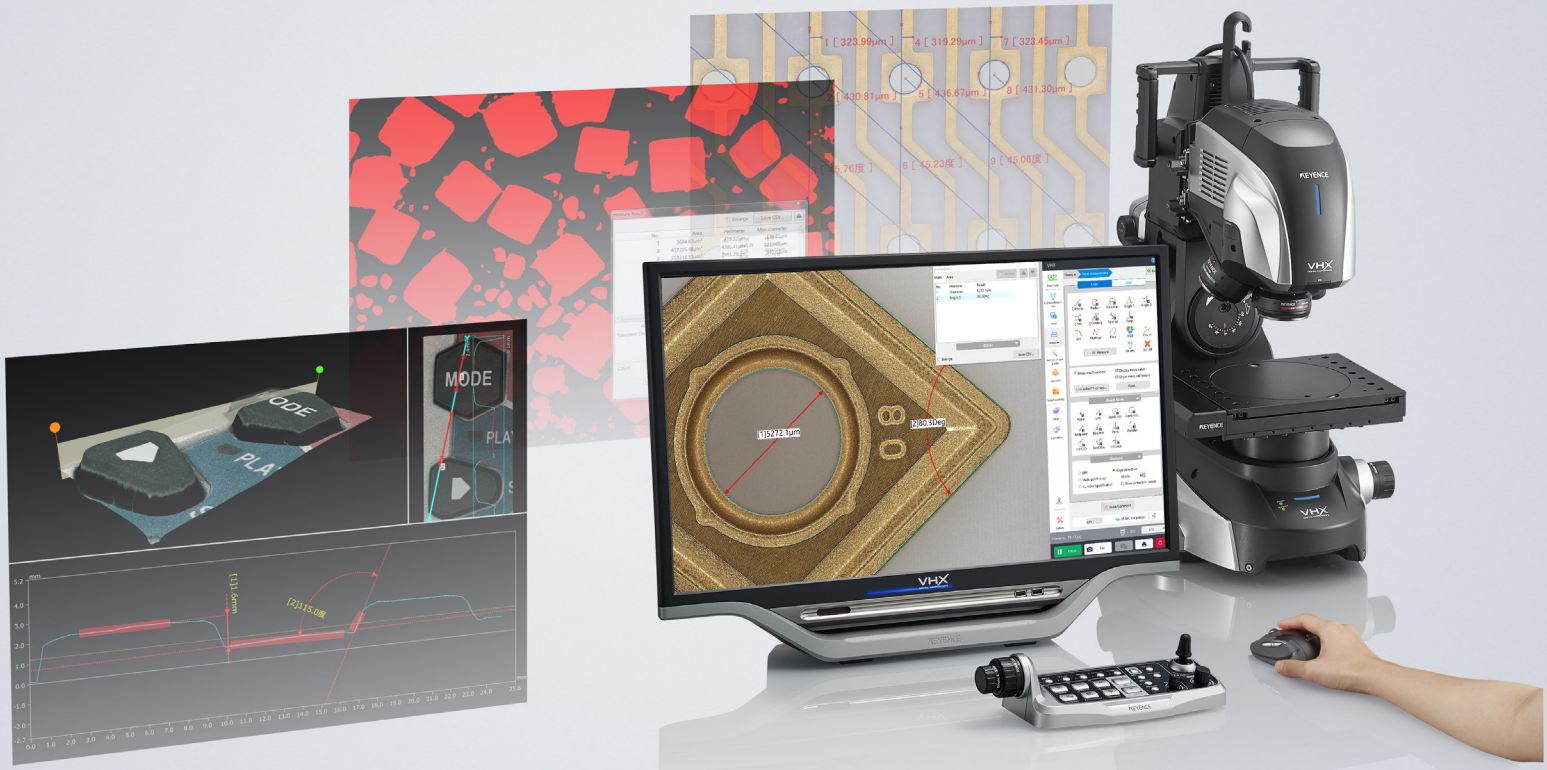
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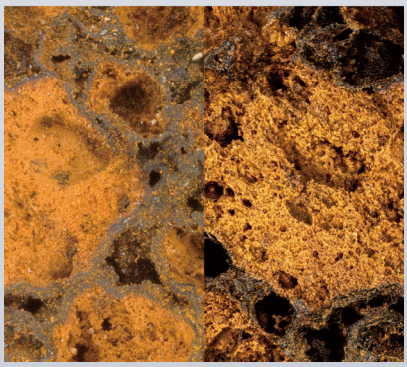




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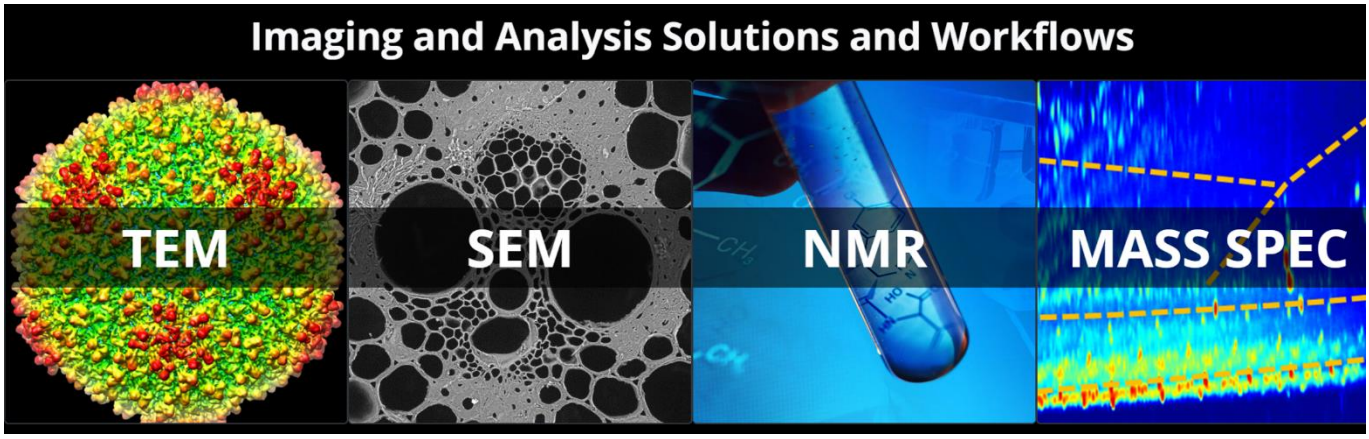


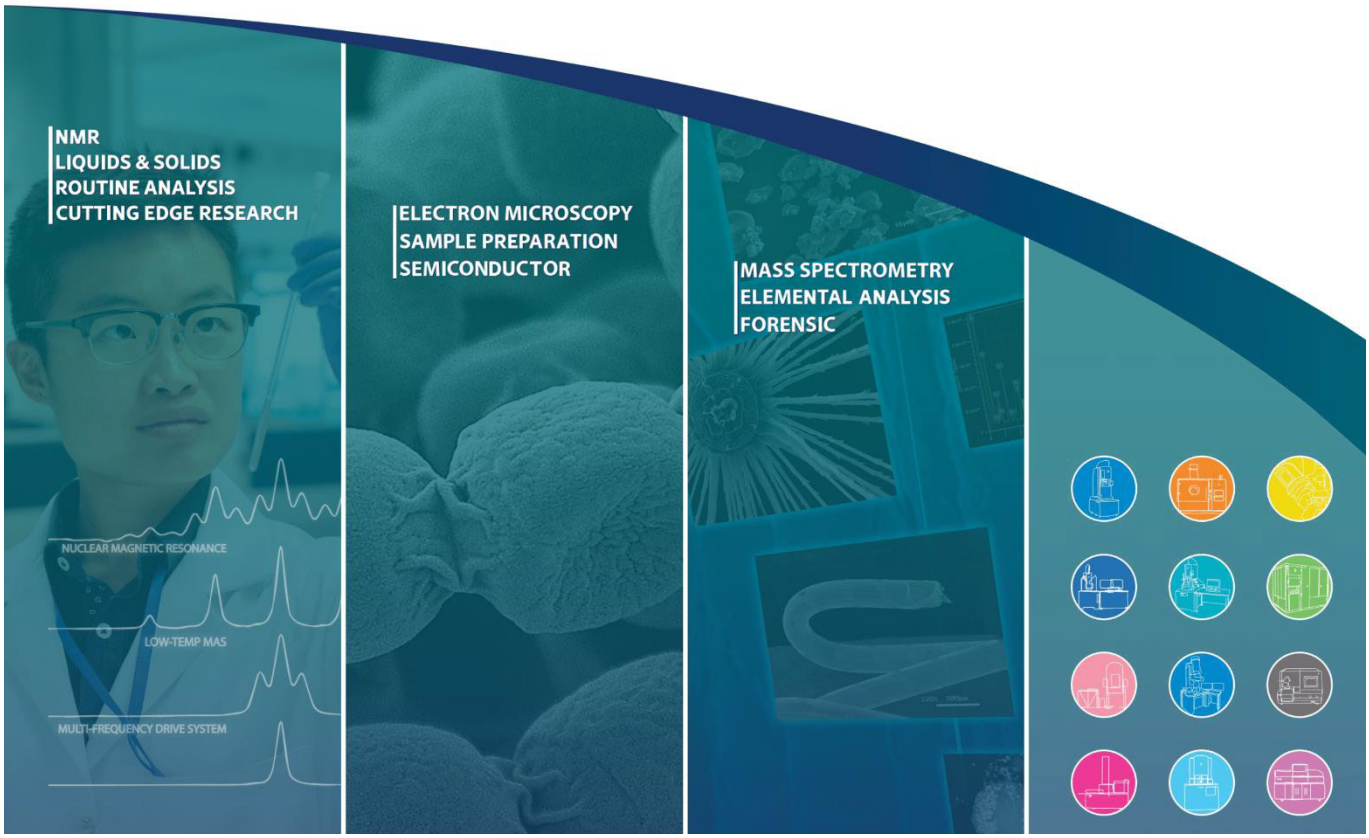
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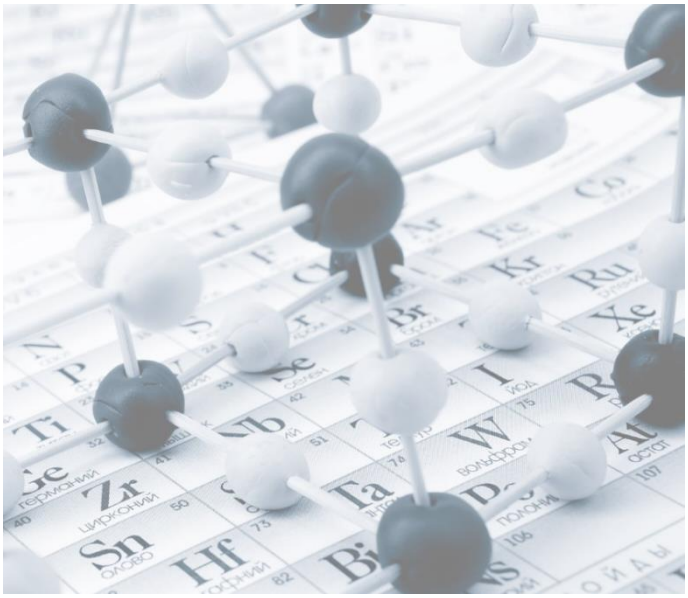
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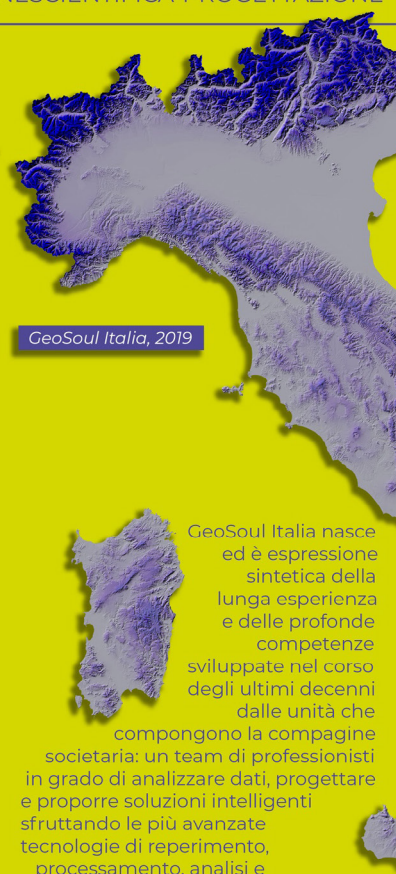
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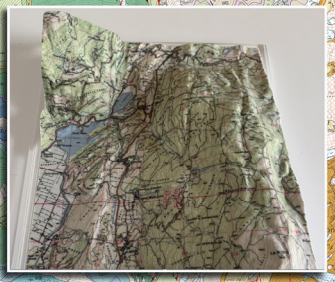
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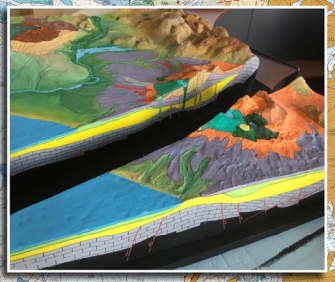
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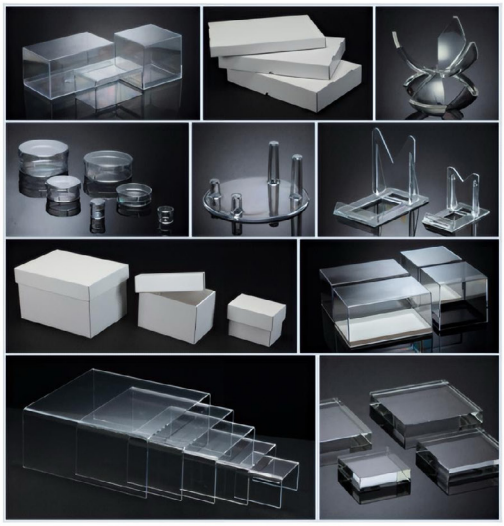
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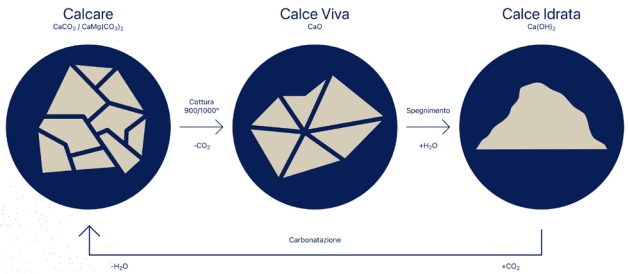
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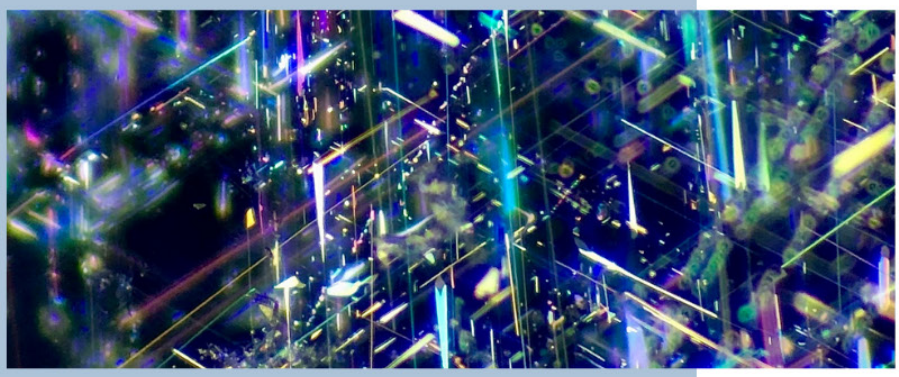
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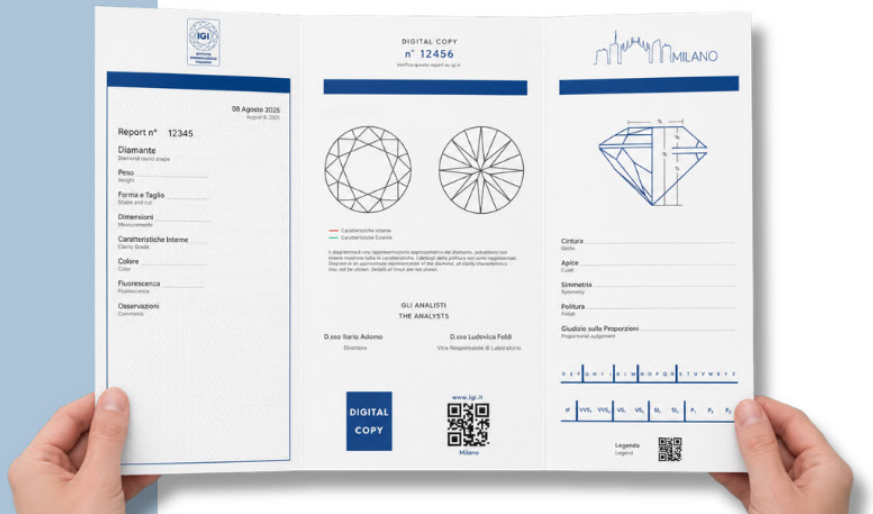
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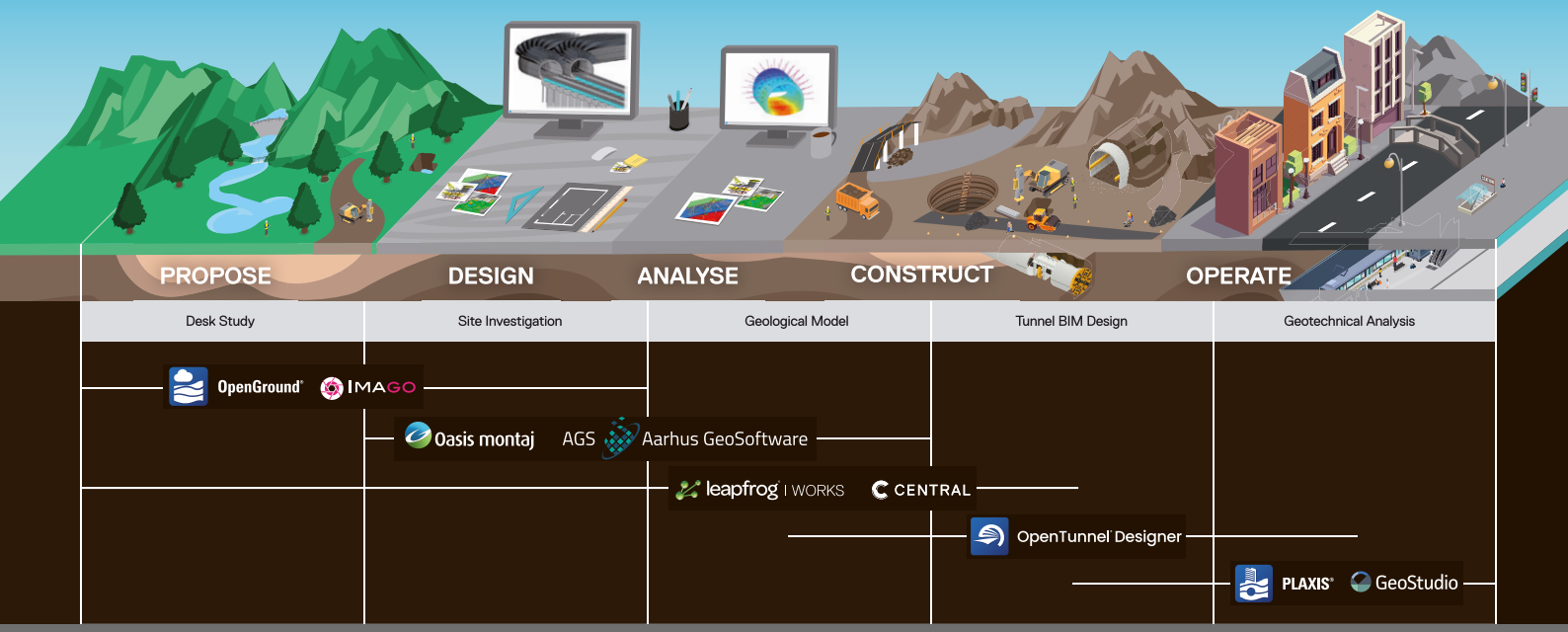
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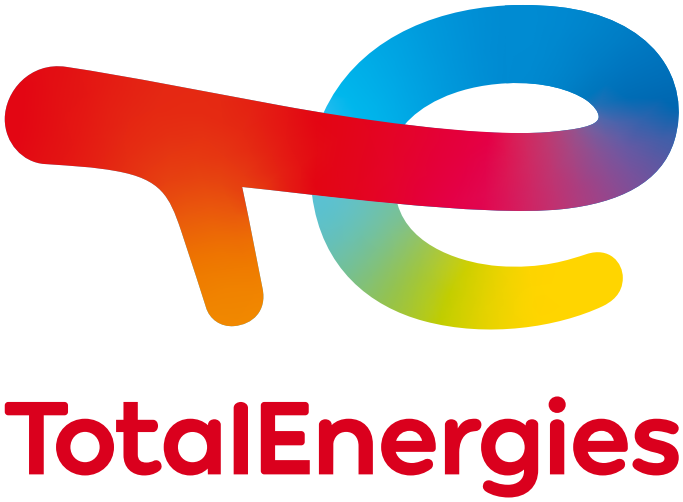
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PLENARY SESSIONS

Past, current, and future perspectives on Structural Geology and Tectonics

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Keywords: structural geology, tectonic processes, quantitative methods.

Structural geology and tectonics are closely related disciplines with connections across all branches of the geosciences. Centuries of field-based observations, experimental studies, and theoretical developments have led to a sound general understanding of structural principles and tectonic processes. Despite this progress, the inherent complexity and heterogeneity of natural systems continue to limit our ability to confidently resolve specific geological problems. In the context of ongoing energy transitions and rising demand for critical mineral resources, the importance of a robust, research-based understanding of structural geology and tectonics is increasing. Advancing quantitative methods, refining conceptual models, and improving knowledge transfer to industry are essential to reduce uncertainty and enhance predictive capability across applied as well as academic domains.

Geopolitics of Energy: "Even if you are not interested in energy and geopolitics, energy and geopolitics will be interested in you"

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Keywords: energy resources, critical raw materials, energy geopolitics.

The presentation will provide an overview of the historical evolution of different energy sources to understand the new paradigms of energy and geopolitics.

Geopolitics could be defined as the way countries and international actors exercise their power and influence in relationships among each other. Such power and influence were initially aimed at controlling land and seas, then underground and underwater resources and more recently the space. A good image of the current geopolitical arena is that of a chessboard on a global scale where, differently from a chess game, several actors are competing against each other. Moreover, recently the rules and the role of international bodies have been disregarded by some of the more relevant actors in the global chessboard.

As regards energy, through the centuries, it has always been the lifeblood of development and economic growth. The industrial revolution was enabled by abundant coal supply, in the past century, the boom of the 1960s, was possible because of cheap hydrocarbon resources. However, such resources have also been an instrument of foreign policy used ruthlessly by some countries as, for example, by OPEC during the oil shocks of the 1970s, or lately by Russia for its energy supplies to the European Union.

More recently China has demonstrated its capability to take advantage of its dominant position in production and refining of critical raw materials and its willingness to use them as a tool for an assertive foreign policy.

The presentation will assess the drivers and the major players in the past and current competition for energy resources. Upcoming challenges in which competition, besides conventional resources, expanding to critical raw materials, will also be covered.

The debt of biological and human evolution to geology

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Keywords: macroevolution, human evolution, geology.

Charles Darwin wanted to be remembered as a geologist, not only because he was grateful for the discovery of Deep Time, but also because geology was his epistemological model of rigorous natural science, capable of identifying patterns of change. Charles Lyell's uniformitarianism led him to an excessively gradualist view of evolution, but contemporary corrections to this idea also owe everything to geology: punctuated speciations; turnover pulses; mass-extinctions. These macroevolutionary and geological factors are essential to understanding human evolution as well: from the initial formation of the Rift Valley in Africa (which initiated the diversification of hominins like us) to the climatic oscillations of the Pleistocene and the resulting migrations of hominins out of Africa. The phylogenetic tree of the genus *Homo* has been shaped by large-scale geological factors. This natural history makes it somewhat ironic that today Homo sapiens, the product of a history of large-scale geological and ecological perturbations, has itself become a geological force capable of altering the fundamental geophysical cycles of the planet.

The esthetics and usefulness of phase diagrams. The scientific vision of Stefano Poli

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Keywords: phase diagrams, thermodynamics, experimental petrology.

The beauty of phase diagrams arises from an intrinsic property: when constructed correctly, they represent ground truth and although their applicability and underlying data may be debated, a phase diagram itself can be objectively correct. As graphical representations of thermodynamic calculations or topological constrains, phase diagrams are uniquely suited to visualize and communicate complex metamorphic, metasomatic and magmatic reactions, and their relevant compositional space; all of which were the scientific endeavor that characterized Stefano Poli's career. Stefano began in the 1980s with volcanological and then metamorphic field-based petrology, and he continued this line of research during his entire career through projects mainly in metamorphic and anatectic terranes across the globe. This start of Stefano Poli's scientific production was synchronous with the search for understanding metamorphic petrology within a rigorous framework of quantitative thermodynamic assessment. In the early 1990s Stefano started to build what would become the most versatile experimental petrology laboratory in Italy, a career move that was to dominate his scientific production and led to the application of petrology to industrial processes. During this first decade of experimental work, hydrous phases in subduction zones were the primary focus, resulting in the 1998 and 2002 landmark papers that today may appear almost self-evident, but which transformed the entire field of subduction related research. The 2000's were then dominated by application of high-pressure petrology to industrial processes, resulting in the foundation of Petroceramics, which, e.g., produced and analyzed all ceramic brakes of Ferrari F1 cars, and has since expanded into activities related to space technology. From the 2010s onward, Stefano's subduction related research moved on to redox processes both in the slab and in the mantle, subsequently evolving naturally to the mobilization and effects of carbon in these environments. Stefano's fascination with carbon extended from the global carbon cycle to carbon-fiber-based ceramics, and led him to move on to his last own experimental project (unimaginable he would ever stop conducting experiments himself), namely CO_2-driven melilititic magmatism. Another pillar of Stefano's research concerned migmatization and granites, integrating fieldwork, melt inclusion studies and experiments into a unified approach. Throughout his career, Stefano strived to explain nature through experiments and thermodynamics, inspiring many generations of students and also collaborators, often moving decisively forward through his theoretical developments. Indeed, theoretical papers on phase petrology and the crystallography of new phases were always interspersed in his publication record. Thriving to understand the true reasons driving reactions and textures, Stefano Poli is leaving a rich inheritance, which through its fundamental nature will last.

SPONSOR SESSIONS

From the memory of earthquakes to the future of geophysics: research infrastructures and innovation for the Earth system

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Keywords: research infrastructures, seismic monitoring, Earthquake Early Warning.

The memory of major earthquakes does not belong only to the past: it provides the foundation for defining the priorities of geophysics for the coming decade, in a context where Earth observation, technological innovation, and scientific cooperation will become increasingly interconnected.

In 2026, anniversaries hold particular significance for the Italian geophysical community, starting with the fiftieth anniversary of the 1976 Friuli earthquake. These occasions provide an opportunity to reflect on events that profoundly affected our country and contributed to shaping the development of research, monitoring systems, and the knowledge needed to understand and address natural hazards. At the same time, they offer an opportunity to reflect on the challenges that Earth Sciences will face in the years ahead.

The major earthquakes of the past have left a fundamental scientific and technological legacy: they have transformed the way we study geophysical processes, supported the growth of observation networks, and strengthened the relationship between research, institutions, and society. Today, the challenges ahead require a further step forward: research infrastructures, the ability to integrate large volumes of data, new technologies, and increasingly strong cooperation among research institutions, universities, and international partners.

Within this framework, the Istituto Nazionale di Geofisica e Vulcanologia plays a central role through strategic initiatives aimed at advancing research and scientific services. These include the renewal of the National Seismic Network, to further enhance the capacity for monitoring, analyzing, and interpreting seismic activity across the country; the development of a national Earthquake Early Warning system, built through a network of collaborations involving OGS, the University of California, Berkeley and numerous other Italian and international partners, translating research outcomes into practical applications to protect people and infrastructure; and the contribution to the Italian candidature of the Einstein Telescope, a major European research infrastructure in which geological and geophysical site characterization represents a key element.

These initiatives share a common goal: strengthening the ability of the scientific community to generate knowledge, develop innovative tools, and provide advanced services. Research infrastructures are not only instruments supporting scientific activities; they are strategic investments for technological progress, training of future generations, and the Italy's capacity to participate in major international scientific challenges.

Looking at the history of earthquakes means building a vision for the future of geophysics. It is through modern infrastructures, shared expertise, and increasingly broad cooperation among scientific institutions that we will continue to develop knowledge, technologies, and services for the benefit of science and society.

The role of geosciences in an energy-hungry world

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Keywords: geosciences, energy transition, energy demand.

The Energy Trilemma has been witnessing a complete change of interpretation very rapidly. In less than three years the global focus has been shifting from the sustainability of the energy sources to the securitization of the access and supply of energy. Such on its turn has been triggering a period of unprecedented volatility for the energy market sector and industry.

The Energy Sector is used to cyclical shocks and rebounds. More recently the magnitude and impact of such cycles have increased due to the geopolitical implications in a common understanding that energy transition and decarbonization of human activities are a must.

The picture is amplified by the not reversible trend of the growth of world population in the next 30 years.

Consequently, the energy demand will grow while the access to energy in the different region of the world is extremely unbalanced.

In the current frantic evolution only three elements are relatively stable: Nations need energy, Energy is produced by the International and national companies, more than the 90% of energy resources are in the hands of governments.

Energy demands huge investments and infrastructures and, they have to be built for lasting for decades.

Such investments on their turn demand for a stable scenario from any point of view.

Each country has been adapting and developing its own energy mix starting from the “domestic” energy sources resolving to import due to the growth of internal demand.

Where we stand in scientific drilling of the ocean floor and continents

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Keywords: Scientific Drilling, Earth and Life sciences, scientific drilling infrastructures.

Almost seventy years after the launch of international scientific drilling programs, for the first time four distinct programs dedicated to the exploration of the ocean and continental subsurface coexist: *International Ocean Drilling Programme* (IODP3, https://iodp3.org/), NSF's U.S. *Sub-Seafloor Sampling Program* (https://sodco.org), *Deep Ocean Drilling Program* (DODP https://www.iodp-china.org) and *International Continental scientific Drilling Program* (ICDP, https://www.icdp-online.org). This apparent organizational fragmentation coincides with a strengthening of the available scientific capacities and with a declared desire for cooperation between all programs.

The scientific objectives are shared and address some of the main challenges of Earth and Life sciences: understanding the dynamics of the lithosphere and the mantle; exploring the deep biosphere and the role of microorganisms in the subsurface; reconstructing the history of the Earth's climate, ice sheets, sea level and ocean-atmosphere-geosphere interactions; identifying the processes that regulate the cycles of the Earth System and the possible tipping points; study geological hazard such as earthquakes, volcanoes, landslides and tsunamis; assess the potential of the subsurface for the energy transition through the geological storage of CO_2 and of geothermal resources, and study offshore aquifers.

To achieve these objectives, scientific drilling is the only tool to observe and sample the subsurface, perform in situ measurements and install observatories, which are indispensable and complementary to geophysical investigations and numerical modeling.

The scientific community today has a large fleet of scientific drilling infrastructures: drilling vessels with riser system, the Japanese *Chikyu* and the Chinese *Meng Xiang*, commercial geotechnical drilling vessels for open-hole drilling and continuous coring, seafloor rigs such as the MEBO of MARUM-University of Bremen, Long Piston Coring Systems, such as those of ships Marions Dufresne and Kaimei, mobile platforms for continental and lake drilling. These are flanked by tools for downhole logging, dedicated laboratories and technical and logistical support for all phases of the projects, from the scientific co-design to implementation. All programmes also invest in the training of new generations of researchers, supporting international workshops and developing interdisciplinary networks.

Scientific drilling remains the indispensable tool for the study of the Earth. Each sample recovered preserves traces of geological, climatic and biological processes that have shaped the Earth and continue to influence its evolution. In this sense, scientific drilling is not only a great research infrastructure, but one of the most powerful tools we have to understand our planet and its future.

How Artificial Intelligence is Changing Geoscience Microscopy

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Keywords: Artificial Intelligence, automated mineralogy, quantitative microscopy.

Artificial intelligence (AI) has rapidly emerged as a transformative force across the geosciences, reshaping the way Earth systems are observed, analysed, and interpreted. The rapid growth of high-resolution datasets, combined with advances in machine learning and deep learning, has enabled researchers to move beyond traditional physics-based approaches and uncover complex, multiscale patterns within geological, atmospheric, and environmental processes. (Zhao et al., 2024).

Alongside this paradigm shift, developments in advanced microscopy and automated analytical workflows are redefining how geoscientific data are generated and interpreted. Thanks to this approach, automated mineralogy - traditionally based on SEM-EDS classification - is extended beyond qualitative or semi-quantitative approaches toward fully quantitative, multi-scale characterization of geological materials. This approach allows the extraction of bulk composition, mineral chemistry, and modal abundance directly from thin sections, significantly streamlining workflows that previously required multiple analytical techniques. (Taylor et al., 2024).

With the advent of deep neural network models, automated mineralogy workflows are further enhanced through AI-driven phase classification, enabling more robust, faster, and highly accurate mineral identification directly from complex datasets. At the same time, the integration of deep learning-based reconstruction methods in X-ray microscopy extends these capabilities into the 3D domain, paving the way to fully automated, high-throughout mineral identification and characterization across multiple scales.

These advances will be illustrated to show how the convergence of quantitative microscopy, large datasets, and AI-driven algorithms is enabling a new generation of correlative, data-rich workflows in geosciences.

Taylor R.J. et al. (2024) - A step forward in quantitative automated mineralogy in 2D and 3D. Geostandards and Geoanalytical Research, 48(3), 579-593.

Zhao T. et al. (2024) - Artificial intelligence for geoscience: Progress, challenges, and perspectives. The Innovation, 5(5), Artificial intelligence for geoscience: Progress, challenges, and perspectives - ScienceDirect.

S1.

Natural melts: messages from Earth's inaccessible depths

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Isotopic fingerprinting of mantle sources of Eastern Mediterranean Neogene volcanism

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Keywords: Eastern Mediterranean magmatism, B-Sr-Nd isotopes, Eastern Mediterranean palaeogeography.

The Aegean-Anatolian region displays a complex tectonic evolution, shaped by the Arabia-Anatolia hard continental collision to the east and the opening of the Aegean back-arc basin to the west. From the Miocene to the Holocene, widespread and compositionally diverse magmatic activity developed in response to the evolving geodynamic framework.

Volcanic rocks ranging from calc-alkaline to ultrapotassic compositions occur across the region, both as arc-related products directly linked to active subduction and as post-collisional magmas sourced from a mantle wedge previously modified by subduction-collision processes. Scattered alkali basaltic activity is also present throughout the region, predominantly retaining sodic affinity and more rarely with mildly potassic character. These magmas originated from the sub-slab asthenospheric mantle and reached the surface either preserving primitive signatures or after undergoing variable degrees of evolution.

We compiled a comprehensive geochemical database including more than 10,000 volcanic rock samples and investigated the geochemical and isotopic characteristics of different volcanic sectors. Particular emphasis was placed on fluid-mobile elements, which are sensitive tracers of slab-derived inputs in subduction-related volcanism and of deep recycling of shallow material in sub-slab-sourced alkali basalts.

For the widespread orogenic magmatism derived from the supra-slab mantle wedge, variations in B isotopes, combined with Sr-Nd isotopic signatures, enable discrimination between fluids and melts from different subducted domains and allow tracing of progressive slab dehydration. This process is particularly evident in the easternmost Mediterranean during the Early-Middle Miocene and in the Aegean sector from the Middle Miocene to the Holocene. Overall, the dataset provides key constraints on the nature of sediments involved in mantle metasomatism.

Variations in subduction-related components can ultimately be framed within the paleogeographic evolution of the Eastern Mediterranean basin, which controlled sediment input into the subducting slab. In particular, B-Sr isotope systematics from Middle Miocene to Pliocene-Holocene volcanic arcs indicate a progressive increase in in situ carbonate production after the Middle Miocene, coupled with a decrease in siliciclastic riverine input. From at least the mid-Late Miocene (~10-6 Ma) onward, Nile River discharge had a negligible influence on sedimentation in both the Levantine basin and the Central Mediterranean slab, highlighting the dominant role of local sedimentary processes in shaping the subduction system.

The B and Sr-Nd isotopic compositions of scattered alkali basalts, whether sodic or potassic, reveal the occurrence of a heterogeneous African sub-slab continental mantle. Moreover, when emplaced under conditions of limited extension, these melts reached the surface only after significant differentiation, often matched by assimilation of crustal material.

Evolution of pre-eruptive timescales in CO_2-rich magmas at São Jorge Island, Azores

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Keywords: Azores hotspot, diffusion timescales, melt inclusions.

The 2022 seismic unrest on São Jorge Island (Azores, Portugal), following a dike intrusion that culminated in a failed eruption (Hick et al., 2026), highlights the need to better understand the island's volcanism. Here we report detailed mineral analyses, diffusion chronometry and volatile element analyses of melt inclusions (MIs), spanning from the early volcanic phases in the Pleistocene to the products of the most recent eruptions on the island (1580 and 1808 CE; Marzoli et al., 2024). Some of the analyzed basaltic and hawaiitic lavas exhibit evidence of magma mixing and rapid assembly of crystals shortly preceding the eruptions. A subset of the studied olivine crystals displays reverse zoning, with rimward increase of forsterite (Fo) content, while others are characterized by crystal cores with distinctly different Fo values within the same rock sample. Diffusion chronometry reveals very short re-equilibration times (days to weeks) for olivine crystals from the two historical eruptions, representing the shortest of three distinct mixing-to-eruption timescales identified in this study, potentially constraining the tempo of future volcanic eruptions. Fully crystallized MIs hosted in olivine and clinopyroxene crystals commonly contain gas bubbles, with CO_2 as the sole volatile species in the fluid phase. Calculated CO_2 concentrations reach up to 0.9 wt.%. Hydrous minerals (amphibole, apatite and phlogopite) within MIs and amphibole phenocrysts in some Holocene lavas attest to an H_2O-rich system. The high CO_2 and inferred H_2O budgets likely enhanced magma mobility of past eruptions and increased their explosive potential. Together, these findings show that São Jorge mafic magmas ascend rapidly through a transcrustal system, with eruptions potentially occurring after short warning times.

Hicks S.P. et al. (2026) - Fault-mediated magma propagation and triggered seismicity revealed by the 2022 São Jorge Azores unrest. Nat. Commun., 17, 3531, https://doi.org/10.1038/s41467-026-71668-6.

Marzoli A. et al. (2024) - Time-dependent evolution and source heterogeneities of ocean island basalts from a weak plume, São Jorge, Azores. J. Petrol., 65, egae122, https://doi.org/10.1093/petrology/egae122.

Thermodynamics of sulfide melts in the CaS-MgS-FeS system: New constraints on melting phase relations in Mercury's interior

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Keywords: sulfide melts, Mercury, ab initio thermodynamic modelling.

Sulfur is the third most abundant volatile component in igneous systems after hydrogen and carbon. Sulfide minerals, liquids and aqueous complexes are the primary means of concentrating a variety of rare and important ore deposits. Furthermore, sulfur plays a key role in planetary differentiation and core formation. Although the behavior of sulfur in silicate melts has been the focus of hundreds of studies that were conducted to constrain the relationships among various oxidation states of this element in silicate melts as a function of pressure, temperature and redox conditions, physico-chemical properties of sulfide melts in planetary interiors are still poorly understood.

Natural sulfide liquids tend to be near mono-sulfidic and FeS-rich with varying amounts of other chalcophile elements. Nevertheless, at quite reducing conditions, oxygen fugacity is sufficiently low as to result in the incorporation of nominally lithophile elements, such as Ca and Mg, into sulfide minerals and melts. The CaS-MgS-FeS sulfide system is of special importance to Mercury, where available data on surface composition by X-ray, gamma-ray and neutron spectrometry suggest exceptionally high sulfur contents of 1-6 wt.% at low Fe contents. These data indicate that highly reducing conditions prevailed during the differentiation of this planet, with estimated fO_2 values ranging from IW-3 to IW-7.

In this work we carried out thermodynamic simulations of binary and ternary phase diagrams in the CaS-MgS-FeS system in order to constrain melting phase relations at P-T conditions compatible with those of Mercury's mantle (i.e., 1-5 GPa and up to 2800 K). Multi-component phase diagrams have been computed by Gibbs free energy minimization based on ab initio DFT-QHA calculations and non-ideal thermodynamic mixing models for the solid and liquid phases, respectively. Thermochemical properties of sulfide melts are then assessed combining the available experimental data with theoretical constraints provided by first principles calculations. The computed phase diagrams provide original insights on the overall stability of alkaline earth sulfides in Mercury's mantle environments, thus getting new light on the internal structure of this planet and complementing geophysical and geochemical informations expected from the joint ESA/JAXA BepiColombo mission.

H_2O in nominally anhydrous minerals form South American xenolith: Insights on mantle metasomatism

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Keywords: mantle metasomatism, H_2O, NAMs.

The uniqueness of Earth lies in its abundant surface water, essential for habitability, sustained by its dynamic nature. Plate tectonics, through subduction, mantle convection and volcanism, continuously recycle crustal material into the deep Earth, resulting in an extreme lateral heterogeneous mantle. Within this framework, the deep cycling of volatiles - especially H_2O - is crucial as they control surface processes and deep dynamics.

Despite the presence of hydrous minerals, the majority of hydrogen (H) in the mantle is hosted in nominally anhydrous minerals (NAMs). Mantle xenoliths represent the direct natural samples to study the otherwise inaccessible Earth's mantle. Combining trace element patterns with H_2O contents is a key tool to constrain the nature, intensity and spatial variability of metasomatism, which progressively alters the original mantle. Understanding H_2O distribution in NAMs and its link to metasomatism is fundamental, as H strongly influences mantle rheology, partial melting, phase transitions, and the stability of lithospheric domains, such as cratons. Nevertheless, the mechanisms controlling H incorporation, preservation and redistribution during mantle metasomatism remain to be precisely constrained.

This study is a multidisciplinary investigation of a suite of nine mantle xenolith samples (spinel ± garnet lherzolites and garnet websterite) from three South American different geodynamic settings, ranging from subduction-related domains to cratonic environments. Petrographic and mineral chemical analyses of NAMs (olivine, ortho/clinopyroxene and garnet) were integrated with FTIR-based H_2O quantification to characterize the primary mantle signatures and metasomatic overprints. H storage is strongly controlled by mineralogy, with clinopyroxene acting as the main carrier of H_2O and trace elements, and thus the primary recorder of metasomatic processes.

The new data indicate a strong covariation between H_2O content and trace element enrichment in the studied mantle xenoliths, reflecting silicate metasomatism driven by both recycling of subducted crustal material and asthenospheric upwelling. Overall, the collected data reveal variable degrees of fertilization of the South American lithospheric mantle, expressed by the transition from cryptic to modal metasomatism and the crystallization of hydrous phases such as pargasite. Subduction-related metasomatism is documented both beneath the stable cratonic domain and the active subduction setting. In the craton, it reflects ancient Neoproterozoic subduction associated with the Gondwana assembly (Brasiliano Orogeny), whereas in the active margin it records ongoing slab-related metasomatism.

These results provide new constraints on mantle metasomatism and the deep H_2O cycle witnessed by South American xenoliths.

Evolution of mafic magmatism in the continental Oslo Rift

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Keywords: rift, mafic magmatism, mantle source.

The Oslo Rift is a mildly alkaline, highly magmatic rift formed in over 40 Myr in the latest Carboniferous to Permian times, as a branch of the Skagerrak Large Igneous Province in Southern Norway. Magmas that build up the Oslo Rift vary in composition all across the TAS diagram, from ultramafic to rhyolitic. We here focus on mafic magmatism, as it can provide information on the mantle source contributions, which have been variably identified in previous studies as the deep convective mantle or the lithosphere. Mafic magmatism is represented essentially by two groups of intrusive rocks: sills and gabbro plugs; and two groups of effusive ones: the so-called B1 lavas, at the base of the sequence, and the B2-3 lavas, further up in the sequence, i.e. intercalated between more felsic lavas or found occurring within calderas. A temporal progression has been suggested in the past, whereby sill intrusions pre-date everything (305-300 Ma by whole-rock Rb-Sr; Sundvoll et al., 1992), followed by the B1 basalts (300 Ma; Neumann et al., 2025), followed by potentially coeval activity of the B2-3 lavas and the gabbros (Neumann et al., 1985). However, new field investigations and high-precision CA-ID-TIMS U-Pb radiometric ages (Nipen et al., 2026) on sills and gabbros challenge this temporal scheme of emplacement. We here present an overview of the geochemical traits of all the four groups. Due to recent infrastructure developments, an impressive amount of new sections and boreholes have been made available. For instance, we sampled sills emplaced in Cambrian and Ordovician black shales from new road sections (Jevnaker, Kistefoss, Kleggerud), one borehole core (Brevik), and classic localities (Gran, Slemmestad, Oslo city center), plus some occurrences in the southern part of the rift (Rognstranda, Rugtvedt), covering a ca. 150 km long transect along the Oslo Rift. B1 lavas have been the subject of a recent review on samples from 5 localities (from North to South, Krokskogen, Jeløya, Vestfold, Skien, Brunlanes; Neumann et al., 2025). A new sample collection has been put together for the B2 basalts (Hurdal, Drammen, Glitrevann, Vestfold). Some preliminary results on the gabbro plugs (on Brandukampen, Buhammeren, and the Aurenhaug plugs) will be followed by more detailed mapping efforts and core-sampling. The major and trace element data we collected so far from these 4 groups of mafic magmas show some general traits, such as i) a clear regional control on the geochemical signatures, partly related to different depths of melting and emplacement processes; ii) a general geochemical trend from more alkaline in the south to less alkaline in the north; iii) well-defined differentiation trends among occurrences from the same location. Future efforts will include radiogenic isotope geochemistry and detailed crystallochemical studies to clarify the relationship between different groups and to deconvolve mantle- from crustal-derived signatures.

Neumann E.R. et al. (1985) - Compositional variations among gabbroic intrusions in the Oslo rift. Lithos, 18, 35-59, https://doi.org/10.1016/0024-4937(85)90005-2.

Neumann E.R. et al. (2025) - Geodynamic evolution of the first basaltic volcanism (B1) in the Oslo Rift (Southeast Norway). Lithos, 512-513, 108133, https://doi.org/10.1016/j.lithos.2025.108133.

Nipen H. et al. (2026) - Sill intrusions in the Oslo Rift were pulsed: New evidence from CA-ID-TIMS U-Pb geochronology. EGU General Assembly 2026, Vienna, Austria, 3-8 May 2026, EGU26-18922, https://doi.org/10.5194/egusphere-egu26-18922.

Sundvoll B. et al. (1992) - Early magmatic phase in the Oslo Rift and its related stress regime. Tectonophysics, 208, 37-54, https://doi.org/10.1016/0040-1951(92)90335-4.

Sulfur in clinopyroxene from tholeiitic basalts: Insights from the Fagradalsfjall 2023 eruption (Iceland)

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Keywords: sulphur, clinopyroxene, degassing.

The reconstruction of volatile budgets for magmas emplaced through geological time remains challenging. We propose a new approach to quantify the sulfur concentration of clinopyroxene-phyric melts, the "sulfur in clinopyroxene" method. This petrological tool uses in-situ S concentrations in clinopyroxene (cpx), measured by synchrotron light microfluorescence, to reconstruct the S content in equilibrium melts through an experimentally determined partition coefficient. To date, this method has been developed and validated for clinopyroxenes crystallizing from tholeiitic basalts (Callegaro et al., 2020), and it has been applied to quantify sulfur emissions from Large Igneous Provinces to investigate the role of these eruptive events in the climate system (Callegaro et al., 2023).

Here, we propose to benchmark this method by applying it to present-day Icelandic lavas. We targeted the 2023 Fagradalsfjall eruption (Reykjanes peninsula, Iceland), which emitted ca. 0.015 km^3 of lava over 26 days. Clinopyroxenes from the 2023 eruption are interpreted to be in equilibrium with the carrier liquid (major-element equilibrium with tephra glass and macrocryst-free matrix compositions) (Caracciolo et al., 2025), and they can be used to estimate the original sulfur budget of the magma and its degassing. We obtained S concentrations in microphenocrysts from this lava ranging between 3 (±1) and 92 (±3) ppm. However, we retain only data points below ca. 40 ppm, as the others are likely reflecting mixed cpx-glass analyses. This results in concentrations of ca. 120 (±55) to 1718 (±178) ppm for the equilibrium melts. We tested our method by comparing our calculated syn-eruptive SO_2 emissions with those estimated with the traditional "petrological method", i.e. by the difference between pre-eruptive and post-eruptive SO_2, preserved in MIs and tephra glass, respectively. Using our "sulfur in clinopyroxene" method, we obtain 0.066-0.103 Mt of released SO_2, comparable to previous estimates of ~0.07 Mt for the same eruption (Caracciolo et al., 2024). This corresponds to SO_2 emissions of 4.1-6.9 Mt/km^3, comparable to values reported for other eruptions on the Reykjanes Peninsula, including the 2021-2023 Fagradalsfjall and December 2023 Sundhnúksgígar eruptions (5.7 ± 1.4 Mt/km^3) and medieval eruptions in the Reykjanes, Svartsengi, Krísuvík and Brennisteinsfjöll volcanic systems (7.3 ± 1.4 Mt/km^3) (SO_2 emissions data used for the calculations are from Caracciolo et al., 2024).

Callegaro S. et al. (2020) - The quintet completed: The partitioning of sulfur between nominally volatile-free minerals and silicate melts. Am. Mineral., 105, 697-707, https://doi.org/10.2138/am-2020-7188.

Callegaro S. et al. (2023) - Recurring volcanic winters during the latest Cretaceous: Sulfur and fluorine budgets of Deccan Traps lavas. Sci. Adva., 9, 1-12, https://doi.org/10.1126/sciadv.adg8284.

Caracciolo A. et al. (2024) - Medieval and recent SO2 budgets in the Reykjanes Peninsula: implication for future hazard. Geochem. Persp. Let., 30, 20-27, https://doi.org/10.7185/geochemlet.2417.

Caracciolo A. et al. (2025) - Mush disaggregation and dike propagation timescales at active volcanoes: Evidence from the 2022-2023 Fagradalsfjall eruptions. J. Petrol., 66(6), egaf054, https://doi.org/10.1093/petrology/egaf054.

The effect of temperature on the speciation of H_2O in a mid-ocean ridge basalt

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Keywords: water, melts, thermodynamics.

Water is the most abundant volatile component in the Earth's mantle and strongly influences the physical and chemical properties of silicate melts such as their viscosity, diffusivity, density and crystallization behavior. Several spectroscopic studies showed that water dissolves in silicate melts primarily as two species: molecular H_2O and OH groups, usually bound to Si. These species are linked to each other through the reaction:

$$H_2O + O = 2OH$$

where O represents a bridging oxygen (i.e., an oxygen atom shared between two Si tetrahedra as Si-O-Si bond) in the silicate melt. Formation of OH therefore depolymerizes the melt structure, strongly reducing melt viscosity. Quantifying the thermodynamics of this speciation reaction and understanding water speciation at high temperatures are thus essential for modeling the behavior and properties of hydrous magmas.

As of today, however, the effect of temperature on water speciation in silicate melts remains poorly constrained. Early studies assumed that glasses quenched from high temperature preserved the equilibrium speciation state of the melt at the experimental conditions. Later work demonstrated this assumption to be incorrect, as structural relaxation of silicate melts above the glass transition temperature (T_g) is extremely rapid, preventing preservation of the high-temperature water speciation during quenching. Due to these experimental difficulties data available today are limited exclusively to in-situ spectroscopic measurements performed on felsic, iron-free melts, limiting their applicability in the modeling of water speciation in natural magmatic systems.

In this study, we investigate the temperature dependence of water speciation in hydrous basaltic glasses at 2 kbar by conducting long-time annealing experiments over a range of temperatures below T_g. Under these conditions, the glass structure is able to relax and the water speciation equilibrates at the temperature of the experiment. At the same time, the extremely high viscosity of the glass below T_g allows preserving the equilibrium water speciation at the experimental temperature during quenching. The concentrations of the water species were then measured using FTIR spectroscopy and were used to derive the thermodynamic parameters (ΔH and ΔS) of the speciation reaction.

Our results provide new constraints on the thermodynamics of water speciation in basaltic melts and have important implications for modeling the structure, dynamics, and transport properties of hydrous magmas in the Earth's interior.

Evidence for compositionally heterogeneous ultrapotassic magmas beneath the Somma-Vesuvius volcanic complex: Insights from igneous xenoliths

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Keywords: LA-ICP-MS analyses, ultrapotassic volcanism, magmatic heterogeneity.

A suite of intrusive xenoliths, including clinopyroxenites, biotite gabbros, olivine-leucite-bearing monzogabbros, foid syenites, leucitolites, and garnet-bearing foidolites, have been found within the pyroclastic deposits of the Somma-Vesuvius volcanic complex. These xenoliths have adcumulate to orthocumulate textures. Mafic and ultramafic cumulates are clinopyroxene-rich, and crystallized from relatively primitive melts, whereas intermediate and felsic intrusive rocks have additional plagioclase, alkali feldspar, leucite, amphibole, garnet, apatite and titanite, and crystallized from evolved, volatile-rich residual magmas. Garnet-bearing foidolite has iron-rich clinopyroxene, leucite, nepheline and haüyne, and no feldspar, suggests the existence of magmas that are underrepresented in the erupted products.

Trace-element systematics and REE distributions indicate that clinopyroxene controlled the REE budget in the ultramafic cumulates. Amphibole, garnet, titanite, apatite, and accessory minerals (e.g., allanite, pyrochlore, and zirconolite), on the other hand, strongly influenced REE partitioning in evolved syenitic rocks, producing highly fractionated and LREE-enriched patterns. Zoned minerals and oscillatory growth textures, and coexistence of mafic and felsic cumulates, indicate prolonged fractional crystallization, crystal accumulation, and repeated recharge by compositionally distinct magmas within compositionally zoned reservoirs. The Sr-Nd isotopic compositions ($^{87}Sr/^{86}Sr$ = 0.706449-0.707668; $^{143}Nd/^{144}Nd$ = 0.512475-0.512580) of the studied xenoliths overlap with those of Somma-Vesuvius volcanic rocks, supporting a genetic link between them.

The occurrence of volatile-rich mineral assemblages (containing phlogopite, amphibole, apatite, sodalite, haüyne, and other foids) and elevated F, Cl, and S concentrations, indicates that volatile-rich ultrapotassic magmas played a significant role in the evolution of the Somma-Vesuvius plumbing system. These results reveal a complex and heterogeneous shallow magma storage system shaped by prolonged differentiation, magma recharge, and volatile accumulation prior to explosive eruptions.

Concurrent leucite-free and leucite-bearing magmatism in the recent stages of activity

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Keywords: Roccamonfina, leucite, potassic magmatism.

We report here the results of a petrological study of lava and pyroclastic products from the recent phase of activity of the Roccamonfina volcano, postdating the ca. 305 ka eruption of the White Trachytic Tuffs (WTT). Rocks mostly belong to a leucite-free low-K series (LKS), but also include products of a leucite-bearing high-K series (HKS). The latter is prominent during the early phases of the volcano activity (>350 ka, older than the Brown Leucitic Tuff or BLT eruption), for which subordinate LKS activity has also been recently recognised. This further emphasizes that the petrological evolution of the volcano was more complex than previously thought, with a more progressive HKS to LKS transition.

Compared to their older counterparts, post-WTT HKS magmas are generally less silica-undersaturated, with leucite mostly in the groundmass instead of being a major phenocryst phase. Compositions range from potassic trachybasalt/basanite to phonolite and are generally lower in K_2O (4.0-8.8 vs. 5.0-11.1 wt.%), Rb (136-437 vs. 271-1196 ppm) and Sr (349-1240 vs. 156-2651 ppm) with respect to pre-BLT HKS basanite/tephrite-phonolite rocks. Primitive-mantle normalised spiderdiagrams for the least evolved HKS rocks of the two periods share the same subduction-related signature, but the post-WTT rocks have lower LILE/HFSE and LREE-MREE/HREE enrichments. Post-WTT LKS rocks range from basalt to (high-silica) trachyte and are mostly silica-saturated to slightly silica-oversaturated, whereas the few pre-BLT LKS rocks are weakly silica-undersaturated trachytes. Except for SiO_2 (45.2-68.9 vs. 46.7-58.8 wt.%) and K_2O concentrations (1.20-7.26 wt.%), post-WTT LKS magmas are distinguished from HKS magmas by very subtle compositional differences, the least evolved rock types of the former having slightly lower Th/Nb, La_N/Yb_N and Dy_N/Yb_N and slightly higher Ta/Nb.

Isotope compositions for the post-WTT rocks define two main clusters, both more Sr-unradiogenic ($^{87}Sr/^{86}Sr$ 0.70747-0.70862 and 0.70658-0.70737) and Nd-radiogenic ($^{143}Nd/^{144}Nd$ 0.51223-0.51228 and 0.51236-0.51240) with respect to the pre-BLT magmas (0.70868-0.71019 and 0.51211-0.51224). Further, two samples from the HKS series make a third group with even lower $^{87}Sr/^{86}Sr$ (0.70652-0.70653) and higher $^{143}Nd/^{144}Nd$ (0.51250-0.51252). Our preliminary results suggest that several source components were likely involved during the recent phase of the Roccamonfina activity, possibly including also those that produced the magmas from the ancient phase of activity. Additional complexities have to be invoked in order to explain the concurrent generation of both leucite-bearing and leucite-free magma series.

Isotopic, spectroscopic and quantum mechanical investigation of hydrogen in diamond: Insights on the origin of Earth's water

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Keywords: H isotopes, natural diamonds, mantle reservoirs.

Water makes our planet unique in the inner Solar System due to its abundance and the unique capability of hosting life. Despite its importance, how and when Earth acquired its water remains a mystery, limiting our understanding of how a life-supporting environment formed and evolved through time. The best chance to answers these questions is given by diamonds, as they represent the deepest samples and robust time capsules that resist breakdown for over billions of years, protecting the information they encapsulate during formation. Natural diamonds contain mineral and fluid inclusions and chemical impurities such as nitrogen (N) and hydrogen (H) which are the most abundant. The concentration of H in natural diamond defects reaches hundreds of at.ppm and may help us to better constrain the types of mantle substrates and fluids involved in diamond formation.

This work aims to characterize the nature of H defects in a set of diamonds with different age, formation depth and parageneses to constrain the presence and sources of H reservoirs in the deep Earth. First, it is important to understand how H is incorporated in diamonds at mantle conditions, how H-defects behave during mantle residence and if it re-equilibrates (in terms of both H-content and isotopic composition) with the surrounding mantle. Fourier-transform infrared spectroscopy and ab initio molecular dynamics simulations are used to understand the atomistic behaviour of H in diamonds.

Comparing the primordial D/H ratio (the ratio of ^{2}H - deuterium - to ^{1}H - protium) of our planet with those of Solar System objects can help to constrain the provenance of Earth's water. Nevertheless, ours is an active planet and its D/H ratio has significantly changed through geological time. Therefore, to reconstruct the origin of Earth's water, it is fundamental to identify a primordial mantle H reservoir and to constrain how Earth's D/H ratio has evolved in the past billions of years. Evidence for the modification of the D/H can be found in different mantle samples, as a consequence of fractionation, mixing between different reservoirs and/or crustal recycling. Understanding how such processes modify the H isotopic composition of the mantle is fundamental to reconstruct the primordial D/H and thus the potential source of Earth's water.

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Experimental constraints on the mantle sources of silica-poor and potassic to ultrapotassic melts

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Keywords: mantle metasomatism, glimmerite, clinopyroxenite.

More than the 90% vol.% of the lithospheric mantle is constituted by nominally volatile-free mineral assemblages with a peridotitic composition, the remaining being constituted by hydrous phases (mostly amphibole ± phlogopite, with chlorite, talc, serpentine and lawsonite in the coldest portion) and Ca-Mg-carbonates. Other accessory phases, such as apatite, ilmenite, rutile and other minerals stable in the subducted olivine-poor slabs are randomly distributed as consequence of the long-lasting effects of plate tectonics.

Despite their rarity, olivine-rich and olivine-poor volatile-bearing lithologies are of critical importance due to their low homologous temperature, especially for the understanding of mantle processes such as metasomatism and the petrogenesis of peculiar rock-types. Indeed, specific metasomatic assemblages are usually invoked as mantle sources of silica-poor, ultracalcic and potassic/ultrapotassic compositions, such as kamafugites. To evaluate the possible contribution of non-peridotitic assemblages in the genesis of kamafugitic magmas, we performed partial melting experiments at 2.7 and 5 GPa, and 1200°C to 1550°C using different starting materials constituted by clinopyroxenites variably enriched in phlogopite (from 20 to 28%), olivine (from 0 to 22%) and accessory phases (apatite ± oxides ± titanite) and a clinopyroxene-apatite-magnetite glimmerite.

At very low degrees of partial melting, the accessory minerals are the main contributors in the melting reactions, resulting in experimental glasses strongly enriched in TiO_2, CaO and P_2O_5. The silica content is always very low. Although these compositions are very different from the known natural magmas, such melts may represent important metasomatic agents in the upper mantle. At increasing melting degrees (50 to 90%), the glasses approach the compositions of kamafugites, partially overlapping for most of the major oxides. Worth noting, these extremely high degrees of melting are referred to the low-solidus components only. These could be variably dispersed within a peridotitic matrix that could not be interested by such high amount of melt extraction. The results indicate that high-degree melting of clinopyroxene- and phlogopite-rich lithologies, with variable model abundances of olivine and accessory phases (apatite, oxides, titanite), commonly occurring as veins in lithospheric peridotites, may be a viable explanation for the genesis of SiO_2-poor, K_2O- and CaO-rich magmas.

Hydrogen and deuterium diffusion in diamond at lithospheric mantle conditions

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Keywords: diffusion, hydrogen, diamond.

Impurities (i.e., interstitial defects) and mineral/fluid inclusions in natural diamonds can provide valuable insights into the compositional evolution of the Earth's mantle through geologic time (Stachel & Luth, 2015). In particular, information about diamond forming fluids, and their respective recycled and/or primordial sources, can be obtained by studying the isotopic composition of hydrogen (i.e., the ratio of deuterium - D - over hydrogen - H) in natural diamond. Hydrogen in diamond occurs in mineral/fluid inclusions, in point- and/or extended defects, or in a relatively more mobile interstitial form. Since most diamonds experience prolonged mantle residence at high temperatures, diffusion of interstitial H may result in re-equilibration with the surrounding mantle via diffusive loss or gain. Consequently, it remains uncertain whether or not the D/H isotopic composition of diamonds is representative of the parental diamond-forming media. Several studies on H and D diffusion in diamond report contradictory results, both in terms of activation energies for diffusion (which vary over an order of magnitude) and diffusion coefficients (Cherniak et al., 2018). These uncertainties are mainly due to experimental difficulties related to graphitization of diamond, the presence of cracks that act as fast diffusion pathways and/or possible radiation damage due to D (or H) implantation. Moreover, the temperature (T) range over which diffusion experiments are performed is often limited, and the effect of pressure (P) on diffusion has been largely overlooked despite its influence on diffusivity, especially at mantle conditions conducive to diamond formation.

Here we compute the diffusivity of H and D in diamond using and path integral ab initio molecular dynamics (PIMD) as implemented in the Vienna Ab Initio Simulation Package (VASP). Post-processing and data extraction was completed using the UMD package (Caracas et al., 2021). By performing PIMD simulations, we were able to account for possible quantum tunnelling effects, that can affect the diffusivity of light elements such as H and D. All simulations were performed at P/T conditions compatible with those expected for diamond-stable regions in the Earth's mantle such that the effect of pressure on H and D mobility could be evaluated. We also performed simulations with H in the neutral, positive and negative charge states, addressing the effect of charge on H mobility in diamond.

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Caracas R. et al. (2021) - Analyzing melts and fluids from ab initio molecular dynamics simulations with the UMD package. J. Vis. Exp., e61534, https://doi.org/10.3791/61534.

Cherniak D.J. et al. (2018) - Diffusion of helium, hydrogen and deuterium in diamond: Experiment, theory and geochemical applications. Geochim. Cosmochim. Ac., 232, 206-224, https://doi.org/10.1016/j.gca.2018.04.029.

Stachel T. & Luth R.W. (2015) - Diamond formation - Where, when and how? Lithos, 220-223, 200-220, https://doi.org/10.1016/j.lithos.2015.01.028.

Hydrogen and helium diffusion in diamond at Earth's mantle conditions

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Keywords: diffusion, diamond, AIMD.

Impurities (i.e., interstitial defects) and mineral/fluid inclusions in natural diamonds can provide valuable insights into the geochemical and geodynamic evolution of the mantle through geologic time (Stachel & Luth, 2015). In particular, information about the isotopic composition of the early mantle, and about the deep H_2O cycle, can be inferred by studying helium (He) and hydrogen (H) impurities in natural diamonds, respectively. However, a critical aspect to consider is whether or not the initial isotopic composition of He and H in diamonds is preserved and thus representative of the original diamond-forming fluid. Since most diamonds experience prolonged mantle residence times at high temperatures, diffusive re-equilibration of He/H with the surrounding mantle, either by loss or gain, may occur. Experimental studies on He and H diffusion in diamond report contradictory results, both in terms of activation energies for diffusion (which can vary over an order of magnitude) and diffusion coefficients. These uncertainties are mainly due to experimental shortcomings related to graphitization of diamond, release of He or H after inclusion decrepitation, or the presence of cracks that act as fast diffusion pathways (Cherniak et al., 2018). Moreover, the temperature range over which such experiments were conducted is often limited, and the effect of pressure on diffusion has not been previously considered, despite its significant impact on estimated diffusion rates.

Here we compute the diffusion of He and H in diamond using ab initio molecular dynamics (AIMD) and machine learning molecular dynamics simulations, as implemented in the Vienna Ab Initio Simulation Package (VASP). Postprocessing was done using the UMD package (Caracas et al., 2021). All simulations were performed across a broad range of high pressure and temperature conditions, compatible with those expected in diamond-stable regions of the Earth's mantle. The diffusion coefficients for He were determined as a function of both pressure (0, 5 and 10 GPa) and temperature (300-3000 K) by combining the MD diffusion trajectory with nudged elastic band (NEB) and phonons calculations. Calculated He diffusivities reveal that He is mobile at diamond forming conditions. At the same conditions, two H atoms migrate toward each other rapidly and remain locked in an interstitial space. This configuration suggests that H atoms may "self-trap" at diamond forming conditions even in defect-free diamonds, thus increasing the probability for H retention throughout geological times.

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Caracas R. et al. (2021) - Analyzing melts and fluids from ab initio molecular dynamics simulations with the UMD package. J. Vis Exp., e61534, https://doi.org/10.3791/61534.

Cherniak D.J. et al. (2018) - Diffusion of helium, hydrogen and deuterium in diamond: Experiment, theory and geochemical applications. Geochim. Cosmochim. Ac., 232, 206-224, https://doi.org/10.1016/j.gca.2018.04.029.

Stachel T. & Luth R.W. (2015) - Diamond formation - Where, when and how? Lithos, 220, 200-220, https://doi.org/10.1016/j.lithos.2015.01.028.

Signals from the asthenosphere: Evidence of HIMU component in the Upper Triassic-Lower Jurassic alkaline magmatism of the Southern Alps

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Keywords: Southern Variscides, magmatism, geochemical reservoir.

The Southern Variscides domain, following the peak of post-collisional calc-alkaline to tholeiitic magmatism during Lower Permian, was affected by several tectono-magmatic cycles from the Triassic to the Early Jurassic, characterized by the presence of mantle-derived melts enriched in alkalis and volatiles, displaying a progressive transition from calc-alkaline to alkaline affinity. This variation was associated with a shift in the geodynamic regime from transtensional to extensional conditions.

Ongoing studies on the isotopic geochemical composition of mantle cumulates related to elusive alkaline magmatism have highlighted a progressive decoupling between the Sr, Nd, and Hf isotope systematics, which become progressively less enriched, and the Pb isotope systematics, in which radiogenic components progressively increase through time, as particularly evidenced by the $^{206}Pb/^{204}Pb$ ratio. Such decoupling, typical of the deep geochemical HIMU component, is discussed in order to decipher the role played by lithospheric and asthenospheric mantle reservoirs as source of the various melts and the link with the tectonic regime.

Earth vs. Mercury: Redox control on planetary evolution

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Keywords: Mercury, redox, experiments.

The redox state of terrestrial bodies, expressed in terms of oxygen fugacity (fO_2), plays a fundamental role in controlling element speciation at depth and, consequently, the chemical and physical evolution of their interiors as well as their melting properties. Among several elements, Fe serves as a key redox proxy as its oxidation state shifts in response to oxygen availability (Fe^0, Fe^{2+}, Fe^{3+}). Knowledge of fO_2 is essential for interpreting planetary diversity in terms of mineralogy and internal structure. In this context, Earth and Mercury represent two opposite end-members.

On Earth, spatial and temporal variations in redox conditions affected the behaviour of volatile elements such as C, O, H, and S, controlling their speciation and mobilization to the surface through melts. These processes played a central role in shaping atmospheric composition and, in turn, enabling habitability. Direct constraints on fO_2 are provided by oxy-thermobarometric reconstruction from natural melts and mantle-derived peridotites and eclogites (e.g., Marras et al., 2024).

In contrast, our understanding of Mercury relies primarily on spectroscopic and geophysical data acquired during space missions. They revealed a S-rich, Fe-poor volcanic crust and a high bulk density, which, when combined with experimental studies (e.g., Namur et al., 2016), point to a highly reduced silicate mantle and a large metallic core where most of the planet's Fe is hosted. However, significant uncertainties remain regarding elements behaviour under such conditions.

Here, results from high-pressure, high-temperature experiments and thermodynamic modelling will be presented to investigate the behaviour of FeO in silicate melts as a function of fO_2 during equilibration with a Fe-rich metallic core. The effects of highly reducing conditions will be discussed in the context of Mercury's mantle and surface lavas composition, with particular emphasis on the low and heterogeneous FeO contents detected on the surface by the MESSENGER space mission.

Although these two planets differ significantly, with Earth relatively oxidized and Mercury highly reduced, understanding Mercury's redox conditions may help better constrain Earth's accretion processes, where reduced, Mercury-like building blocks may have played a role.

Marras G. et al. (2024) - Ferric iron in eclogitic garnet and clinopyroxene from the V. Grib kimberlite pipe (NW Russia): evidence of a highly oxidized subducted slab. J. Petrol., 65(6), egae054, https://doi.org/10.1093/petrology/egae054.

Namur O. et al. (2016) - Sulfur solubility in reduced mafic silicate melts: Implications for the speciation and distribution of sulfur on Mercury. Earth Planet. Sc. Lett., 448, 102-114, https://doi.org/10.1016/j.epsl.2016.05.024.

The crustal carbonatites of the Ivrea-Verbano Zone: Field, petrographic and geochemical evidence

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Keywords: Ivrea-Verbano Zone, crustal carbonatites, high temperature shear zone.

Carbonatites are a hot topic in petrological studies. Their occurrences have been re-evaluated in recent years due to the importance of volatile and critical elements cycles through mantle and crust. A recent study has proposed the occurrence of Jurassic mantle derived carbonatites in the Ivrea-Verbano Zone (Galli et al., 2019). Here, we reassess the available evidence and show that: (i) on the basis of field relationships, most carbonate-rich rocks can be interpreted as metamorphic anatectic dykes intruded into high-grade gneisses and calc-silicate rocks (ii) trace-element, accessory minerals and C-O isotopic imprinting are different from primary carbonatitic, mantle - derived magmas; (iii) there is no evidence for systematic fenitization or intrusive associations typical of carbonatitic intrusions; (iv) the chronology of the IVZ is dominated by Mesozoic extensional regime characterized by abundant high-T shear zones which locally exceeded the melting T of marbles. We conclude that the carbonatites of the Ivrea-Verbano Zone are consistent with crustal-derived carbonate-rich melts formed by syntaxis of high-grade marbles and subsequent antiskarn processes (Parlapiano et al., 2025). They resemble the crustal-derived carbonatites as defined by Su et al. (2024). The origin of these rocks is very likely related to locally confined partial melting episodes of the melange of marbles, metapelites, (meta-) mafic rocks induced by thermal effects associated with faulting, such as the effect of shear heating or fault-related fluid influx, during the Triassic-Jurassic exhumation of the western paleomargin of Adria. High pressure piston-cylinder melt-rock experiments of a melange of carbonate and metamafic rocks from the Kinzigite Unit of the Ivrea-Verbano Zone are currently in progress in order to better constrain the petrogenesis of these crustal carbonatites.

Galli A. et al. (2019) - Jurassic carbonatite and alkaline magmatism in the Ivrea zone (European Alps) related to the breakup of Pangea. Geology, 47, 1-4, https://doi.org/10.1130/G45678.1.

Parlapiano F. et al. (2025) - The Role of high-pressure Antiskarn Process in the formation of crustal Ca-carbonatites of Ivrea-Verbano Zone (Northern Italy). 2025 SGI-SIMP Congress, Padova (Italy), 16-18/09/2025, Abstract Book, 228, https://doi.org/10.3301/ABSGI.2025.03.

Su B.X. et al. (2024) - Crustal-derived versus mantle-derived carbonatites. Lithos, 488-489, 107826, https://doi.org/10.1016/j.lithos.2024.107826.

A rare corundum-ferropericlase assemblage in a super-deep diamond from Juína, Brazil

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Keywords: metasomatism, sublithospheric mantle, corundum.

Super-deep diamonds represent the deepest direct samples of the Earth's mantle, occasionally capturing rare mineral inclusions that record the mineral paragenesis and the melt-rock reactions of the inaccessible Earth. We report the first detailed geochemical characterisation of co-existing corundum and ferropericlase inclusions recovered from a single *Type IIa* diamond from Juína, Brazil. The ferropericlase has an Mg# of 72 and contains 0.93-1.00 wt.% NiO. These values are lower than those typical of ferropericlase equilibrated with bridgmanite in lower-mantle harzburgite and lherzolite (Mg# > 80 and NiO ~1.20-1.38 wt.%) (Walter et al., 2022), pointing to a hybridised mantle source at depths ≥250 km. Corundum is virtually pure Al_2O_3 (99.40 wt.%) with minor but variable TiO_2 (0.75-1.17 wt.%), and it displays a fractionated trace element pattern: relative to CI chondrite, it is moderately enriched in Ti, Hf, and Zr, and depleted in Cr, Ni, Fe, Mg, and all rare earth elements. The cooccurrence of these two phases cannot be explained by a single mantle assemblage. We propose that diamond growth occurred at a lithological boundary within a subducting slab. Ferropericlase records reaction between depleted ambient mantle and an Al-saturated metasomatic agent (melt/fluid) released from the slab's basaltic crust, while corundum crystallised simultaneously. The encapsulation of both phases in one diamond requires local oxidising conditions that stabilise corundum + ferropericlase, indicating that slab-derived oxidised components create the redox gradients necessary for diamond precipitation. These results provide direct mineralogical evidence for redox and chemical heterogeneity at slab-mantle interfaces in the transition zone to uppermost lower mantle.

Walter M.J. et al. (2022) - Geochemistry of Silicate and Oxide Inclusions in Sublithospheric Diamonds. Rev. Mineral. Geochem., 88, 393-450, https://doi.org/10.2138/rmg.2022.88.07.

Carbonatites and carbonate-rich lithologies in the Proterozoic Oulad Dlim Massif, SW Morocco

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Keywords: Oulad Dlim Massif, carbonatites, Rare Earth Elements.

The demand for critical raw materials, such as REE and Nb, is steadily increasing to move towards a decarbonised energy transition. Carbonatitic rocks stand out as the most prominent source of REE, occasionally also associated with Nb enrichment (Chen et al., 2024). In spite of their petrological relevance and strategic importance, the petrogenesis of carbonatites and their genetic relationship with silicate rocks commonly cropping out in the same district are far from being fully understood. Therefore, the distinction of carbonatites from other carbonate-rich lithologies is challenging, yet essential for both petrological studies and REE mineralisation evaluation projects. The Oulad Dlim Massif in SW Morocco is a key area to investigate such kind of lithologies. This massif is part of the western peri-cratonic envelope of the Reguibat Shield, recording a complex, ~3 Gyr-long, tectono-magmatic history and polyphase metamorphism. It is composed of four main tectonic domains which span from Archean to Silurian-Devonian and consist mostly, though not exclusively, of meta-igneous and meta-sedimentary units of varying metamorphic grade, including eclogite and granulite facies rock types (Bea et al., 2020). The Oulad Dlim Massif also hosts several carbonatitic complexes, the largest of which is the Gleibat Lafhouda complex. This complex comprises three ~1.85 Ga Mg-carbonatitic intrusions emplaced within the Bulautad leucocratic gneisses of the Eastern Archean Domain. They also host REE-Nb mineralisations within their hydrothermally altered and strongly weathered caps (Boukirou et al., 2022). Further westward, several tens of lenticular to circular outcrops of brownish carbonate-rich lithologies, with a maximum size of few hundreds m long and few tens of m wide can be found scattered within the meta-sedimentary Essedra Complex of the Ediacaran Domain (Fekkak et al., 2025). These lithologies, preliminarily identified as weathered carbonatites by the Moroccan Geological Survey, have not yet been fully investigated. A petrographic, mineralogical and compositional study conducted on these lithologies reveals a wide variety of textures and mineral assemblages, the latter being dominated by carbonate minerals, such as dolomite, ankerite and calcite with minor amounts of serpentine, quartz, chlorite, talc, amphibole and/or goethite. These carbonate-rich lithologies are associated with high-grade metamorphic basement rocks consisting of banded amphibole felsic gneisses, granulite-facies migmatitic gneisses and marbles. In stark contrast, the Gleibat Lafhouda carbonatites exhibit much simpler compositions consisting mainly of dolomite and minor apatite. The presence of veins and bands of iron oxides/hydroxides and secondary carbonate, extensively recorded within the more altered carbonatite facies and within the Fe-rich products, speaks for a relevant role of post-magmatic processes in concentrating critical raw material in low-temperature mineral paragenesis.

Bea F. et al. (2020) - The Archean to Late-Paleozoic architecture of the Oulad Dlim Massif, the main Gondwanan indenter during the collision with Laurentia. Earth-Sci. Rev., 208, 103273, https://doi.org/10.1016/j.earscirev.2020.103273.

Boukirou W. et al. (2022) - Petrogenesis of the late Paleoproterozoic Gleibat Lafhouda dolomite carbonatite (West African Craton Margin, Moroccan Sahara) and its relevance to the onset of fragmentation of the Columbia supercontinent. Chem. Geol., 594, 120764, https://doi.org/10.1016/j.chemgeo.2022.120764.

Chen P. et al. (2024) - Global rare earth element resources: A concise review. Appl. Geochem., 175, 106158, https://doi.org/10.1016/j.apgeochem.2024.106158.

Fekkak A. et al. (2025) - Carte géologique du Maroc au 1/100.000, feuille de Madnat Essedra - Notice explicative. Notes et Mémoires Serv. Géol. Maroc N° 650 bis.

Petrological data to understand magmatic plumbing systems: The Yali Upper Pumice explosive eruption (Aegean Arc, Greece)

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Keywords: plumbing system, geothermobarometry, magma interaction.

Constraining magma origin and storage conditions and characterizing the structure of the plumbing systems is fundamental to improve our understanding of volcanoes and to contribute to volcanic risk mitigation.

This study focuses on the island of Yali (Greece), an active volcanic complex of the South Aegean Volcanic Arc related to the subduction of the African plate beneath the Aegean plate. The volcanic edifice consists of two different sectors, connected by a sedimentary isthmus, characterized by distinct stratigraphy and eruptive histories. The northeastern sector is dominated by effusive products, while the southwestern sector is dominated by explosive activity, with a thick pyroclastic succession including the Yali Lower Pumice (~52 ka), Yali Upper Pumice (31 ka), and a reworked layer of variable thickness.

This work focuses on the last explosive eruption, the Yali Upper Pumice (YUP), with the aim to investigate the architecture of the related plumbing system and the magma evolutionary processes during their ascent to the surface.

The deposits are characterized by the coexistence of different magma types: a dominant evolved magma (SiO_2 ~70-74 wt.%) and a mafic component, with compositions of ~53-55 wt.% and ~60 wt.% SiO_2 erupted as mafic enclaves of various types. These enclaves display a microcrystalline, diktytaxitic texture, typical of a rapid quenching when mafic, hot magma inject into a more evolved host and leads to the formation of skeletal, interdigitated crystals with interstitial glass and vesicles.

Detailed mineral chemistry analyses were performed, applying various geothermobarometers to amphibole and clinopyroxene (Ridolfi, 2021; Higgins et al., 2022; Chicchi et al., 2023) to estimate magma storage depths. These analyses highlight the coexistence of variable crystal compositions, with plagioclase ranging between $An_{90\text{-}60}$, clinopyroxene displaying Mg# values of 0.9-0.7, amphibole with Mg# of 0.8-0.6, and olivine with Fo_{85}. In addition, whole-rock geochemical data, including major and trace elements as well as Sr-Nd isotopic ratios, were used to investigate the origin and relationships among the different magmas.

The results show a wide compositional variability in both trace elements (e.g., Ba ranges from 200 to 800 ppm, and Co from 30 to 1 ppm) and isotopic ratios ($^{87}Sr/^{86}Sr$ increases from 0.7039 to 0.7049 and $^{143}Nd/^{144}Nd$ decreases from 0.51279 to 0.51257). The data suggest a complex plumbing system, characterized by a shallow evolved magma chamber and variably evolved deeper reservoirs that feed successive mafic magma injections, likely playing a key role as eruption triggers.

Chicchi L. et al. (2023) - Frontiers of thermobarometry: GAIA, a novel Deep Learning-based tool for volcano plumbing systems. Earth Planet. Sci. Lett., 620, 118352, https://doi.org/10.1016/j.epsl.2023.118352.

Higgins O. et al. (2022) - Machine learning thermobarometry and chemometry using amphibole and clinopyroxene: a window into the roots of an arc volcano (Mount Liamuiga, Saint Kitts). Contrib. Mineral. Petrol., 177, 10, https://doi.org/10.1007/s00410-021-01874-6.

Ridolfi F. (2021) - Amp-TB2: An Updated Model for Calcic Amphibole Thermobarometry. Minerals, 11(3), 324, https://doi.org/10.3390/min11030324.

Tracing slab-derived CO_2 in arc magmatism: Experimental constraints from subducted marine sediment analogues

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Keywords: subduction, carbon cycle, arc magmatism.

Arc magmas carry a CO_2 signal that ultimately reflects processes occurring within the subducting slab at depths that are largely inaccessible to direct observation. Although this signal is commonly discussed in terms of mantle melting and magma differentiation, its origin may be strongly controlled by devolatilization, redox evolution and fluid-mediated carbon transfer from subducted sediments. In this contribution, we focus on the production of CO_2-rich slab fluids at sub-arc conditions, using high-pressure experiments on graphite-carbonate-fluid systems as simplified analogues of marine sediments containing carbonate and organic-derived carbon.

We present experimental results obtained at 3 GPa and 700°C in graphite-$CaCO_3$-fluid systems buffered near FMQ, over a wide range of graphite proportions. The experiments show that graphitic carbon exerts a strongly non-linear control on the CO_2 fraction of the fluid. At very low graphite contents, small increases in graphite abundance produce a disproportionate rise in XCO_2, whereas at intermediate graphite fractions the fluid composition approaches a carbonate-graphite-fluid equilibrium plateau. Only at graphite-rich compositions does the system evolve towards more typical GCOH-like behaviour.

This curvature is especially relevant for subducted marine sediments, where organic carbon commonly occurs at the percent level. A graphite abundance of about 1 wt.% falls within the region of maximum sensitivity, implying that minor variations in residual carbonaceous matter can strongly affect the production of CO_2-bearing fluids. Building on these experimental constraints, we incorporate the derived parameterization into CorgArc, a forward model coupling slab thermal structure, Arrhenius-type graphite oxidation kinetics and carbon isotope mass balance. The model reproduces first-order arc CO_2 fluxes and $\delta^{13}C$ values close to the global arc average without requiring extensive carbonate decarbonation or unrealistically large proportions of subducted organic carbon, provided that redox conditions allow efficient oxidation of residual carbonaceous matter.

These results suggest that the CO_2 component feeding arc magmas may be strongly controlled by redox-sensitive reactions involving small amounts of organic-derived graphite in carbonate-bearing sediments. Rather than treating slab carbon transfer as a simple consequence of carbonate breakdown, the proposed framework links mineral-fluid equilibria, reaction kinetics and isotopic systematics to the origin of CO_2 released beneath volcanic arcs. In this sense, arc-magmatic CO_2 can be read as a message from sedimentary carbon recycling at sub-arc depths.

Petrographic and geochemical characterization of the Emile Baudot Seamount lavas: Insights into the western Mediterranean Cenozoic magmatism

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Keywords: Emile Baudot Seamount, Valencia Trough, Western Mediterranean.

The Valencia Trough is a Miocene back-arc basin developed between SE Spain and the Balearic Islands contemporaneously to the Ligurian-Provençal basin to the north. Both basins opened as consequence of NW subduction of oceanic lithosphere during the first phases of the Apennine-Maghrebian Orogeny. During the basin opening, the Balearic Promontory rotated ~30° clockwise and the Sardinia-Corsica block rotated ~60° counterclockwise. A small-volume mildly sodic magmatism postdates the massive subduction-related igneous activity within the two basins and neighbouring shoulders (SE Spain, SE France and western Sardinia), mostly emplaced during ~25-15 Ma.

The Emile Baudot volcanic field (EBVF) represents a poorly known Pleistocene activity developed when metasomatic effects related to the subducting slab had moved far away south-westwards, now confined to the Aeolian Island area, where an active Benioff-Wadati plate is clearly imaged with seismology. This study provides the first comprehensive petrographic, geochemical, and isotopic characterization of fourteen volcanic samples dredged from the EBVF. Petrographic and semi-quantitative mineral chemical analyses reveal porphyritic lavas with alkali basaltic paragenesis (clinopyroxene, olivine and plagioclase phenocrysts set in a hypocrystalline to holohyaline groundmass made up of microliths of plagioclase, clinopyroxene, olivine, opaque minerals and apatite, plus volcanic glass).

Whole-rock compositions span over a wide range, mostly due to the variable seawater alteration. The least altered samples mostly fall in the TAS basanite field (CIPW normative olivine > 10 vol%), with high TiO_2 and a transitional sodic-potassic compositions. Based on the Mg#, Cr and Ni contents, these samples represent slightly fractionated magmas, probably due to olivine and clinopyroxene fractionation. Primitive mantle-normalised trace element patterns highlight enrichments in incompatible elements similar to average HiMu-OIB.

The isotopic ratios ($^{87}Sr/^{86}Sr$ = 0.7028-0.7031; $^{143}Nd/^{144}Nd$ = 0.51287-0.51296; $^{206}Pb/^{204}Pb$ = 18.64-19.18) indicate a depleted mantle source with FoZo-like affinity, supporting the involvement of a sub-lithospheric, HIMU-influenced mantle component. These data suggest that the Valencia Trough magmatism was controlled by lithospheric extension and passive asthenospheric upwelling, rather than by thermal anomalies and no influence from the modifications that occurred during the previous subduction episodes in the W Mediterranean. The EBVF represents a clear expression of anorogenic magmatism developed in a post-collisional, extensional setting, coherent with the CiMACI province and stands for a key reference for the youngest western Mediterranean magmatism.

The never-ending need of field mapping and petrography: On the complexely shaped roots of the Sesia Magmatic System, Ivrea-Verbano Zone, Italy

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Keywords: crust-mantle transition, assimilation, lower continental crust.

The geochemical signatures of mantle-derived magmas in continental settings are known to be significantly modified by fractional crystallization, melt-rock reaction, and crustal assimilation. A significant part of these processes occurs at the crust-mantle transition zone, which is by nature rarely exposed. Volcanic rocks and xenoliths are typically used as proxies for geochemical and geothermobarometric models, but only the rare exposed sections of continental crust provide direct insight into their physical framework. A premier example is the Ivrea-Verbano Zone in Italy, and specifically the Sesia Magmatic System. Its basal unit, the Mafic Complex, represents Permian basic magmatic rocks emplaced into the lower continental crust of the Adria plate. Among the most significant localities is the Sesia valley between Balmuccia and Vocca, which exposes a mantle peridotite lens followed by a sequence of gabbroic and ultramafic lithologies intercalated with metasedimentary septa. There is a long-lasting debate on whether this section might represent the only available fossil crust-mantle transition zone in a continental setting, still connected to the present-day mantle of the Adria plate. While previous research has established the kilometer-scale architecture and the geochemical signatures of these units, higher-resolution field relations remain to be fully explored.

Here we present the results of a detailed field mapping campaign and petrographic characterization of this section, focusing on the first 2 km overlaying the Balmuccia peridotite to the east. Collected data include areal extent and the general description of the outcrops, lithological variations, magmatic foliation, ductile and brittle structures, and secondary alterations. These data are supported by drone imagery, thin section petrography and mineral chemistry, which are combined with the available literature. Results confirm the large lithological variability of both the magmatic sequence and the metasedimentary septa, and show extremely large variations in modal mineral abundance (e.g., garnet, sulphides) from the outcrop to the thin section scale. Despite literature data suggests a close associattion between the magmatic rocks containing garnet and/or sulphides and the metasedimentary septa, a close spatial relationship is not clear when field relations are investigated at a larger scale. In fact, the interpretation of the size and geometry of the different units and their mineralogical variations is further complicated by the lack of exposure and the presence of both ductile and brittle shear zones, the former likely active since the Triassic. Overall, our data suggest that the architecture of the Mafic Complex along the Balmuccia-Vocca section is significantly more heterogeneous than previously recognized, further supporting the importance of outcrop-scale investigations as a key reference for studying crust-mantle transition zones in continental settings.

From ultra-depleted archean mantle to re-fertilized domains: Evidence of multistage metasomatism and recycled oceanic components in garnet xenocrysts from the Newlands Kimberlite, South Africa

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Keywords: ultra-depleted Cr-pyrope, uvarovite-rich garnet, mantle metasomatism.

The study of new samples collected from the Newlands diamondiferous kimberlite (South Africa) reveals a wide variety of garnet xenocrysts, rare Cr-diopside, and an absence of mantle xenoliths. Several Cr-pyrope types, together with uvarovite-rich (green) garnets, were identified on the basis of their major and trace element compositions. A group of Cr-pyropes characterized by extremely low CaO (The occurrence of Ca-rich Cr-pyropes with high Fe^{3+}, V, and U concentrations, and the positive correlation between Fe^{3+} and these elements, suggests equilibration with relatively oxidized melts involving a contribution from recycled oceanic components. In contrast, another group of Cr-pyrope grains displays “normal” lherzolitic REE patterns (Griffin et al., 1999) and likely represents a fertile (re-fertilized) lherzolite matrix equilibrated with silicate melts formed at pressures of ~3.5-2.0 GPa. Trace element signatures of the resulting melt are comparable to those of the primary South African olivine-lamproite group (Howard, 2026 and references therein).

Overall, the Cr-pyrope populations record a continuum of melt-rock interaction that evolved through time and space, reflecting progressive changes in the nature of metasomatic agents: from carbonated high-density fluids, to carbonatitic melts, and finally to CO_2-rich kimberlitic melts carrying recycled oceanic crust components. These processes ultimately generated a newly re-fertilized mantle domain.

The rare uvarovite-rich (green) garnets from Newlands are characterized by high Cr contents (Cr_2O_3 = 11.8-12.1 wt.%) and elevated Ca contents (CaO = 19-21 wt.%). Despite these unusual compositions, they retain a mantle signature, as indicated by high Mg# values (81-83), and plot within the same stability field as the re-fertilized, well-equilibrated Cr-pyropes, corresponding to pressures of ~2.5 GPa and temperatures of 1000-1050°C. Compared with the other Newlands mantle garnets, they exhibit anomalously high Fe^{3+}/Fe_total ratios together with the highest V (400-470 ppm) and U (up to 1.2 ppm) contents observed in the entire garnet population. We infer that these garnets formed through the reaction of peridotite with melts derived from subducted oceanic crust entrained within an upwelling mantle domain, likely well before their incorporation into the host kimberlite.

The co-existence of uvarovite-rich garnet and Cr-pyrope further suggests the juxtaposition of re-fertilized mantle fragments produced by metasomatic melts that assimilated significant proportions of recycled oceanic crust.

Griffin W.L. et al. (1999) - Cr-Pyrope Garnets in the Lithospheric Mantle. I. Compositional Systematics and Relations to Tectonic Setting. J. Petrol., 40, 679-704, https://doi.org/10.1093/petroj/40.5.679.

Howarth G.H. (2026) - Kimberlites and olivine lamproites of the Kalahari Craton and related diamond deposits. S. Afr. J. Geol.,129(1), https://doi.org/10.25131/sajg.129.1.2740.

The Limeira I, Lemes and Pântano Cretaceous kimberlites and their crystal and xenolith cargo indicate highly metasomatized and oxidized lithospheric mantle beneath the APIP province (Brazil)

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Keywords: kimberlites, APIP, xenoliths.

The Late Cretaceous Limeira I, Lemes and Pântano kimberlites are in the Alto Paranaíba Igneous Province (APIP) along the southern margin of the São Francisco craton. They host an unusually diverse collection of mantle-derived xenoliths and xenocrysts of mantle and magmatic origin. The kimberlites are composed of olivine, monticellite, phlogopite/tetraferriphlogopite, Al-free Cr-magnetite and chromite, magnesian ilmenite, rutile, highly zoned perovskite, apatite, priderite, baddeleyite and zirconolite, as well as carbonates, sulfates and xenocrysts, including highly corroded orthopyroxenes, phlogopites and clinopyroxenes. The kimberlites also host a remarkable suite of xenoliths, including dunite, wehrlite, phlogopite-ilmenite-websterite, olivine-ilmenite-glimmerite, potassic-richterite-bearing clinopyroxenite, and chromite-monticellite-kalsilite rocks. Rutile with either priderite or perovskite reaction rims and magnesian chromian ilmenite with perovskite rims are also observed. Trace element concentrations of olivine, perovskite, clinopyroxene and Fe-Ti oxides indicate that perovskite is by far the dominant host of REE, Sr, Nb, Ta, Th, and U. Olivine has a range of transition element concentration (Ni, Co, Mn, Zn) indicating crystallization from increasingly evolved melt compositions. A relatively oxidized crystallization environment is indicated by magnetite-ilmenite pairs that plot within a temperature range of 1000 to 800°C and along or slightly above the NNO buffer. The presence of potassic richterite- and kalsilite-bearing xenoliths, a mineral assemblage that is unstable in kimberlites, provides compelling evidence that kamafugite magmas or related intrusive rocks were sampled and entrained by the ascending kimberlite magma. The absence of garnet xenocrysts in the Limeira and Lemes kimberlites indicates that their entrainment predominantly took place at shallower lithospheric mantle levels, from the spinel facies upward into the crust unlike nearby occurrences, such as Pântano (Bandeira et al., 2026) and the deeper Três Ranchos kimberlite (Guarino et al., 2024). Taken together, these findings, and bulk-rock major and trace element and isotope geochemistry (Melluso et al., 2008; Azzone et al., 2022; Bandeira et al., 2026 and references therein) suggest that the Limeira I, Lemes and Pântano kimberlites, as well as the kamafugite magmas that are also abundant in the area, are the crystallized products of partial melts of heterogeneous and strongly metasomatized F-H_2O-CO_2-rich lithospheric mantle of the São Francisco craton.

Azzone R.G et al. (2022) - Tracking crustal assimilation processes in kimberlites from the Alto Paranaíba Igneous Province, Brazil: Petrographic and geochemical controls and the role of perovskites. Lithos, 432, 106888, https://doi.org/10.1016/j.lithos.2022.106888.

Bandeira J.C. et al. (2026) - Mantle compositional architecture and diamond potential of the Alto Paranaíba Igneous Province, Brazil: Insights from garnet xenocryst compositions in kimberlites. Lithos, 532-533, 108516, https://doi.org/10.1016/j.lithos.2026.108516.

Guarino V. et al. (2024) - Stabilization and evolution of the Brazilian subcontinental lithospheric mantle: insights from garnet xenocrysts and peridotite xenoliths of Três Ranchos kimberlite (APIP, Brazil). Gondwana Res., 130, 18-35, https://doi.org/10.1016/j.gr.2024.01.005.

Melluso L. et al. (2008) - Major-and trace-element composition of olivine, perovskite, clinopyroxene, Cr-Fe-Ti oxides, phlogopite and host kamafugites and kimberlites, Alto Paranaiba, Brazil. Can. Mineral., 46(1), 19-40, https://doi.org/10.3749/canmin.46.1.19.

S2.

Metamorphic petrology and petrochronology: Decoding the archives of the crustal rock library

CONVENERS & CHAIRPERSONS:

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From California to Piemonte: The quest for lawsonite in the frame of changing paradigms in metamorphic petrology

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Keywords: lawsonite, pseudomorph, subduction.

Lawsonite $CaAl_2Si_2O_7(OH)_2 \bullet H_2O$ is now a well-known and widespread mineral species that petrologists use in their daily studies. It is, however, worth recalling the main steps that allowed lawsonite acquiring this status.

Lawsonite has been found simultaneously in Piemonte (Franchi, 1895) and in California (Ransome, 1895). The latter author has given its name in honour of its mentor, Prof. A. Lawson. From 1895 to 1910, lawsonite was reported from a growing number of localities worldwide, always part of a mineral assemblage containing glaucophane, or closely associated with glaucophane-bearing rocks. The development of experimental petrology since the 1960's (from R.C. Newton & G.C. Kennedy to S. Poli) has established its stability field at high P / low T conditions, and therefore lawsonite became a key indicator of the blueschist- to eclogite-facies associated with low geothermal regimes in subduction zones.

With the recognition of lawsonite pseudomorphs by F. Ellenberger (1960), a new avenue was established. Rather than being confined to the most external part (i.e. the lowest temperature) of the metamorphic domain in the Alps, it was shown by W.S. Fyfe, N. Fry, P. Bearth, G.V. Dal Piaz and others that lawsonite distribution extends in the whole metamorphic domain of the Alps, from the Ligurian nappes to the Tauern Window, being a witness of an early ('ephemeral') stage of the subduction history.

Today, lawsonite (and its pseudomorphs) is frequently used to reconstruct P-T paths, and we understand much better its occurrence and stability with respect to bulk-rock and fluid composition, as well as its preservation (or consumption) during exhumation. Even more, lawsonite (+ its pseudomorphs) is used to investigate the behaviour of fluids and the rheology of rocks in subduction zones. A large amount of information may be gained from the detailed study of specific cases. An overview of all these works will be presented in their historical context. Lawsonite is a unique example where pseudomorphs are more largely distributed, and even more useful for understanding petrological processes, than the 'fresh' mineral.

Ellenberger F. (1960) - Sur une paragenèse éphémère à lawsonite et glaucophane dans le métamorphisme alpin en Haute-Maurienne (Savoie). Bull. Soc. Géol. France, S7-II, 190-194, https://doi.org/10.2113/gssgfbull.S7-II.2.190.

Franchi S. (1895) - Notizie sopra alcune metamorfosi di eufotidi e diabasi nelle Alpi occidentali. Boll. R. Comit. Geol., Serie II, VI (2), 181-204.

Ransome F.L. (1895) - On lawsonite, a new rock-forming mineral from the Tiburon Peninsula, Marin County, California. Bull. Dept. Geol. Sc., 1, 301-312.

U-Pb geochronology of metamorphic garnet by LA-MC-ICPMS

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Keywords: U-Pb, garnet, LA-ICPMS.

Laser-ablation ICPMS U-Pb dating has proven to be of great value for many geoscience disciplines. For a long time, this technique has primarily been used to date accessory minerals such as rutile, monazite, and especially zircon. Recently, this technique has been applied to rock-forming minerals with low U and high common-Pb concentrations, such as garnet, carbonates and others. Although carbonate dating is the most developed field with a tens of publications per year from an increasing number of different laboratories. However, due to the petrological/geodynamical interest of the petrology/petrochronology community, the oral communication will be devoted to the U-Pb geochronology of metamorphic garnet.

Garnet U-Pb dating by LA-ICPMS has an immense potential for investigating and possibly re-evaluating fundamental processes operating in the crust and mantle, including orogenies and craton formation and reworking. However, the abundance of inclusions and/or the extremely low U concentrations (usually

In this talk, we will have an overview of the current state of garnet U-Pb dating by LA-MC-ICPMS, encompassing obstacles, challenges, solutions, and perspectives.

U-Pb dating of magnetite, a potential first reference material

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Keywords: magnetite, U-Pb, LA-ICPMS.

The density of metamorphic reactions occurring in subduction zones, due to intense fluid-melt activity, is very high. One of the minerals resulting from all these reactions, both in the downgoing slab and in the serpentinized mantle wedge, is magnetite. Its study is crucial to understanding geodynamic processes, as it gives information about oxidized fluids, temperature, trace elements mobility, etc.. It encompasses not only metamorphic petrology but also tectonic processes of accretion, exhumation/obduction, as well as ore geology, as it is a ubiquitous mineral in numerous ore deposit types. Being able to date magnetite, providing a temporal framework to all these reactions, is to put in one more piece of this big puzzle.

Advances in analytical techniques and instrumentation, above all regarding the laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS), have made that currently, the U-Pb dating reaches far beyond the traditionally dated minerals (zircon, monazite, rutile, etc.). In this context, at the FIERCE laboratory of the Goethe University-Frankfurt, we have investigated the possibility of dating magnetite.

Magnetite from several localities have been studied, resulting in a variety of U and Pb contents (up to a few µg/g in the case of U) as well as a significant spread on the U/Pb ratios. This has allowed us to date the studied samples, with internal precisions as good as 1.5% in the best of the studied cases.

Recognising the possibility of dating such a mineral is only the first step in the implementation of the technique. Ideally, the availability of reference materials for magnetite analyses would be very advantageous. In this communication, we will present a potential reference material for U-Pb dating of magnetite by means of LA-ICPMS. The same sample has been analysed by LA-ICPMS, and U-Th/He method. Likewise, blind tests have been made by analysing unknown samples containing magnetite and garnet/apatite in equilibrium. All the results are successful, and therefore, we propose the first reference material for magnetite geochronology.

In-situ Mg and Fe stable isotopes by LA-MC-ICP-MS: Analytical challenges, new potential reference materials and application to Calabria lower crust

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Keywords: Fe-Mg isotopes, LA-MC-ICP-MS, Calabria lower crust.

Magnesium (Mg) and iron (Fe) are major constituents of many rock-forming minerals (e.g., olivine, garnet, mica, amphibole), and their isotopic compositions provide insights into a wide spectrum of geological processes such as intracrystalline diffusion, fluid-rock interaction and hydrothermal alteration, fractional crystallization, partial melting, and planetary differentiation (Teng, 2017; Johnson et al., 2020). Mg isotopes also trace carbonation-decarbonation reactions, whereas Fe isotopes are sensitive to redox processes. Despite this potential, only a limited number of in-situ Mg and Fe isotope studies have been published to date, using a variety of analytical setups and instrumentation. For Mg isotopes, challenges include isobaric interferences and matrix effects, partly mitigated by wet plasma conditions. Fe isotope measurements are also affected by matrix effects requiring matrix-matched standards, and by argon-related polyatomic interferences requiring at least medium mass resolution.

Here, we present analytical protocols developed over the last year for *i*n-situ Mg and Fe isotope determination using a Neptune *XT* MC-ICP-MS coupled to a Teledyne Analyte Excite 193 nm laser ablation system at the Geochemistry Laboratory (Milano), together with potential geological applications.

Mg isotope analyses of reference glasses (USGS, MPI-DING) and mineral standards (e.g., San Carlos olivine) under dry and wet plasma and low to medium mass resolution show generally good homogeneity (± 0.1-0.3‰, 2σ for δ^{26}Mg) but achieving consistent isotopic accuracy between analytical sessions and relative to published values remains challenging. For Fe isotopes, analyses of well-characterized standards (glasses and olivines) yield overall satisfactory results within the uncertainty of reference values. Newly investigated olivine, garnet (pyrope-almandine), mica (biotite, phlogopite), and amphibole were also assessed for micro-scale homogeneity and potential as matrix-matched standards. Results show good reproducibility under self-bracketing conditions, with external precision of 0.05-0.15‰ for both δ^{26}Mg and δ^{56}Fe, in good agreement with values reported in the literature.

These results define current analytical limitations and support future improvements for applying in-situ Mg-Fe isotopes to metasomatism, crustal recycling, and magmatic differentiation in crustal and mantle systems. A promising application is the investigation of Mg and Fe isotopic behavior in mica and garnet during metamorphism in the Calabria lower crust, to constrain fluid-mediated processes, partial melting, and granite genesis. In particular, Mg-Fe chemical and isotopic zoning, together with diffusion profiles in garnet, may be tentatively used to quantify metamorphic timescales and assess kinetic isotope fractionation during intracrystalline diffusion.

Johnson C. et al. (2020) - Iron Geochemistry: An Isotopic Perspective. Springer, 360 pp., https://doi.org/10.1007/978-3-030-33828-2.

Teng F.-Z. (2017) - Magnesium Isotope Geochemistry. Rev. Min. Geochem., 82, 219-287, https://doi.org/10.2138/rmg.2017.82.7.

In-situ Lu-Hf garnet geochronology coupled with trace elements and elastic thermobarometry to define P-T-t path of the Seve Nappe Complex in the Kebnekaise region, Swedish Caledonides

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Keywords: garnet geochronology, elastic thermobarometry, suduction.

The Seve Nappe Complex (SNC) is composed of continental rocks representing the outermost Baltica margin that were subducted and exhumed during the closure of the Iapetus Ocean leading to collision of Baltica and Laurentia during the Caledonian orogeny. The SNC consists of metasedimentary rocks that host amphibolites, eclogites, peridotites, and pyroxenites. High- to ultrahigh-pressure ((U)HP) metamorphism within the SNC has been documented from several localities in Jämtland, Västerbotten and Norrbotten counties. The Kebnekaise region within Norrbotten includes the Kebnekaise and Mårma terranes. The Kebnekasie terrane comprises the Kebne Dyke Complex composed of amphibolites, mafic rocks, and rare felsic rocks related to the opening of the Iapetus Ocean. The Mårma terrane comprises the Vássačorru Igneous Complex (bimodal igneous complex), Vierručohkka amphibolite (mafic dyke), the Leavasvággi gneiss (orthogneiss and paragneiss), and the Aurek Assemblage (gabbro and amphibolites). Several studies have tried to calculate pressure-temperature (P-T) conditions of metamorphism from different rocks in the Kebnekaise region in search of HP-UHP metamorphic conditions. In the Kebne Dyke Complex, P-T estimates range between 9 - 14 kbar and 590 - 800°C. In the Mårma terrane, P-T-time estimates yielded peak-P metamorphic condition at 10.5 - 11.75 kbar and 550 - 610°C at c. 480 Ma. The peak-T condition was reached during the retrograde path at 7.4 - 8.1 kbar and 615 - 675°C at c. 440 Ma. In order to better understand the timing and the P-T estimates of metamorphic conditions recorded in the Kebnekaise region, rocks belonging to the Vierručohkka amphibolite and Aurek Assemblage are currently being studied using in-situ Lu-Hf garnet geochronology, quartz-in-garnet (QuiG) and zircon-in-garnet (ZiG) elastic thermobarometry, and zircon-in-rutile and Ti-in-quartz (TitaniQ) thermometry. Preliminary results show that the Aurek-rocks underwent HP metamorphism, evinced by the replacement of plagioclase with kyanite and zoisite. Furthermore, different textural positions of garnets within the same rocks suggests two metamorphic events. Preliminary results of TitaniQ from a Vierručohkka garnet amphibolite yielded P-T estimates of c. 800°C and c. 15 kbar. Further south within the SNC, two different ages are recognized through in-situ Lu-Hf garnet geochronology. There, the older metamorphic event yielded c. 480-490 Ma while a younger garnet age is at c. 450-460 Ma. Results from this northern part of the paleo-Baltica margin will provide new information on the possibility of multiple metamorphic events related to subduction-exhumation dynamics during Iapetus Ocean closure.

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Almandine-1O and spessartine-1O in the Franciscan blueschists from Laytonville Quarry, northern California: Petrographic, optical and compositional features

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Keywords: garnet, metamorphism, non-cubicity.

The best example of optically anisotropic, sector-zoned garnet has just been discovered in stilpnomelane-garnet ironstones from Laytonville Quarry. The analyzed sample was metamorphosed under low-T (< 400°C) blueschist facies conditions, and consists of garnet and stilpnomelane in similar amounts, with minor quartz and accessory titanite, apatite, sulfides and ilmenite.

Garnet is subhedral to euhedral and < 300 μm in diameter. It locally shows rim dissolution and replacement by stilpnomelane. Optically, all garnet crystals show a weak birefringence even under conventional crossed polars. Analysis by polychromatic polarization confirms the already known sector-zoned pattern of birefringence, with six pairs of opposed pyramidal sectors displaying equal optical orientation. The twelve pyramids define the overall rhombic dodecahedral shape of the crystals. The optical sector zoning is accompanied by a subtle oscillatory concentric zoning, more developed at crystal rims where chemical zoning in Fe and Mn is strongest.

Optical measurements reveal that the birefringence in this garnet is 0.00053, and indicate that the optic axes in each sectors are oriented tangentially and form angles of 90° and 60° to each other.

Ferric iron in the garnet was measured by electron microprobe using the flank method: the Fe^{3+}/Fe_{tot} is in the range 5-8%. It follows that the andradite component is not negligible, and decreases the grossular content, so that the compositional zoning becomes: core = $Alm_{39}Sps_{43}Grs_{13}Pyr_{01}Adr_{03}$ and rim = $Alm_{60}Sps_{21}Grs_{11}Pyr_{02}Adr_{07}$. Therefore, the garnet can be classified as spessartine in the inner core, and almandine in the rest of each crystal. Notably, the pyrope content is extremely low, and X_{Mg} is < 0.03. The chemical zoning has no relationship with the optical sector zoning. Rather, some steps in the chemical zoning profile overlap with the optical concentric oscillations.

Transmission FTIR spectra recorded from garnets show weak absorption in the OH-stretching region, suggesting garnets contain trace amounts of OH and no molecular H_2O. However, as garnets contain numerous inclusions, it is not clear whether the observed OH-signal is due to garnet or OH-bearing mineral inclusions.

Analysis of the blueschist-facies rocks from the Laytonville Quarry deepens our knowledge of non-cubic Fe-Mg-Mn-Ca garnets increasingly observed in low-T metamorphic rocks, and allows discussion of the relationships of (non) parallelism among their optic and crystallographic axes.

An accessory mineral with a primary role: Titanite recording deformation across heterogeneous microdomains in continental shear zones

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Keywords: microstructures, microdomain composition, trace elements.

Titanite is increasingly recognized as a powerful petrochronometer capable of linking deformation, metamorphism and time in continental shear zones. Because it incorporates Rare Earth Elements (REE) and High Field Strength Elements (HFSE) and can be dated by U-Pb methods, titanite represents an integrated archive of metamorphism, deformation and fluid-assisted recrystallization (Kohn, 2017). However, its response to deformation is not uniform and is strongly controlled by the microstructural and chemical microdomain in which it occurs (Corvò et al., 2023; Langone et al., 2025).

This contribution presents an overview of titanite behaviour in compositionally heterogeneous mylonites developed at different crustal levels, comparing examples from the Ivrea-Verbano Zone (IVZ, Southern Alps), representative of extensional deformation at mid- to lower-crustal conditions, with a transpressive greenschist-facies shear zone exposed in the Palmi area (Calabria; Prosser et al., 2003). In the IVZ, titanite occurs in banded mylonites where mafic, felsic and calc-silicate layers alternate at the mm-cm scale. Despite comparable metamorphic-deformation histories, titanite displays markedly different microstructural, chemical and isotopic signatures depending on the host microdomain. SEM and EBSD analyses reveal variable intracrystalline deformation, including lattice distortion, misorientation gradients, subgrain formation, localized high-strain domains and neocrystallization. These features are preferentially developed in amphibole-rich microdomains, whereas in carbonate-bearing layers deformation is largely partitioned into matrix minerals and titanite remains comparatively undeformed. Trace-element data indicate that titanite chemistry reflects the bulk composition of the surrounding assemblage. A systematic decoupling between trace-element signatures and U-Pb isotopic systematics is observed: chemical compositions commonly record regional metamorphic conditions, whereas isotopic resetting correlates with deformation-related microstructures. This relationship is strongest in amphibole-rich domains and weaker in carbonate-rich layers, likely reflecting differences in REE budget, fluid distribution and strain accommodation. In the Palmi shear zone, titanite shows sigmoidal geometries and intracrystalline deformation localized at grain rims and tips, suggesting titanite involvement during low-temperature deformation. Across both settings, titanite behaviour reflects the interplay among P-T conditions, fluid availability, strain partitioning and microdomain composition. These observations demonstrate that titanite can record deformation from greenschist- to granulite-facies conditions, preserving growth, recrystallization or mixed isotopic signatures. Titanite therefore emerges as a key archive for decoding deformation and tectono-metamorphic evolution across continental shear zones.

Corvò S. et al. (2023) - Crystal plasticity and fluid availability govern the ability of titanite to record the age of deformation. Earth Planet. Sc. Lett., 620, 118349, https://doi.org/10.1016/j.epsl.2023.118349.

Kohn M.J. (2017) - Titanite petrochronology. Rev. Mineral. Geochem., 83(1), 419-441, https://doi.org/10.2138/rmg.2017.83.13.

Langone A. et al. (2025) - Reactive and resilient: the contrasting behaviour of monazite and titanite during deformation (the Forno-Rosarolo shear zone; Ivrea-Verbano Zone). Geol. Mag., 162, e18, https://doi.org/10.1017/S0016756825100022.

Prosser G. et al. (2003) - Strain localisation driven by marble layers: The Palmi shear zone (Calabria-Peloritani terrane, Southern Italy). Geol. Acta, 2, 155-166.

Challenging the Permo-Triassic paradigm: Ediacaran roots of the Finero lower-crustal section

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Keywords: Ivrea-Verbano Zone, Finero Mafic Complex, ancient crustal fragments.

Geochronology of the deep crust constrains the timing of formation and transformation of continental roots, providing a temporal framework for crust-mantle interactions and crustal evolution. The Finero Mafic Complex (Ivrea-Verbano Zone, southern Alps, Italy) is a classic lower crust-upper mantle section, traditionally interpreted as a product of Permian-Triassic magmatism (Zanetti et al., 2013; Langone et al., 2017) and lithospheric thinning prior to Alpine orogenesis. Despite its significance, direct geochronological constraints on key internal units remain limited because mafic lower-crustal rocks pose inherent challenges for conventional radiometric dating, including sparse and small zircon populations, inheritance, and high-temperature isotopic disturbance during metamorphism and melt-rock interaction. We present zircon U-Pb ages from the Layered Internal Zone (consisting of gabbros - garnet hornblendites - anorthosites - pyroxenites - with minor peridotites) of the Finero Mafic Complex in the northern Ivrea-Verbano Zone that define five distinct age populations spanning the Archean (ca. 2.7-2.8 Ga) and Proterozoic (ca. 2.1 Ga, 1.1 Ga, 695 Ma, and 567 Ma). Strikingly, these zircons lack the Paleozoic inheritance that characterizes gabbroic plutons in the southern Ivrea-Verbano mafic complex. The absence of Paleozoic inherited grains, coupled with the youngest coherent zircon population at ca. 567 Ma, supports an Ediacaran crystallization age, substantially older than the widely inferred Permian-Triassic event. This interpretation is reinforced by a published bulk-rock Sm-Nd isochron age of 533±20 Ma from the adjacent Amphibole Peridotite (Lu et al., 1997), collectively indicating that a significant portion of the Finero lower crust was established during Ediacaran magmatism rather than in the late Paleozoic. At this time the studied rocks formed part of the Adriatic plate along the northern margin of Gondwana, together with the Calabria-Peloritani terrane, among other terranes positioned outboard of Africa. Subsequent tectonothermal events overprinted the Layered Internal Zone during melt fluxing, forming melferite (i.e., rocks formed by melt-rock interaction in high-strain melt migration pathways, Daczko & Piazolo, 2022) and promoting amphibole and garnet growth. Recognition of Ediacaran roots within this iconic mafic complex opens new opportunities for correlation with other deeply exhumed crustal sections, such as those preserved in Calabria. This finding calls for a reassessment of the age, evolution, and tectonic significance of lower-crustal domains in the Alps and highlights the potential for ancient crustal fragments to remain preserved within younger orogenic systems.

Daczko N.R. & Piazolo S. (2022) - Recognition of melferite - A rock formed in syn-deformational high-strain melt-transfer zones through sub-solidus rocks: A review and synthesis of microstructural criteria. Lithos, 430-431, 106850, https://doi.org/10.1016/j.lithos.2022.106850.

Langone A. et al. (2017) - Ductile-brittle deformation effects on crystal-chemistry and U-Pb ages of magmatic and metasomatic zircons from a dyke of the Finero Mafic Complex (Ivrea-Verbano Zone, Italian Alps). Lithos, 284-285, 493-511, https://doi.org/10.1016/j.lithos.2017.04.020.

Lu M. et al. (1997) - The mafic-ultramafic complex near Finero (Ivrea-Verbano Zone), II. Geochronology and isotope geochemistry. Chem. Geol., 140, 223-235, https://doi.org/10.1016/S0009-2541(97)00050-8.

Zanetti A. et al. (2013) - SHRIMP U-Pb Zircon Triassic Intrusion Age of the Finero Mafic Complex (Ivrea-Verbano Zone, Western Alps) and its Geodynamic Implications. J. Petrol., 54, 2235-2265, https://doi.org/10.1093/petrology/egt046.

First evidence of bi-modal Cambrian magmatism in the Pinerolo-Sanfront Unit, Dora-Maira Massif, Western Alps

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Keywords: Dora-Maira, U-Pb geochronology, Cambrian basement.

The Dora-Maira Massif is a major tectonic window in the Western Alps, exposing continental basement units, of Briançonnaise affinity, stacked at different structural levels. It extends from the Maira Valley, to the south, to the Susa Valley, to the north, bounded eastward by the Po Basin sediments and overlain westward by oceanic-derived Upper Penninic units. The lowermost unit of the nappe stack, the Pinerolo-Sanfront Unit, has traditionally been interpreted as a monocyclic sequence composed of Permo-Carboniferous metasediments (micaschist, metaconglomerate, metasandstone, and graphitic phyllite; Borghi et al., 1984), and orthogneiss and meta-mafic rocks with a Permian protolith. We present new field observations and U-Pb zircon geochronological data (LA-ICP-MS) from metabasite and orthogneiss (Cadoppi et al., 1993) samples collected within the framework of the CARG geological mapping project (Sheet 172-Pinerolo). Both lithologies contain early Cambrian magmatic zircon, documenting for the first time in the Pinerolo-Sanfront Unit a bimodal magmatic event, related to the Cadomian Orogeny (Siegesmund et al., 2021). These results challenge the traditional view of the Pinerolo-Sanfront Unit as exclusively composed of Permo-Carboniferous rocks and instead indicate the presence of a previously unrecognised pre-Carboniferous basement. This interpretation is consistent with the recent discovery of Silurian palynofloras in this unit (Carosi et al., 2025) and calls for a re-evaluation of the evolution and significance of this sector of the Western Alps.

Borghi A. et al. (1984) - Osservazioni geologiche nella val Germanasca e nella media Val Chisone (Alpi Cozie). Boll. Mus. Reg. Sci. Nat. Torino, 2, 503-530.

Cadoppi P. et al. (1993) - Filoni aplitici albitizzati nel Carbonifero del Massiccio Dora-Maira (Alpi Cozie). Atti Acc. Sci. Torino, 127, 273-284.

Carosi R. et al. (2025) - Buried, not erased: palynofloras in ultra-high-pressure metamorphic rocks. Sci. Rep., 15(1), 35865, https://doi.org/10.1038/s41598-025-23551-5.

Siegesmund S. et al. (2021) - The birth of the Alps: Ediacaran to Paleozoic accretionary processes and crustal growth along the northern Gondwana margin. Int. J. Earth Sci., 110, 1321-1348, https://doi.org/10.1007/s00531-021-02019-7.

Decoding a Gondwana margin suture: P-T-D-t evolution of the Dessent Unit (Northern Victoria Land, Antarctica)

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Keywords: northern Victoria Land, Ross Orogen, high-temperature mylonite.

Remnants of the Early Paleozoic Ross Orogen occur in northern Victoria Land in Antarctica. So far, three main fault-bounded tectono-metamorphic units have been recognised, namely: (i) the Wilson Terrane (WT), which is composed of low- to high-grade metamorphic rocks and Cambro-Ordovician igneous rocks; (ii) the Bowers Terrane (BT), which is dominated by volcanic and sedimentary rocks with a low-grade metamorphic overprint; and (iii) the Robertson Bay Terrane, which contains very low-grade (meta-)turbidites. The WT and BT are tectonically juxtaposed by a transpressional shear belt that locally incorporates eclogite-facies rocks.

In the Mountaineer Range, this boundary is marked by the Dessent Unit (DU) (Capponi et al., 1988; Goodge, 2020) composed of metasedimentary rocks and amphibolite (e.g. Capponi et al., 1988; Palmeri et al., 2012; Scambelluri et al., 2003). Although petrological datasets are available for the amphibolites (e.g., Palmeri et al., 2012; Scambelluri et al., 2003), data concerning the metasedimentary rocks remain scarce, leaving the tectono-metamorphic evolution of the DU only poorly constrained (Goodge, 2020).

In this study, we present a combined microstructural, petrological and petrochronological reappraisal of DU metasediments collected and studied during various PNRA-Italian Antarctic scientific expeditions. Our results indicate that the main regional foliation in the DU is related to at least a second deformation phase, as an older foliation is preserved within microlithons and intertectonic porphyroblasts.

Microstructural observations further document of upper amphibolite to lower granulite-facies (HT) non-coaxial shearing. Pseudosections and mineral compositions suggest that most of the metasediments equilibrated within a P-T range of 600-650°C and 6.5-8.5 kbar. This was followed by cooling and decompression, which is consistent with the results obtained for DU amphibolites (Palmeri et al., 2012). Garnet U-Pb petrochronology, assisted by trace-elements compositional maps, was applied to infer the timing of prograde metamorphism. The obtained ages indicate that the metasediments shared a common metamorphic history with the amphibolites and provide new insights into the prograde-to-peak P-T-D path of the DU and its role within the Ross Orogen.

Capponi G. et al. (1988) - Metamorphic assemblages in layered amphibolites and micaschists from the Dessent Formation (Mountaineer range - Antarctica). Mem. Soc. Geol. It., 43, 87-95.

Goodge J.W. (2020) - Geological and tectonic evolution of the Transantarctic Mountains, from ancient craton to recent enigma. Gondwana Res., 80, 50-122, https://doi.org/10.1016/j.gr.2019.11.001.

Palmeri R. et al. (2012) - Boninite-derived amphibolites from the Lanterman-Mariner suture (northern Victoria Land, Antarctica): New geochemical and petrological data. Lithos, 140-141, 200-223.

Scambelluri M. et al. (2003) - Petrology, geochemistry and geochronology of the Dessent Unit, northern Victoria Land, Antarctica: some constraints on its evolutionary history. Geol. Jahrb., B85, 95-131.

New frontiers in the study of deep carbon fluxes at convergent margins: Insights from fluid inclusion gas extractions

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Keywords: fluid inclusions, deep carbon fluxes, convergent margins.

At convergent margins, deep carbon fluxes driven by metamorphic processes and fluid-rock interactions significantly impact Earth's climate and habitability, by modulating greenhouse gas emissions (e.g. CO_2 and CH_4), and by delivering life-essential energy sources to the deep biosphere (e.g. CH_4). Microthermometry and micro-Raman spectroscopy of fluid inclusions (FIs) from exhumed metamorphic rocks, has opened a window into the nature of metamorphic C-O-H fluids over a wide range of pressure-temperature conditions and geodynamic settings. Yet, the isotopic composition of FIs in metamorphic rocks as well as their CO_2-CH_4 storage potentials have been rarely investigated, leading to large uncertainties regarding their origin and impact on volatile fluxes.

To bridge this gap, we applied a novel approach to study deep carbon fluxes at convergent margins. We combined FI petrography and micro-Raman spectroscopy with bulk FIs mechanical extraction analyses to release CO_2 and hydrocarbons from FIs and measure their concentrations and isotope ratios through Cavity Ring-Down Spectroscopy (CRDS). In this study we summarize the results collected during the past five years on 270 rock samples from several exhumed metamorphic terranes, spanning from the Archean to the Phanerozoic.

We present a series of case studies highlighting FIs not only as a widespread, microscopic archive of deep C-O-H fluids and isotopic signatures, but also as active drivers of hidden carbon fluxes at convergent margins. Our research quantifies the CH_4-CO_2 storage/release potential of FIs across diverse geodynamic settings and lithologies, including ultramafic, metamafic, metasedimentary, and metasomatic rocks. Furthermore, we decipher the mechanisms releasing these deep gases from FIs throughout their tectonic evolution, from fluid-rock interactions and metamorphic reactions during subduction and exhumation, to ultimate atmospheric degassing via surface erosion. Finally, we show how metamorphic CH_4 isotope analyses provide critical insights into the cycling of organic carbon in the deep Earth, across the Archean-Phanerozoic eons.

Hidden pre-Alpine records preserved within the garnets of the Briançonnais nappes of the Central Alps

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Keywords: Central Alps, Variscan metamorphism, garnets.

Studying the poly-metamorphic and polycyclic evolution of metasedimentary rocks often proves to be challenging, mainly because of the tendency of their mineral associations to easily re-equilibrate during subsequent metamorphism. On the other hand, garnets, which are often important constituents of these rocks, can be regarded as time-capsules due to their generally high resistance during retrograde and/or polycyclic metamorphism (e.g., Baxter et al., 2017and references therein). The analysis of the inclusions and of the textures preserved within these minerals thus became a well-known tool for deciphering the metamorphic evolution of such rocks, especially in high-grade terrains (e.g., Tacchetto et al., 2019).

Recent geological mapping campaigns in the Tambo and Suretta nappes (Central Alps) already highlighted the presence of a widespread HT signature despite the general Alpine overprint, interpreted as pre-Alpine in age. Two samples from the southernmost portion of the Tambo in particular show relic garnets with peculiar cloudy textures, due to the high density of inclusions mainly composed by rutile-ilmenite needles, carbonates, graphitic material and micrometer-sized multiphase inclusions. Similar textures are usually reported for garnets found in high-grade metamorphic contexts (e.g., Ague & Eckert, 2012), conditions frequently observed within the rocks of the Variscan remnants across Europe.

Despite the necessity for additional focused analyses, both meso- and micro-scale investigations point toward the conclusion that the Tambo Nappe still records long-lasting evidence related to the Variscan Orogeny and subsequent evolution. These new observations suggest the possible presence of a high-grade metamorphic event not yet characterized within this nappe. HP remnants of Variscan age have been already identified within the structurally higher Suretta Nappe (Nussbaum et al., 1998), and, considering the similarities observed between the two units, it is not unlikely to hypothesize a common pre-Alpine metamorphic evolution for the entire Briançonnais terrain of the Central Alps.

If proved, the recognition of a pre-Alpine high-grade imprint within these units would possibly open new interpretations regarding the geodynamic significance of the easternmost portion of the Briançonnais microcontinent during and after the Variscan Orogeny.

Ague J.J. & Eckert Jr J.O. (2012) - Precipitation of rutile and ilmenite needles in garnet: Implications for extreme metamorphic conditions in the Acadian Orogen, USA. Am. Mineral., 97(5-6), 840-855, https://doi.org/10.2138/am.2012.4015.

Baxter E. et al. (2017) - Garnet: A rock-forming mineral petrochronometer. Rev. Mineral. Geochem., 83(1), 469-533, https://doi.org/10.2138/rmg.2017.83.15.

Nussbaum C. et al. (1998) - Two subduction events in a polycyclic basement: Alpine and pre-Alpine high-pressure metamorphism in the Suretta nappe, Swiss Eastern Alps. J. Metamorph. Geol., 16(5), 591-605, https://doi.org/10.1111/j.1525-1314.1998.00154.x.

Tacchetto T. et al. (2019) - Multiphase inclusions in peritectic garnet from granulites of the Athabasca granulite terrane (Canada): evidence of carbon recycling during Neoarchean crustal melting. Chem. Geol., 508, 197-209, https://doi.org/10.1016/j.chemgeo.2018.05.043.

Reading the HP-UHP history of Dora Maira whiteschists through garnet grains

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Keywords: Dora Maira whiteschists, garnet grains, chemical-mechanical modification.

Dora Maira whiteschists in the Western Alps have been the most studied ultra-high-pressure (UHP) rocks in the world and can be used to investigate the evolution of Earth's crust during subduction and exhumation. Garnet is a key component of these rocks and preserves evidence of their compression and decompression history, making it a valuable tool for identifying processes acting at HP-UHP conditions. We studied garnet grains using EPMA, SEM-EDS, and SEM-EBSD analyses to characterize their chemical composition and microstructural evolution. Moreover, we applied U-Pb garnet dating to constrain their crystallization age.

Garnet grains are pyrope-rich (up to 98% pyrope component). We distinguished four pyrope types on the basis of element distribution patterns, major inclusion assemblages and microstructures. Pyrope grains display a concentric to patchy chemical zoning, which is particularly evident in the calcium distribution. The originally concentric chemical zoning formed during two garnet growth stages from prograde metamorphism (~63 Ma) to peak conditions (~38 Ma). The concentric zoning was subsequently modified by incipient to complete recrystallization of the pyrope grains, promoting calcium redistribution. We document for the first time this unusual calcium zoning pattern associated with ductile deformation. During decompression of the whiteschists, this ductile deformation alternated with brittle deformation. Evidence of brittle behavior in garnet includes parallel fractures and later radial fractures related to the coesite-to-quartz transition.

Our study shows for the first time that garnet grains can preserve evidence of both ductile and brittle deformation along a single P-T path under UHP to HP conditions. We highlight that the close interplay between mechanical and chemical behavior in garnet requires caution when interpreting chemical zoning alone as a record of metamorphic evolution.

Mechanical controls on metamorphic reactions and chemical records

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Keywords: metamorphic reactions, chemical processes, timescales.

Metamorphic rocks are commonly interpreted as records of progressive pressure-temperature evolution and long-term chemical equilibration However, increasing evidence suggests that mechanical processes may strongly influence mineral reactions, deformation mechanisms, and chemical redistribution across a wide range of spatial and temporal scales.

This contribution explores the coupling between deformation, reaction kinetics and chemical evolution in metamorphic systems. Particular emphasis is placed on the interplay between intracrystalline deformation, mineral reactions, transient stress states and the preservation or modification of chemical records in metamorphic minerals. Recent microstructural observations, high-pressure experiments and thermo-mechanical models increasingly indicate that mechanical processes may locally enhance, inhibit or redirect reaction pathways and chemical transport processes in ways that are not fully captured by classical petrological approaches.

Examples discussed in this presentation include the preservation of chemical zoning during high-temperature metamorphism, reaction-induced deformation processes and experimental observations of rapid reaction triggering during short-lived pressure changes. These observations raise broader questions regarding the role of stress, deformation and timescale-dependent processes in controlling mineral transformations, diffusion processes, and petrochronological records.

Together, these perspectives highlight the need for stronger integration between petrology, rock mechanics, microstructural analysis and thermo-mechanical modelling to better understand how mechanical processes influence the chemical and mineralogical evolution of rocks in the deep Earth.

Unconventional, redox water and hydrous mineral formation from dry minerals and H_2-fluids

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Keywords: water, H_2, redox water.

Water availability in the lithosphere exerts a fundamental control on Earth's evolution and on the conditions that allow life to persist. The global geological water cycle, linked to plate tectonics, has long been understood as a system governed by the behaviour of oxygen and hydrogen - whether in fluids, melts, or bound within mineral structures. Recent work, however, has revealed that molecular hydrogen (H_2) production in the lithosphere is far more significant than previously appreciated: a water mass equivalent to roughly 25-50% of annual global inputs into subduction zones is converted to H_2 each year. Because H_2 can decouple from the water cycle and escape to space over geological timescales, this has profound implications for Earth's long-term hydrogen budget.

Here we present evidence that when H_2-rich fluids interact with oxygen-bearing minerals, they produce an unconventional form of water, or redox water, as well as hydrous minerals from initially dry reactants (Vitale Brovarone et al., 2026). This previously unrecognised pathway affects the residence time of hydrogen in Earth's interior and the conditions at which free water and hydrous mineral pahses can form inside the Earth and on other celestial bodies. These findings open new perspectives on the deep-water cycle and its role in controlling the chemical evolution of the lithosphere and the functioning of rocky planetary bodies.

Vitale Brovarone A. et al. (2026) - Unconventional water and hydrous mineral formation from dry minerals and H_2 fluids. Sci. Adv., 12, eaee6559, https://doi.org/10.1126/sciadv.aee6559.

Differentiation of the Calabria crustal section: New constraints from petrography, geochronology, and geochemistry of lower crustal mafic rocks

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Keywords: cum-bearing mafic rocks, polyphase crustal differentiation, zircon U-Pb dating.

The Serre Massif in Calabria (southern Italy) provides a rare exposure of a tilted section of continental crust largely shaped during the late stages of the Variscan orogeny. It preserves lower-crustal lithologies, including mafic and felsic granulites and migmatitic paragneisses, overlain by a ~13 km-thick mid-crustal batholith. The latter mainly consists of granitoids belonging to calc-alkaline (tonalite to granite) and strongly peraluminous (granodiorite to granite) suites, representing the ultimate products of crustal differentiation (Schenk, 1990; Rottura et al., 1990). These granitoids were emplaced during the late Variscan following decompression and widespread partial melting of the lower crust. Mafic lithologies, including amphibole gabbros and (quartz) diorites, are comparatively less abundant throughout the section but display a wide range of mineralogical and textural features, recording complex magmatic processes, including crustal assimilation and interaction with anatectic melts (Biget et al., 2026). Despite their significance for crustal evolution, their timing, origin, and petrogenesis remain however poorly constrained.

Here, we present petrographic observations, mineral and whole-rock geochemical and isotopic data, together with new zircon U-Pb ages for mafic lithologies sampled throughout the lower crust. These include deep-seated metagabbros and mafic granulites forming the base of the exposed crustal section, as well as cummingtonite-bearing (micro)gabbros and norites occurring mainly as lenses, dykes, and sills within the Migmatitic Border Zone. This transitional zone between the lower crust and the granitoids of the middle crust also hosts mafic gneisses/amphibolites.

New major and trace element data for rock-forming minerals (plagioclase, pyroxene, amphibole, and biotite) are used to better constrain the petrogenetic evolution of these lithologies. New zircon U-Pb ages reveal contrasting emplacement histories. Amphibolites (sporadically bearing garnet and/or orthopyroxene) record an early differentiation event older than 450 Ma, subsequently overprinted by late-Variscan metamorphic and magmatic events. In contrast, other mafic lithologies from the Migmatitic Border Zone yield exclusively Variscan ages. Metagabbros and mafic granulites from the deep crust record a broad spectrum of zircon U-Pb ages, spanning from the Precambrian to the Permo-Carboniferous, reflecting a complex geological history and making interpretations of their emplacement timing challenging. These results highlight the polyphase nature of crustal differentiation in Calabria and provide new insights into the temporal relationships between lower-crustal mafic rocks and mid-crustal granitoids.

Ongoing work integrating whole-rock Sr-Nd isotopes and in situ Sr-Nd isotopic analyses will further constrain magma sources and quantify mantle versus crustal contributions during crustal differentiation.

Biget T. et al. (2026) - Tracing anatexis and bottom-up crustal homogenisation with *in situ* Sm-Nd isotopes. Geochem. Persp. Lett., 38, 46-52, https://doi.org/10.7185/geochemlet.2602.

Rottura A. et al. (1990) - Petrogenesis of contrasting hercynian granitoids from the Calabrian arc, southern Italy. Lithos, 24(2), 97-119, https://doi.org/10.1016/0024-4937(90)90019-w.

Schenk V. (1990) - The exposed crustal cross section of southern Calabria, Italy: Structure and evolution of a segment of hercynian crust. In: M.H. Salisbury, Fountain D.M. (Eds.), Exposed Cross-Sections of the Continental Crust, Springer, 21-42, https://doi.org/10.1007/978-94-009-0675-4_2.

Post-collisional extension and mafic magmatism: The Punta Falcone magmatic complex (northern Sardinia, Italy)

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Keywords: gabbro, emplacement mechanism, thermobarometry.

The Sardinia-Corsica batholith is a huge magmatic system composed of several coalescent plutons emplaced during the Variscan post-collisional phase. Gabbroic complexes and mafic dikes swarms of calc-alkaline affinity cluster in the time-interval 290-270 Ma, marking the end of Variscan magmatic activity. The Punta Falcone gabbroic complex is one of the best exposed of such intrusions. Despite its relatively small surface exposure (about 0.15 km^2), geophysical constraints indicate that most of the magmatic body likely continues offshore to the west in the Bonifacio straits. The observed rocks-types range in composition from gabbro/gabbronorite to quartz-gabbronorite, whereas the felsic rocks range in composition from granodiorites to granite on Q'-ANOR normative diagram.

Overall, the contact between basic and acidic rocks is irregularly-shaped and characterized by magmatic breccias composed of very fine-grained amphibole-bearing leuco-monzogranite associated to fragments of gabbro and coarse-grained granodiorite.

In Harker variation diagrams, the samples show clearly a linear trend with a marked gap between gabbroic rocks and granites, as well as a typical calc-alkaline fingerprint. Amphibole-only thermobarometry (Ridolfi, 2021) applied to secondary calcic amphiboles both within mafic and felsic rocks indicate crystallization pressure between about 1.2-1.7 Kbars, which is consistent with field observations and regional geology constraints. A pre-emplacement evolution at slightly higher pressure (about 4 Kbars) could be inferred for the basic magma by (early crystallized) clinopyroxene-only thermobarometry (Wang et al., 2021). In addition, evidence of interaction between basic/acidic magma at upper crustal levels is supported by relatively high T estimates, around 800°C for all rock types, and nearly homogeneous Log fO_2 at -14.5 recorded both on gabbroic and granitic rocks. All these observations indicate the the Punta Falcone magmatic complex represents a basic magma batch that mixed with crustal-derived melts at 2.4-5.4 Kbars before final emplacement and cooling at sub-volcanic conditions, as commonly observed for coeval early Permian plutonic/sub-volcanic complexes in the Corsica-Sardinia block.

Ridolfi F. (2021) - Amp-TB2: an updated model for calcic amphibole thermobarometry. Minerals, 11(3), 1-9, https://doi.org/10.3390/min11030324.

Wang X. et al. (2021) - A new clinopyroxene thermobarometer for mafic to intermediate magmatic systems. Eur. J. Mineral., 33(5), 621-637, https://doi.org/10.5194/ejm-33-621-2021.

When garnets forget: Rheological controls on UHP preservation and pitfalls of P-T-based tectonic models in the Dora-Maira Massif (Western Alps)

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Keywords: Dora-Maira, P-T-d path, UHP.

New mapping, structural and P-T-d data) from the north-central Dora-Maira Massif, collected within the framework of the CARG geological mapping project (Sheet 172-Pinerolo), allow an integrated reconstruction of the tectono-metamorphic evolution of both orthogneiss and micaschist. Structural and petrological analyses demonstrate that both lithologies share the same Alpine metamorphic evolution, reaching ultra-high-pressure (UHP) conditions within the coesite-chloritoid eclogite facies (530-560°C, 2.6-2.9 GPa), as supported by newly identified coesite relicts and thermodynamic modelling. Despite this shared P-T history, micaschist and orthogneiss display markedly different degrees of metamorphic re-equilibration. In micaschist, UHP evidence is preserved as coesite relicts and peak mineral assemblages, faithfully recording the full prograde-to-peak P-T evolution. In orthogneiss, re-equilibration is controlled by the interplay between deformation and fluid availability. Low-strain, fluid-deficient domains retain the original magmatic framework and show only partial metamorphic overprinting, whereas high strain domains acted as preferential pathways for externally derived fluids, promoting recrystallization and re-equilibration under eclogite-facies conditions. Crucially, even where garnet crystallized in the orthogneiss, it records only part of the prograde evolution, yielding P-T conditions of 500-540°C and 19-22 kbar, well below the UHP peak. This behaviour is analogous to that observed in polymetamorphic garnets (Nosenzo et al., 2023; Manzotti et al., 2025), where successive metamorphic events or incomplete re-equilibration result in chemical zoning that reflects only portions of the total P-T path rather than peak conditions. White mica compositions, less susceptible to re-equilibration, retain higher-pressure signatures (~27-29 kbar), consistent with UHP conditions documented in the adjacent micaschist. The absence of UHP evidence in orthogneiss therefore reflects not a difference in metamorphic history, but rheological and structural controls on mineral re-equilibration during exhumation (Dana et al., 2026). Apparent P-T differences between adjacent lithologies of the same tectonic unit are thus not real, but rather artifacts of variable preservation of peak mineral assemblages or the consequent limitations of thermobarometric modelling. Using P-T estimates alone as a criterion to distinguish separate tectonic units is therefore misleading, and thermobarometric reconstructions must always be integrated with structural observations (at various scale) to avoid misleading tectonic interpretations in heterogeneous UHP terranes.

Dana D. et al. (2026) - Heterogeneous deformation and partial (re-) equilibration of high-pressure orthogneiss in the Dora-Maira Massif (Western Alps). Tectonophysics, 930, 231201, https://doi.org/10.1016/j.tecto.2026.231201.

Manzotti P. et al. (2025) - Garnet growth across the quartz-coesite transition in metapelites: equilibrium vs. kinetics. Eur. J. Mineral., 37(4), 455-482, https://doi.org/10.5194/ejm-37-455-2025.

Nosenzo F. et al. (2023) - H_2O budget and metamorphic re-equilibration in polycyclic rocks as recorded by garnet textures and chemistry. Lithos, 452, 107230, https://doi.org/10.1016/j.lithos.2023.107230.

Prograde garnet zoning controlled by microscale compositional heterogeneities in a coesite-bearing marble (Lago di Cignana Unit)

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Keywords: elastic geobarometry, UHP metamorphism, Lago di Cignana Unit.

Understanding of early metamorphic stages is often hindered by mineral recrystallisation and elemental redistribution during retrogression. Garnet uniquely can preserve information through compositional zoning and emerges as a crucial mineral in this context. The variability and spread of mineral inclusions in garnet enable the integration of thermodynamic tools, like pseudosections and elastic geothermobarometry, providing insights into pressure and temperature (P-T) conditions of equilibration. While these studies excel with metapelitic rocks due to their mineral variability, near-monomineralic lithotypes such as impure quartzite or marble lack mineralogic changes owing to their stability over a wide P-T range. Moreover, existing solution models are ill-suited to unconventional bulk rock compositions, thereby compromising reliable geothermobarometric results.

In our study, we employ elastic geobarometry to trace prograde garnet growth in Mn-rich garnets from an impure marble in the Lago di Cignana Unit, Italy. The rock, dominated by calcite, dolomite, and quartz, features garnet porphyroblasts exhibiting strong core-to-rim compositional zoning. Garnet cores and mantles contain quartz, rutile, calcite, and apatite inclusions, while coesite, aragonite, zircon, and rutile are found in garnet rims. The three investigated garnets display variations in shape, zonation, and inclusion type and size, yet share a comparable core-to-rim composition. Elastic geobarometry on quartz inclusions in garnet reveals distinct growth stages, indicating formation at pressures ranging from 1.2 GPa and 430°C to 1.8 GPa and 500°C. The final stage with coesite-bearing garnet rims occurs under ultra-high-pressure (UHP) conditions. The variations in P-T during garnet growth indicate variable growth timing and may stem from local changes in chemical composition at the thin-section scale or reaction overstepping.

The Deep Carbon Lab: A composite research laboratory for advanced geological and multidisciplinary investigations

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Keywords: research, analytical service, analytical facilities.

Based at the Department of Biological, Geological, and Environmental Sciences (BiGeA) of the University of Bologna, the Deep Carbon Lab is a research laboratory designed to pursue research and analytical service in a broad range of scientific fields, to boost both pure scientific knowledge advancement and industrial applications. It hosts a wide variety of instruments and facilities, pertaining to two different fields of application: microscopic characterization and isotopic geochemistry. This composite setting allows both stand-alone and integrated analytical workflows.

The Deep Carbon Lab is equipped with several facilities:

- A Zeiss correlative microscopy platform consisting of camera-equipped standard and motorized petrographic microscopes and macroscopes; a dedicated software for automatic acquisition of large sample scans (stitching) and referenced multi-magnification overlay; an SEM equipped with EDS (100mm) and EBSD detectors.
- A NewTec cold-cathodoluminescence microscope equipped with motorized stage for stitching.
- A stable isotope platform equipped with a Picarro G2201-1 CRDS analyzer for $\delta^{13}C$ measurements in CO_2 and CH_4, equipped with three different peripherals for analyzing gases, carbonates, and graphite/organic matter; an Aerodyne TILDAS analyzer for $\delta^{13}C$ and δD measurements in gaseous CH_4.
- A fluid inclusion extraction facility including vacuum lines for purification.
- A sample preparation facility including a microdrill for in-situ sample preparation; a diamond wire saw; a carbon-coater; a vibrational polishing machine for EBSD sample preparation; a fume hood; a planetary mill; a hydraulic press; a laboratory oven; a centrifuge; a ultrasonic bath; a high-precision balance.

Three examples of integrated workflows are presented.

(1) The Zeiss platform for correlative microscopy exploits a sample holder that allows for georeferencing all images acquired with the motorized optical microscope, the SEM, and the cathodoluminescence system in a unique reference frame, guaranteeing immediate identification of target areas in every instrument and more accurate investigations without loss of information. Additionally, such system can be exploited to navigate more easily a sample when it is analyzed in an instrument external to the Lab (e.g., Raman system or microprobe).

(2) The fluid inclusion analytical workflow integrates optical microscopy in thin section, extraction of the gases contained in the fluid inclusions through ball milling, and analyses of the extracted gases with CRDS and/or TILDAS analyzers.

(3) Carbon stable isotope analysis integrates petrographic and cathodoluminescence microscopy to identify single or multiple generations of carbonates, followed by milling/crashing (single generation) or micro-mill (multiple generation) sample preparation for CRDS analysis through acidification. Additionally, existing consolidated routines can also integrate other analytical techniques such as Raman spectroscopy.

The Deep Carbon Lab is open for collaborations with national and international research institutions and private companies.

Retrieving fluid compositions during crustal melting using the Raman spectrum of cordierite

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Keywords: COH fluids, cordierite, μ-Raman spectroscopy.

Cordierite is known to accommodate volatiles, e.g. CO_2 and H_2O, in its structural channels. The amounts incorporated into cordierite depend primarily on the composition and activity of the fluid phase and temperature. Therefore, cordierite has been suggested as a natural sensor of fluid compositions in high-grade metamorphic settings (Harley et al., 2002). In this study, we investigate peritectic cordierite formed at fluid-saturated conditions in experiments on partially melted metapelites. The aim is to evaluate the potential of retrieving fluid compositions from cordierite volatile contents determined by μ-Raman spectroscopy.

We performed partial melting experiments on synthetic graphitic metapelites at 8 kbar and 950°C in a piston cylinder apparatus. Although the oxygen fugacity of the experiments was not strictly controlled by conventional buffering, the fluid composition was directly measured ex-situ by capsule piercing QMS (Tiraboschi et al., 2016). Since the starting metapelite contains graphite, the fluid composition lies along the graphite saturation surface, and oxygen fugacities can be calculated using the equation of state by Connolly and Cesare (1993). The composition of the phases has been analyzed by electron microprobe, and the relative proportions of C-O-H species in co-existing melt and cordierite have been investigated using μ-Raman spectroscopy.

Raman spectra show that cordierite channels host either dominantly CO_2 and H_2O or dominantly CH_4 and H_2O, depending on the sample, and that the relative proportions of these species closely match their molar proportions in the co-existing fluid phase as measured by the capsule-piercing QMS. These results suggest that fluid compositions in fluid+graphite-saturated anatectic systems can be retrieved from Raman spectra of cordierite. Future work aims to quantify total H and C in cordierite and glass, and to extend the approach to natural samples. Given that cordierite is a common peritectic phase during crustal melting at low- to mid-pressure conditions, this approach could provide a useful tool for estimating fluid compositions in natural anatectic systems.

Connolly J.A.D. & Cesare B. (1993) - C-O-H-S fluid composition and oxygen fugacity in graphitic metapelites. J. Metamorph. Geol., 11(3), 379-388, https://doi.org/10.1111/j.1525-1314.1993.tb00155.x.

Harley S. et al. (2002) - Cordierite as a sensor of fluid conditions in high-grade metamorphism and crustal anatexis. J. Metamorph. Geol., 20(1), 71-86, https://doi.org/10.1046/j.0263-4929.2001.00344.x.

Tiraboschi C. et al. (2016) - Quantitative analysis of COH fluids synthesized at HP-HT conditions: an optimized methodology to measure volatiles in experimental capsules. Geofluids, 16(5), 841-855, https://doi.org/10.1111/gfl.12191.

Almandine-1O and Spessartine-1O in the Franciscan blueschists from Laytonville Quarry, northern California: Crystallographic features

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Keywords: birefringent garnet, Laytonville Quarry, ferric iron.

Occurrences of anhydrous garnets enriched in almandine-spessartine-grossular component showing sector-zoned birefringence are increasingly reported in low-grade metamorphic rocks in localities around the world (Cesare et al., 2019). Despite several proposed hypotheses (Hofmeister et al., 1998; Cesare et al., 2019), the origins of optical anisotropy in garnet have remained unclear. Recently, reduction from cubic to orthorhombic symmetry due to Al-Fe^{3+} ordering in octahedral sites has been demonstrated to cause the birefringence of garnets from the Cazadero blueschists (Franciscan Complex, USA), strengthening the idea that garnets can directly grow non-cubic in low-T metamorphic environments (Cesare et al., 2019).

Stilpnomelane-garnet metasediments from Laytonville Quarry (Franciscan Complex, USA), equilibrated at T, almandine-spessartine-grossular solid solution garnets. Garnets in these rocks show optically well-defined sector zoning under polychromatic polarizing light, not corresponding to any chemical zonation. Chemically, these crystals have a spessartine-rich core, typical Mn bell-shaped distributions, and almandine-rich rims.

Crystal structure refinements, performed on grains separated from single birefringent sectors (n = 2) analyzed by single-crystal X-ray diffraction (SCXRD), determined these garnets as *I*2/*a*12/*d* orthorhombic (*Fddd* unconventional setting) with pseudo-tetragonal (which is in turn pseudo-cubic) unit-cell parameters ($c > a, b$; $c - a$ = 0.002 to 0.005 Å). Slight cation ordering between Al and Fe^{3+} within octahedral sites leads to reduction from cubic to orthorhombic symmetry, where *Y1* and *Y2* sites are occupied by 5% and 1% of Fe^{3+}, respectively. This result is supported by cation-anion bond distances, which are longer in cation sites with greater Fe^{3+}, and by EPMA data processed by the flank method, which indicates $Fe^{3+}/\Sigma Fe$ of ~5 to 8% in these almandine-rich garnets. These observations further support symmetry lowering as the cause of the optical anisotropy.

Overall, the present crystallographic investigation on Laytonville Quarry samples confirms and extends the results obtained in garnets from Cazadero blueschists, reinforcing the idea that common almandine-spessartine garnets grow non-cubic at low-T conditions due to a small but non-negligible andradite component coupled with Al-Fe^{3+} octahedral site ordering. Our results recommend reassessment of garnet thermodynamic properties and urge a revision to the nomenclature and classification of this key mineral in the lithosphere, in agreement with current IMA - CNMNC rules (Nickel & Grice, 1998). Therefore, we propose to name the orthorhombic Fe- and Mn-rich garnet end-members as almandine-*1O* and spessartine-*1O,* andtodistinguish them from their cubic analogues (almandine-*1C* and spessartine-*1C*).

Cesare B. et al. (2019) - Garnet, the archetypal cubic mineral, grows tetragonal. Sci. Rep., 9, 14672, https://doi.org/10.1038/s41598-019-51214-9.

Hofmeister A.M. et al. (1998) - Prevalence and origin of birefringence in 48 garnets from the pyrope-almandine-grossularite-spessartine quaternary. Am. Mineral., 83(11-12), 1293-1301, https://doi.org/10.2138/am-1998-11-1218.

Nickel E.H. & Grice J.D. (1998) - The IMA Commission on New Minerals and Mineral Names: procedures and guidelines on mineral nomenclature. Mineral. Petrol., 64(1), 237-263, https://doi.org/10.1007/BF01226571.

Whiteschists in the Adula nappe - New P-T estimates and potential implications for the interpretation of pressure variations

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Keywords: UHP, Adula nappe, P-T estimates.

We present new P-T estimates for whiteschists recently discovered in the Central Alps (Adula nappe). Whiteschists were found as veins cross-cutting eclogite lenses, which in turn are embedded in a thick pile of alternating metaragranitoids and mica schists. Veins developed after brittle fracturing which provided the fluid pathways. Whiteschists show a peak assemblage consisting of garnet + talc + kyanite + chlorite + biotite + Na-amphibole + rutile. Garnet composition is highly variable from almandine-rich cores to unusually high content of pyrope in large rims (up to 65%).

Garnet cores contain abundant inclusions, including quartz, Ca-Na-amphibole, chlorite, paragonite and talc. Rims contain instead the mineral of the peak assemblages. The P-T estimations point toward a significant P increase occurred during garnet growth, from HP (Grt-core) to UHP (Grt-rim) conditions. These findings represent a unicum in the regional tectono-metamorphic pattern, raising fundamental questions about the processes that control the dynamic and heterogeneous pressure distribution throughout reacting and deforming fluid-rock interface volumes. Field and petrological investigations are combined with visco-frictional numerical modelling of fluids stresses along shear zones to provide potential explanation of the apparent discrepancies between the regional tectonic settings and petrologically-inferred pressure-temperature-depth paths.

Sampling the beginning of garnet growth: 3D constraints on sectioning bias

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Keywords: garnet crystal size distribution, sectioning bias, numerical simulation.

Chemical zoning of major elements in garnet is widely used as a proxy for defining the P-T history of metamorphic terranes, assuming it preserves an accurate record of its growth (Tracy et al., 1976; Kohn, 2014). Reconstructing the earliest P-T stages of garnet growth requires access to the core composition of the largest garnet grains in a given sample. In practice, observations are commonly made on two-dimensional thin sections, introducing a sectioning bias: the earliest garnet composition (i.e., the composition of the first nucleated crystal in a volume of rock) may be systematically absent in the analysed section. However, garnet crystals are three-dimensional objects, with heterogeneous crystal size distributions and possibly complex zoning patterns (George & Gaidies, 2017). In most cases, it is unknown whether the earliest garnet composition, located in the core of the largest grain, will be intersected in a single thin section.

In this study, we combine X-ray micro-computed tomography, three-dimensional crystal size distribution analysis, and major- and trace-element compositional mapping of garnet to quantify sectioning bias in garnet-bearing micaschists. Using MnO zoning profiles from garnet-bearing Himalayan micaschists, we simulate random and targeted sectioning strategies on virtual three-dimensional crystal populations. The results show that, even when targeting the largest apparent grain in a thin section, 68.3% of sectioned grains (1σ) reach at least only 94% of the normalised maximum MnO content (MnO_{max}) in samples with a small range of garnet sizes, and at least only 75% of MnO_{max} in samples with a wide range of crystal sizes. At the 2σ level, these thresholds drop to only 76% and 59% of MnO_{max}, respectively.

The results indicate that the probability of sampling a composition close to the earliest garnet core remains low regardless of the sampling strategy adopted. Overall, quantifying sectioning bias provides a framework for assessing the reliability of garnet-based P-Treconstructions, particularly when focused on the early metamorphic history.

George F.R. & Gaidies F. (2017) - Characterisation of a garnet population from the Sikkim Himalaya: insights into the rates and mechanisms of porphyroblast crystallisation. Contrib. Mineral. Petrol., 172, 57, https://doi.org/10.1007/s00410-017-1372-y.

Kohn M.J. (2014) - Geochemical Zoning in Metamorphic Minerals. In: Holland H.D. & Turekian K.K. (Eds.), Treatise on Geochemistry, Elsevier, 249-280, https://doi.org/10.1016/B0-08-043751-6/03176-5.

Tracy R.J. et al. (1976) - Garnet composition and zoning in the determination of temperature and pressure of metamorphism, central Massachusetts. Am. Mineral., 61, 762-775.

Unusual HREE-rich garnet from an atypical corundum bearing migmatite: A case study from the Ivrea-Verbano Zone (Southern Alps, Italy)

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Keywords: Ivrea-Verbano Zone, garnet-bearing rocks, HREE.

Rare Earth Elements (REE) are critical raw materials for advanced technologies, renewable energy systems and medical applications (Baxter et al., 2013). Global production is largely dominated by deposits enriched in Light Rare Earth Elements (LREE), whereas garnet exhibits a strong affinity for HREE (±Y, Sc), reaching concentrations of several thousand ppm (Zirakparvar, 2022). Unlike conventional REE-bearing minerals such as monazite, garnet is typically U–Th poor, mechanically robust and can be locally abundant (>60 vol.%). Consequently, garnet-rich rocks exposed in continental crustal sections represent promising unconventional HREE reservoirs.

The Ivrea-Verbano Zone (IVZ) is a continental crustal section where garnet-rich migmatites, garnetites and garnet-bearing mafic intrusions form laterally continuous layers extending for several kilometres (Sinigoi et al., 1995). Therefore, this zone is an ideal laboratory to investigate HREE distribution and mobility under high-temperature conditions. Garnet-bearing lithologies are locally overprinted by ductile deformation occurred mostly under upper amphibolite facies conditions. Mylonites allow to study the possible influence of different deformation mechanisms and/or reactions on elemental redistribution.

We conduct a combined microstructural and geochemical investigation (SEM, EPMA and LA-ICP-MS) of garnet-bearing migmatites showing typical mineral assemblage of metapelite (Grt+Sil+Kfs+Qz+Pl+Bt) with rare occurrence of corundum-bearing migmatites made of Kfs+Pl+Grt+Bt+Crn+Spl (Corvò et al., 2022). Garnet from the latter shows two different textural features as function of the hosting layer: within the leucosome it is generally smaller and more euhedral; conversely garnet in the biotite-rich melanosome is characterised by larger sizes and contains numerous inclusions of biotite and plagioclase. The studied rocks are from the transition zone between amphibolite- and granulite facies metamorphic rocks, in the proximity of a gabbroic sill and are locally overprinted by ductile deformation.

Garnet from the migmatitic metapelites does not show inter-grain chemical variability and has HREE content in the range of 52-115 ppm (45<Y<178 ppm; 118<Sc<175 ppm). Conversely, an inter-grain chemical variability within the same sample has been observed in garnet from corundum-bearing migmatites: grains within the melanosome has low HREE content comparable with metapelitic migmatites whereas garnet associated with leucosomes shows exceptionally high HREE (from about 1600 up to 2000 ppm), Y (2146-2781 ppm) and Sc (490-656 ppm) contents.

In order to shed light on the process leading to the coexistence of two types of garnet within the same sample and the exceptional high contents of HREE (+Y and Sc) in one of them, further petrographic and microstructural investigations coupled with geochemical analyses and in situ garnet dating are in progress.

Baxter E.F. et al. (2013) - Garnet: Common mineral, uncommonly useful. Elements, 9(6), 415-419, https://doi.org/10.2113/gselements.9.6.415.

Corvò S. et al. (2022) - Role of inherited compositional and structural heterogeneity in shear zone development at mid-low levels of the continental crust (the Anzola shear zone; Ivrea-Verbano Zone, Southern Alps). Lithos, 422-423, 106745, https://doi.org/10.1016/j.lithos.2022.106745.

Sinigoi S. et al. (1995) - Density-controlled assimilation of underplated crust, Ivrea-Verbano Zone, Italy. Earth Planet. Sc. Lett., 129(1-4), 183-191, https://doi.org/10.1016/0012-821X(94)00230-V.

Zirakparvar N.A. (2022) - Industrial garnet as an unconventional heavy rare earth element resource: Preliminary insights from a literature survey of worldwide garnet trace element concentrations. Ore Geol. Rev., 148, 105033, https://doi.org/10.1016/j.oregeorev.2022.105033.

Two Carboniferous partial melting events in the Variscan High-Grade Metamorphic Complex of the northern Asinara Island (Italy)

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Keywords: Variscan orogeny, petrochronology, HT-LP metamorphism.

The Variscan migmatitic complex of Asinara Island is composed of both metatexite and diatexite, and small granitoid bodies. Migmatitic metapelites and orthogneisses are the major lithologies in the area, with lenses of partially molten banded amphibolites embedded within them. As their metamorphic history remains unclear, we reconstructed the metamorphic history of this high temperature/low pressure (HT/LP) portion of the Variscan crust. We analysed the whole-rock compositions of the different lithologies and estimated their pressure-temperature (P-T) paths and metamorphic ages using phase equilibrium modelling and trace-element thermometry. The banded amphibolites and associated leucosomes, indicate peak conditions and water-fluxed partial melting at ca. 750°C and 0.5 GPa. In contrast, Ti in biotite thermometry indicates ~640°C and ~660°C in metapelites and orthogneisses, respectively, at a pressure fixed at 0.5 GPa.

The preliminary U-Pb ages calculated from garnet in the orthogneisses indicate a metamorphic peak at ~350 Ma. In contrast, garnets from the leucosomes of amphibolites, and the granitoids/diatexites in the area yield younger ages of 300 Ma. These results are consistent with two distinct metamorphic stages: (1) an early Carboniferous Barrovian event and (2) a late Carboniferous-early Permian HT-LP metamorphism, both previously recognised in northern Sardinia (Carmignani et al., 1994) and in the southern Variscan sector (Martinez-Catalán et al., 2014).

Furthermore, most of the apatite from various lithologies gave younger ages of ~280 Ma, possibly reflecting the lower closure temperature of the U-Pb system in this phase or simply slow cooling after HT-LP metamorphism. Moreover, apatite crystals in the proximity of a single fracture of granitoid/diatexite yielded an even younger age of ~260 Ma. This very young age could be potentially related to hydrothermal mineralisation already observed in the other Variscan rocks (Deroin & Bonin, 2003), however a more detailed explanation is needed.

Carmignani L. et al. (1994) - The hercynian chain in Sardinia (Italy). Geodin. Acta, 7(1), 31-47, https://doi.org/10.1080/09853111.1994.11105257.

Carosi R. et al. (2004) - The structural evolution of the Asinara Island (NW Sardinia, Italy). Geodin. Acta, 17(5), 309-329, https://doi.org/10.3166/ga.17.309-329.

Deroin J.P. & Bonin B. (2003) - Late Variscan tectonomagmatic activity in Western Europe and surrounding areas: the Mid-Permian Episode. Boll. Soc. Geol. It., Vol. Sp., 2, 169-184.

Martinez-Catalán J.R. et al. (2014) - The late Variscan HT/LP metamorphic event in NW and Central Iberia: relationships to crustal thickening, extension, orocline development and crustal evolution. Geological Society, London, Sp. Pub., 405, 225-247, https://doi.org/10.1144/SP405.1.

S3.

Frontiers in Planetary Geology: from crust to core of Solar System bodies

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Extreme redox in the Solar System: The Ksar Ghilane 022 Parent Body

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Keywords: achondrite, sulfides, Mercury-like.

Ksar Ghilane 022 (KG 022) is an ungrouped achondrite, collected in Tunisia in 2023 (Gattacceca et al., 2025). It is a pyroxenite composed of mainly clinopyroxene (>90%), a small amount of orthopyroxene crystals and minor plagioclase. The sample is characterized by low shock levels and presents calcite veins and saline structures linked with secondary, terrestrial processes. On top of these phases, the meteorite contains sulfide-rich metallic bubbles displaying different grades of alteration (Rider-Stokes et al., 2025).

This project aims to investigate in depth this sample to better constrain the processes and geology of its parent body, and the relationship between it and the planets of the inner solar system. A multi-methodological approach has been employed, using i) optical microscopy, ii) JEOL JSM-6490 scanning electron microscopy, iii) JEOL JXA 8530F electron microprobe analyses, iv) WiTech 300 alpha micro-Raman Spectroscopy and v) laser ablation techniques between the Department of Geosciences of the University of Padova and the Goethe University Frankfurt. Furthermore, noble gas analyses were conducted at the Department of Geosciences of the University of Heidelberg.

Analysis of the Ksar Ghilane 022meteorite reveals a pyroxenitic structure dominated by iron-free augite and enstatite, with the latter both as phenocrystals and micrometric-sized exsolution, and albite plagioclase rims. The matrix is defined by a widespread presence of sulfide-rich blebs, featuring iron-chromium-manganese sulfides, like daubréelite (Cr_2FeS_4) and alabandite (MnS), alongside minor oldhamite (CaS), metallic iron, and enigmatic sodium-rich accessory phases.

These findings enable a detailed reconstruction of the parent body's thermal history through orthopyroxene-clinopyroxene geothermometry (Nimis & Grütter, 2010), while trace element collected via LA-ICP-MS and noble gas analyses aid in clarifying respectively crystallization timing and cosmic-ray exposure.

The combination of highly magnesian silicates and complex sulfides suggests that KG 022 formed under extreme reducing conditions comparable to those inferred for Mercury (Nittler et al., 2011). Therefore, this meteorite could be a successful proxy for understanding the geological processes that shaped highly reduced bodies, like the Hermean planet, and, combined with the upcoming information from the new exploration missions, might represent a protagonist when defining the evolution of our solar system.

Gattacceca J. et al. (2025) - The Meteoritical Bulletin, No. 113. Meteorit. Planet. Sci., 60, 1587-1591, https://doi.org/10.1111/maps.14374.

Nimis P. & Grütter H. (2010) - Internally consistent geothermometers for garnet peridotites and pyroxenites. Contrib. Mineral. Petr., 159, 411-427, https://doi.org/10.1007/s00410-009-0455-9.

Nittler L.R. et al. (2011) - The Major-Element Composition of Mercury's Surface from MESSENGER X-ray Spectrometry. Science, 333, 1847-1850, https://doi.org/10.1126/science.1211567.

Rider-Stokes B.G. et al. (2025) - Insights into pyroxene-dominated surfaces and implications for ongoing space exploration missions. Icarus, 441, 116713, https://doi.org/10.1016/j.icarus.2025.116713.

The geometrical parameters of extensional faults on Ariel

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Keywords: icy satellites, chasma, extension.

In this work, we explored the parameters of the main chasmata on Ariel, the icy satellite of Uranus. Being a candidate ocean world, Ariel's young surface presents the opportunity to study multiple extensional features (Beddingfield et al., 2025). Building on previous mapping (Croft & Soderblom, 1991) and Voyager 2 data, such as the Digital Elevation Model and image mosaic (Schenk & Moore, 2020), we used three-dimensional digital outcrop interpretation and visualisation software (VRGS, 2003) to measure dip angle, length, and throw of extensional faults. From these parameters, we calculated the length distribution, displacement-length relationships, and extension of the mapping area. Dip-angle values for normal faults appear to be lower than previously estimated under Andersonian assumption, suggesting an increase for estimates of extension from 1.3% to between 3 and 5%. These values, while uncertain due to possible lithospheric flexure and ductile flow, suggest that chasmata exhibit non-Andersonian behavior.

Beddingfield C.B. et al. (2025) - Ariel's Medial Grooves: Spreading Centers on a Candidate Ocean World. Planet. Sci. J., 6(2), 32, https://doi.org/10.3847/PSJ/ad9d3f.

Croft S.K. & Soderblom L.A. (1991) - Geology of the Uranian satellites. In: Bergstralh J.T., Miner E.D. & Matthews M.S. (Eds), Uranus, University of Arizona Press, 561-628.

Schenk P.M. & Moore J.M. (2020) - Topography and geology of Uranian mid-sized icy satellites in comparison with Saturnian and Plutonian satellites. Philos. Trans. R. Soc. A, 378(2187), 20200102, https://doi.org/10.1098/rsta.2020.0102.

VRGeoscience Limited (2003) - VRGS [computer software]. Available at: https://www.vrgeoscience.com/.

Diamond nanostructures investigation in ureilites

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Keywords: diamond, diaphite, stacking faults.

Nanostructural defects within diamonds, including diaphite (intimate intergrowths of diamond and graphite), nanotwins, and stacking faults, serve as robust and reliable markers of shock metamorphism preserved in ureilite meteorites. These nanometric features record the extreme pressure-temperature regimes experienced during hypervelocity impact events on their parent asteroid. Recent investigations have underscored the diagnostic power of these nanostructures (Nèmeth et al., 2023; Barbaro et al., 2025; García et al., 2025), prompting the present study focused on samples from the Almahata Sitta meteorite fall. By bridging nanoscale defect populations to macroscale impact dynamics, this work aims to elucidate the evolutionary history imprinted in these extraterrestrial materials.

Two diamond-bearing ureilites fragments, AhS 209b and AhS 72, were carefully selected from the 2008 Almahata Sitta meteorite fall, a polymict breccia derived from the disrupted asteroid 2008 TC_3. Preparation involved extracting lamellae using focused ion beam (FIB) milling, targeted at diamond-rich sites previously identified through FEI Quanta 3D DualBeam® Scanning Electron Microscope-Focused Ion Beam (SEM-FIB) imaging at the Department of Physics, Goethe University Frankfurt. Subsequent transmission electron microscopy (TEM) analysis was conducted on a Thermo Scientific Talos F200-X G2 S/TEM instrument operating at 200 kV, within the Schwiete Cosmochemistry Laboratory at the Department of Geoscience, Goethe University. HRTEM imaging was systematically acquired along multiple crystallographic zone axes, with Fast Fourier transforms (FFTs) of the HRTEM datasets enabling precise determination of lattice parameters, identification of twin boundaries, and semi-quantification of disorder-related defects.

HRTEM imaging coupled with FFT analyses reveals widespread diaphite nanostructures, featuring coherent interfaces between diamond and graphite phases. These defect assemblages correspond to shock pressures in the range of 15-30 GPa, accompanied by post-shock temperatures exceeding 1500°C; these conditions are fully consistent with heterogeneous impact deformation across the ureilite parent body (UPB). This inherent structural complexity strongly implies a formation history involving multiple shock events drawing compelling parallels to shock metamorphosed diamonds from terrestrial impact craters (Murri et al., 2019).

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Barbaro A. et al. (2025) - Nano-scale impact shock features of diamond and graphite in ureilites. Carbon, 243, 120583, https://doi.org/10.1016/j.carbon.2025.120583.

García L.N. et al. (2025) - Diaphite structures of Campo del Cielo cliftonites indicate a terrestrial collision-induced moderate shock process. Meteorit. Planet. Sci., 60, 2114-2124, https://doi.org/10.1111/maps.70024.

Murri M. et al. (2019) - Quantifying hexagonal stacking in diamond. Sci. Rep., 9, 10334, https://doi.org/10.1038/s41598-019-46556-3.

Németh P. et al. (2023) - Canyon Diablo lonsdaleite is a nanocomposite containing c/h stacking disordered diamond and diaphite. Philos. T. Roy. Soc. A, 381, 20220344, https://doi.org/10.1098/rsta.2022.0344.

Quantifying shock in ureilitic olivine by SC-X-ray diffraction and micro-Raman spectroscopy

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Keywords: olivine, meteorites, shock metamorphism.

Identifying shock metamorphism in silicates is crucial for reconstructing meteorite impact histories and planetary surface evolution. Here we applied electron backscatter diffraction (EBSD), single-crystal X-ray diffraction (SC-XRD), and micro-Raman spectroscopy (MRS) to evaluate shock deformation in olivine from Antarctic ureilites FRO 95028 (U-S2), FRO 97013 (U-S3/4), and FRO 01012 (U-S6) from the Museo Nazionale dell'Antartide, Siena (PNRA expeditions, 1995-2001). Our aims were to verify the shock levels previously assigned to these meteorites and to assess the effectiveness of SC-XRD and MRS for estimating shock in extraterrestrial ureilite materials.

EBSD analysis revealed distinct differences in dislocation structures and shock-related deformation among the samples. SC-XRD identified progressively stronger shock signatures across the specimens, a trend that became more pronounced when compared to undeformed terrestrial San Carlos olivine. MRS showed systematic P1 and P2 peak-center shifts to higher wavenumbers that correlate with increasing shock intensity. Together, these findings show that SC-XRD and MRS, alongside EBSD, provide precise, in situ measures of lattice strain and residual stress, making them powerful tools for probing impact histories on planetary surfaces.

The brachinites and brachinite-like ungrouped achondrites: A unique meteorite group

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Keywords: brachinites, ungrouped brachinite-like achondrites, chromium isotopes.

Brachinites (BRAs) are an olivine-rich meteorite group displaying equilibrated textures and homogenous mineral compositions (Keil, 2014). Ungrouped brachinite-like achondrites (BLAs) share many similarities with BRAs, although textural and compositional features have been used previously to propose a different origin for their parent bod(ies)y (Crossley et al., 2020). A complete petro-mineralogic, geochemical and O-Cr isotopic survey on 5 BRAs and 10 BLAs highlights a compositional continuum, rather than the existence of two distinct groups. Analysed samples show recrystallized with mean grain-sizes of 0.2-0.6 mm, dominated by olivine (60.2-93.6 vol%, $Fa_{17.5-34.3}$) and clinopyroxene (0.1-11.5 vol%, $Fs_{9.6-11.6}Wo_{41.4-45.6}$). Orthopyroxene and plagioclase occur in variable amounts and are only present in some samples. Accessory phases are chromite, phosphate, troilite and FeNi alloy altered to Fe-oxy/hydroxides. Both BRA/BLAs show the presence of olivine reduction rims assemblage (orthopyroxene+troilite) with increasing modal percentage from the most FeO-rich (BRAs) to the most FeO-depleted (BLAs) samples, while the frequent occurrence of microcrystalline Fe-phosphate with barbosalite-dufrenite composition could support a hydrothermal/metasomatic origin on the parental body, instead of a terrestrial origin (Hyde et al., 2014). $(La/Sm)_{CI}$-$(Gd/Yb)_{CI}$ and V/Ti_{CI}-V/Yb_{CI} systematic displays overlapping ranges for both BRA/BLAs, with values showing variable degree of silicate melt extraction, whereas REE patterns suggest re-fertilization processes and with positive Ce anomalies indicative of fluid-rock interaction during hydrothermal/metasomatic processes. Overall, bulk major/trace element compositions depict the same broad correlation between magmatic differentiation and lithology oxidation degree. $\Delta^{17}O$ ranges from -0.03±0.02 to -0.30±0.01 (within the brachinites range, Greenwood et al., 2017), while $\varepsilon^{54}Cr$ values span a -0.42 to +0.69 range, matching and widening the literature values. Petro-mineralogic analyses highlight a wide compositional overlap for BRA/BLAs and a continuous trend going from the most FeO-rich to the most FeO-depleted members and the significant overlap of BRA/BLAs in the $\Delta^{17}O$-$\varepsilon^{54}Cr$ compositional space does not support the presence of two distinct reservoirs/parent bodies. Our data support the hypothesis that BRAs and BLAs belong to the same meteorite group whose original parent body had been variably affected by partial melting processes, limited variation in oxygen fugacity during melt extraction and secondary post-magmatic processes. Therefore, the BRAs and BLAs belong to a unique group, and the literature should be revisited accordingly.

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Crossley S.D. et al. (2020) - Sulfide-dominated partial melting pathways in brachinites. Meteorit. Planet. Sci., 55, 1-23, https://doi.org/10.1111/maps.13558.

Greenwood R.C. et al. (2017) - Melting and differentiation of early-formed asteroids: The perspective from high precision oxygen isotope studies. Chem. Erde-Geochem., 77, 1-43, https://doi.org/10.1016/j.chemer.2016.09.005.

Hyde B.C. et al. (2014) - Characterization of weathering and heterogeneaous mineral phase distribution in brachinite Northwest Africa 4872. Meteorit. Planet. Sci., 49, 1141-1156, https://doi.org/10.1111/maps.12320.

Keil K. (2014) - Brachinite meteorites: Partial melt residues from an FeO-rich asteroid. Chem. Erde-Geochem., 74, 311-329, https://doi.org/10.1016/j.chemer.2014.02.001.

The challenges of identifying and protecting exogeoheritage

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Keywords: exogeoheritage, conservation, planetary exploration.

The pace of space exploration has visibly accelerated, reminiscent of the 1960s space race era. However, following this reinvigorated drive to establish a presence in the Solar System, a critical issue demands attention: exogeoconservation, the protection of irreplaceable geological heritage on celestial bodies beyond Earth. As scientific and commercial ventures prepare to exploit extraterrestrial resources at increasingly faster pace, exogeoconservation can no longer be ignored. The worlds we seek to explore and exploit contain invaluable records of Solar System evolution and quantitative, data-driven foundations are now required for balanced policies enabling responsible resource utilization while protecting the geological heritage.

While planetary protection policies set strict rules to prevent biological contamination of other worlds, no parallel system exists for managing the impact on abiotic environments and materials. Over 20 years ago, the concept of "planetary parks" was proposed to protect unique geological sites (Cockell & Horneck, 2004). More recently, authors have called for the establishment of exogeoconservation as a discipline based on terrestrial geoconservation practices that protect geoheritage, i.e. geological features of scientific, cultural or aesthetic importance (Matthews & McMahon, 2018). However, implementation has stalled. Existing international laws like the Outer Space Treaty lack mechanisms to identify and designate geological conservation areas on celestial bodies. And, although it has been proposed to draw an example from the Antarctic Treaty System's regulation system, a fundamental barrier remains: criteria for identifying exogeoheritage features are undefined and attempts to directly translate geoconservation methods to Mars using orbital data have failed to pinpoint targets for protection (Fletcher et al., 2025). This underscores the fundamental lack of strategies and policies to inventory and assess the significance of extraterrestrial geological environments in the context of a fast evolving exploration pace. On Earth, geoconservation relies on extensive field mapping and hierarchization based on rarity, scientific value, and other factors, and now analogous exogeoheritage assessment tools and benchmarks tailored to remote planetary data are needed. The new space race era presents both challenges and opportunities, and it is a collective responsibility to seize this moment and chart a course that balances progress with conservation.

Cockell C. & Horneck G. (2004) - A planetary park system for Mars. Space policy, 20(4), 291-295, https://doi.org/10.1016/j.spacepol.2004.08.003.

Fletcher C. et al. (2025) - Practical exogeoconservation of Mars: Lessons from the Mars Desert Research Station, Utah. Planet. Space Sci., 256, 106038, https://doi.org/10.1016/j.pss.2025.106038.

Matthews J.J. & McMahon S. (2018) - Exogeoconservation: Protecting geological heritage on celestial bodies. Acta Astronaut., 149, 55-60, https://doi.org/10.1016/j.actaastro.2018.05.034.

Characterizing Venus's resurfacing history with volcanoes and coronae

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Keywords: Venus, resurfacing, planetary geology.

Venus's geological history, especially its resurfacing history, is difficult to interpret due to a near random distribution of relatively few craters and has led to a debate over Venus's global tectonic style and resurfacing rates (Herrick et al. 2023). In lieu of craters, we use recently published, global datasets of coronae (ovoid tectonic and magmatic features unique to Venus) and volcanic edifices to qualitatively and quantitatively characterize patterns of resurfacing for different geological settings on Earth's sister planet (Gülcher et al., 2025; Hahn & Byrne, 2023). We identify statistically significant "volcano-poor regions" in the area surrounding coronae in the low-elevation, volcanic plains which cover about 70% of the planet's surface. With cross-cutting relationships, we show that within these volcano-poor regions the volcanic edifices that do exist tend to be emplaced after the corona has formed, implying that resurfacing via lava flows or tectonic disruption has erased much of the pre-existing edifices. Using the total area of the volcano-poor regions in the plains (27% of Venus's surface) and the estimated age of geological settings (based on crater counting) we calculate rough resurfacing rates for both the plains and for Venus as a whole. Resurfacing rates for the plains range from 0.15 to 0.36 km^2/yr, a significant fraction of the 1 km^2/yr resurfacing rate associated with equilibrium resurfacing models (Phillips et al., 1992). This suggests that coronae are a major player in the ongoing resurfacing of Venus and that Venusian volcanic edifices can be used to at least qualitatively characterize the planet's resurfacing history.

Gülcher A.J.P. et al. (2025) - Coronae on Venus: An Updated Global Database and Insights Into Morphology, Spatial Distribution, Geological Setting, and Lithospheric Properties. J Geophys. Res.-Planet, 130(5), e2024JE008749, https://doi.org/10.1029/2024JE008749.

Hahn R.M. & Byrne P.K. (2023) - A Morphological and Spatial Analysis of Volcanoes on Venus. J Geophys. Res.-Planet, 128(4), e2023JE007753, https://doi.org/10.1029/2023JE007753.

Herrick R.R. et al. (2023) - Resurfacing History and Volcanic Activity of Venus. Space Sci. Rev., 219(4), 29, https://doi.org/10.1007/s11214-023-00966-y.

Phillips R.J. et al. (1992) - Impact craters and Venus resurfacing history. J Geophys. Res.-Planet, 97(E10), 15923-15948, https://doi.org/10.1029/92JE01696.

Optimising Cr purification for isotopic studies: Higher yields and lower interferences for better geochemical and cosmochemical results

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Keywords: chromium, ion exchange chromatography, isobaric interferences.

Chromium purification for geochemical and cosmochemical purposes has generally been regarded as a difficult and sometimes unpredictable exercise. Indeed, Cr typically occurs in multiple species and oxidation states in acidic solutions (Larsen et al., 2016), each one having different isotopic compositions and elution characteristics, creating distinct Cr elution peaks with variable isotopic composition during chromatographic purification. This can result in poor yields and, consequently, in a collected Cr fraction that may present a non-representative isotopic composition.

Moreover, high precision Cr isotope measurements require extensive purification to prevent isobaric interferences on ^{50}Cr and ^{54}Cr by isotopes of Ti, V or Fe. This has led to the proposal of purification protocols with two to four steps, using sometimes up to three different types of resins to optimise the purity of the final product (Torrano et al. 2021; Zhu et al. 2021). Although many of these protocols allow for high-precision analysis of Cr isotope compositions, these methods are neither simple nor economical or time efficient. The ideal purification would use only one type of resin and limit itself to one or two steps while guaranteeing a yield close to 100%, without compromising on purification of Cr from its matrix.

We present an optimised Cr purification method derived from previous works by Liu et al. (2019). The purification is achieved by a cation exchange protocol with two purification steps, both using the Bio-Rad AG50W-X12 200-400 mesh resin and ThermoScientific 5mL Pierce centrifuge columns.

Before the 1st step, the sample is refluxed at 160°C in 0.2 mL of 10 M HCl for 4 days, to ensure total conversion of Cr in Cr(III)-Cl, in 4 mL beakers to avoid total evaporation of the acid. Then, the sample is diluted to 2 mL of 1 M HCl and loaded onto 1.5 mL of resin. Since Cr only weakly adheres to the resin in this setup, its collection with the eluted acid can be initiated immediately upon loading. The rest of Cr is eluted with an additional 12 mL of 1 M HCl. Matrix can subsequently be eluted with 6 M HCl. For the second purification step, the sample is dried and digested in a 0.16 M HNO_3 - 3% H_2O_2 mixture for at least 4 days at room temperature. It is then loaded on 0.33 mL of resin in a 5 mL Pierce column. In this configuration, Ti is eluted with 3 mL of 0.5 M HF, and V with 11 mL of 1 M HCl. Finally, Cr is eluted with 4 mL of 2 M HCl.

While Liu et al. (2019) reported a yield of about 85% and most of the other proposed protocols reported yields of about 95%, we obtained yields of more than 97% while almost eliminating interferents. These high yields can be explained by a strict adherence to the guidelines describing how to efficiently convert Cr to the desired species in order to optimise the purification (Larsen et al. 2016). We thus provide a relatively fast, yet reliable Cr purification protocol for geological samples using a limited amount of reusable resin.

Larsen K.K.D. et al. (2016) - Chromatographic Speciation of Cr(III)-Species, Inter-Species Equilibrium Isotope Fractionation and Improved Chemical Purification Strategies for High-Precision Isotope Analysis. J. Chromatogr. A, 1443, 162-74, https://doi.org/10.1016/j.chroma.2016.03.040.

Liu, C.-Y. et al. (2019) - High-Precision Measurement of Stable Cr Isotopes in Geological Reference Materials by a Double-Spike TIMS Method. Geostand. Geoanal. Res., 43, 647-661, https://doi.org/10.1111/ggr.12283.

Torrano Z.A. et al. (2021) - The Relationship between CM and CO Chondrites: Insights from Combined Analyses of Titanium, Chromium, and Oxygen Isotopes in CM, CO, and Ungrouped Chondrites. Geochim. Cosmochim. Ac., 301, 70-90, https://doi.org/10.1016/j.gca.2021.03.004.

Zhu K. et al. (2021) - Chromium Isotopic Insights into the Origin of Chondrite Parent Bodies and the Early Terrestrial Volatile Depletion. Geochim. Cosmochim. Ac., 301, 158-86, https://doi.org/10.1016/j.gca.2021.02.031.

Preserving the extraterrestrial samples: An integrated non-invasive protocol for the 3D (bulk) characterization of rare Enstatite Chondrites (ECs)

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Keywords: meteorites, enstatite, chondrites.

The application of non-destructive or minimally destructive analytical protocols is essential for the comprehensive characterization of precious extraterrestrial materials, ensuring their preservation for future studies. The effectiveness of non-invasive methodologies meteorites has already been demonstrated in studies involving Al-Haggounia 001 (Manzari et al., 2023) and the Mt. Gariglione micrometeorite (Agrosì et al., 2025).

With this objective, we are investigating fragments of two Antarctic enstatite chondrites loaned by NASA: EET 87746 (EH4) and GRO 95517 (EH3). The aim of this study is to investigate their mineralogical composition, with a particular focus on rare phases, mineral distribution, textures, and microstructures, to provide further insights into their origin and evolutionary history.

The fragments were investigated using a multi-analytical approach integrating Scanning Electron Microscopy (SEM-EDS), µ-Raman spectroscopy, and micro-Computed Tomography (µ-CT). The correlation between SEM-EDS chemical mapping and µ-CT imaging allows for a volumetric reconstruction of the samples, providing bulk compositional data and porosity without compromising sample integrity.

Preliminary results indicate that both meteorites are primarily characterized by enstatite-rich chondrules, nickel-iron alloys, sulfides (troilite, daubréelite, niningerite and oldhamite) dispersed in a plagioclase matrix. EET 87746 also contains phosphides (schreibersite) and well-preserved Calcium-Aluminum-rich Inclusions (CAIs). Both meteorites exhibit signs of terrestrial weathering, with secondary oxidized phases (limonite and jarosite) filling pores and deep fractures beneath the fusion crust. The porosity values recorded are 0.88% for GRO 95517 and 0.59% for EET 87746; the silicate matter (chondrules and matrix represent 63.69% and 41.06% for GRO 95517 and EET 87746, respectively. Dense phases make up 18.08% of the GRO 95517 sample, while they constitute 17.54% of EET 87746.

Crucially, µ-Raman spectroscopy allowed for the identification of silica (SiO_2) polymorphs. Cristobalite and tridymite were detected within the matrix of GRO 95517, while coesite was identified within the mesostasis in EET 87746. The distribution of these rare phases offers key parameters to reconstruct the complex thermal and shock metamorphism history of parent bodies.

Agrosì G. et al. (2025) - Unique (Al, Cu)-alloys discovered in a micrometeorite from Southern Italy. Commun. Earth Environ., 6,271, https://doi.org/10.1038/s43247-025-02245-w.

Manzari P. et al. (2023) - New insights on the porosity and grain features of Al Haggounia 001, an impact-melt meteorite, Lithos, 438-439, 107015, https://doi.org/10.1016/j.lithos.2022.107015.

Triggering hydrothermal systems in the Martian crust. The record of the Nakhla Martian meteorite

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Keywords: Nakhla, martian water, Mars.

The nakhlites are clinopyroxenites, augite-rich igneous cumulate rocks. They formed from the solidification of basaltic magmas ~1.4-1.3 Ga ago through a series of four magmatic events, in the Middle Amazonian period of the Martian history (e.g., Treiman, 2005). They were likely emplaced as lava flows or shallow magmatic intrusions. A formation in large volcanic constructs of Tharsis, Elysium, or Syrtis Major is inferred based on the match of crystallization ages and crater counting of the Martian surface. About ~630 Ma ago, after 700 Ma from their crystallization, nakhlites underwent mild aqueous alteration due to infiltration of water from atmospheric or crustal reservoirs through the lava pile. This process resulted in the production of the hydrated secondary mineral veinlets rich in phyllosilicates, Fe-oxides/hydroxides and carbonates observed in nakhlites. Based on cosmic-ray exposure ages, Nakhlites were ejected from the Martian surface ~11 Ma ago by an asteroid impact and fell to Earth over the last 10,000 years.

The driver of aqueous alteration of the nakhlites is unknown, yet it could provide unique insights into the processes that were capable of generating liquid water within the Amazonian crust of Mars. Daly et al. (2019) suggested that aqueous alteration resulted from the activation of a hydrothermal system of permafrost melt-water triggered by an impact, based on the distribution of aqueous alteration products and microbrecciation in the Lafayette and MIL 03346 nakhlites.

We are currently studying the textural, microstructural and mineralogical relationships between shock and aqueous alteration features in the Nakhla Martian meteorite to check the role of impacts in generating hydrothermal systems. The study is conducted through microanalytical scanning electron microscopy coupled with microanalytical transmission electron microscopy on specific region of interest sampled by focused ion beam methods from a thick section extending for about about 0.5 cm^2. Here we report the occurrence of wadsleyite - a high-pressure polymorph of olivine - at the walls of unshocked carbonate + phyllosilicate veinlets filling fractures in olivine. This documents an intimate association of shock deformation and aqueous alteration, and strongly support earlier suggestion (Daly et al., 2019) that hypervelocity impacts generated hydrothermal systems on the Martian crust.

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Daly L. et al. (2019) - Boom boom pow: Shock-facilitated aqueous alteration and evidence for two shock events in the Martian nakhlite meteorites. Sci. Adv., 5, eaaw5549, https://doi.org/10.1126/sciadv.aaw5549.

Treiman A.H. (2005) - The nakhlite meteorites: Augite-rich igneous rocks from Mars. Chem. Erde-Geochem., 65, 203-270, https://doi.org/10.1016/j.chemer.2005.01.004.

Transmission Electron Microscopy investigation of Ca phosphates in lunar meteorites: Implications for lunar magmatic volatile content

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Keywords: apatite, meteorites, volatiles.

Constraining the lunar volatile budget is fundamental to understanding the Moon's formation and thermochemical evolution. Apatite ($Ca_5[PO_4]_3[F,Cl,OH]$) is the primary proxy for estimating magmatic volatiles, typically accommodating F^-, Cl^-, OH^-, and S^{2-} within its crystal lattice (McCubbin et al., 2015) and crystallizing in late-stage interstitial mesostasis of lunar basalts (Pernet-Fisher et al., 2014). However, interpreting volatile abundances remains debated due to magmatic degassing, fractional crystallization, and shock metamorphism (Boyce et al., 2014). This study uses TEM to investigate the nanostructures and nanochemistry of lunar phosphates, distinguishing primary signatures from secondary modifications.

Two thick sections of lunar meteorites NWA 4734 (low-Ti mare basalt) and NWA 6950 (lunar gabbro) were investigated using JEOL JXA-8530F EPMA at Goethe University Frankfurt to locate and characterize phosphates within mesostasis regions and determine major and minor element compositions. Two FIB lamellae targeting apatite and their associated material were extracted using a Helios 5 Hydra CX Plasma FIB at TU Darmstadt for TEM investigation.

Initial BSE/SEM investigations reveal distinct phosphate populations between the two meteorites. In the lunar gabbro NWA 6950, REE-rich merrillite is the dominant phosphate, occurring as elongated interstitial laths and anhedral crystals (- ranging between 0.607 and 0.805 apfu). Their average mineral formula is $(Ca_{4.770}Na_{0.006}Mg_{0.012}Mn_{0.003}Fe_{0.069}Y_{0.031}Ce_{0.009})(P_{2.830}Si_{0.075}S_{0.006}O_{12})(F_{0.687}Cl_{0.038}Z_{0.274})$. The missing component (Z) in the anion column is traditionally attributed to OH, though it might mask structural vacancies (Hazrah & Antao, 2022). These phosphates are associated with accessory ilmenite, troilite, zirconolite, chromite and late-stage Si-K-rich glass, orthoclase, Fe-rich pyroxene and anorthositic plagioclase. FIB lamellae were carefully extracted across an apatite-merrillite phase boundary in NWA 6950 and through an apatite grain hosting inclusions and cross-cutting micro-veins in NWA 4734. TEM investigations of the lamellae are currently in progress, with findings to be presented at the conference.

The upcoming TEM work will assess critical nanoscale complexities like zonation, subsolidus features, and potential volatile-rich nano-inclusions. If present, such inclusions would suggest that some volatiles may be physically trapped within a different phase rather than structurally bounded. Characterizing these features, alongside shock-induced defects, will constrain post-crystallization volatile migration, providing a good framework for quantifying magmatic degassing and understanding lunar volcanic history.

Boyce J.W. et al. (2014) - The lunar apatite paradox. Science, 344(6183), 400-402, https://doi.org/10.1126/science.1250398.

Hazrah K. & Antao S. (2022) - Apatite, $Ca_{10}(PO_4)_6(OH,F,Cl)_2$: Structural Variations, Natural Solid Solutions, Intergrowths, and Zoning. Minerals, 12(5), 527, https://doi.org/10.3390/min12050527.

McCubbin F.M. et al. (2015) - Magmatic volatiles (H, C, N, F, S, Cl) in the lunar mantle, crust, and regolith: Abundances, distributions, processes, and reservoirs. Am. Mineral., 100(8-9), 1668-1707, https://doi.org/10.2138/am-2015-4934CCBYNCND.

Pernet-Fisher J.F. et al. (2014) - Estimating the lunar mantle water budget from phosphates: Complications associated with silicate-liquid-immiscibility. Geochim. Cosmochim. Acta, 144, 326-341, http://dx.doi.org/10.1016/j.gca.2014.09.004.

Mitigating the HiRISE RED4 CCD data gap in stereo DTM production: An adaptive workflow for righ-resolution Martian DTM generation

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Keywords: Mars, HiRISE RED4 CCD gap, Digital Terrain Models.

High-resolution Digital Terrain Models (DTMs) derived from HiRISE stereo observations are fundamental for the geomorphological analysis of the Martian surface, enabling meter-scale investigation of slopes, sedimentary bodies, aeolian landforms, impact-related features and candidate exploration terrains. Since the early development of HiRISE stereo processing, these datasets have represented one of the most accurate topographic products available for local- to regional-scale studies on Mars. Open-source workflows based on ISIS and the NASA Ames Stereo Pipeline (ASP) have made HiRISE DTM generation broadly accessible to the planetary science community. Since 2023, however, the intermittent failure of the RED4 CCD has produced a central data gap in many recent HiRISE observations. Because RED4 lies near the center of the focal plane, its loss disrupts CCD mosaicking, tone balancing and stereo processing more severely than edge-CCD losses, often causing standard pipelines to fail at the mosaicking or stereo-preparation stage. The HiRISE team has recently introduced a mitigation strategy in which the overlapping IR10 CCD is radiometrically matched to the surrounding RED data and inserted in place of the missing RED4 as a synthetic component, named SYN4. While effective, this approach has so far been implemented within selected internal HiRISE pipelines and is not yet integrated into the openly available ASP/ISIS chain on which most external users rely. We present an adaptive HiRISE stereo processing workflow that integrates the SYN4/IR10 concept into a fully open-source ASP/ISIS chain. The workflow follows the standard sequence of image preparation, bundle adjustment, stereo correlation, point-cloud generation, DEM extraction and co-registration to reference topography, but introduces an automatic preprocessing step that checks the availability of RED4 for each input observation. When RED4 is missing, the workflow activates an IR10-based fallback prior to CCD mosaicking: IR10 is radiometrically matched to the adjacent RED CCDs and ingested as a SYN4 substitute, restoring the continuity of the RED mosaic before stereo reconstruction proceeds. This preserves the usability of stereo pairs that would otherwise fail at the mosaicking stage and keeps the rest of the chain unchanged, ensuring full reproducibility. The workflow was tested on two HiRISE stereo pairs acquired in 2025 in Arabia Terra: ESP_088933_2200 / ESP_089012_2200 (convergence angle 28.0°) and ESP_089500_2200 / ESP_089645_2200 (convergence angle 12.4°). The two pairs were selected to evaluate the workflow under contrasting stereo geometries, an ideal high-convergence case and a marginal low-convergence case below the nominal HiRISE threshold. Both pairs were processed through the full pipeline, producing continuous DTMs across the RED4 gap with no visible seams or correlation drop-outs along the SYN4 strips. Vertical consistency was assessed against an independent HRSC reference DTM, chosen because its different instruments, mission and processing chain provide a fully external benchmark. A topographic profile crossing the SYN4 strip shows close agreement between the HiRISE and HRSC datasets along the entire ~9 km transect, with no detectable offset or discontinuity at the SYN4 boundaries. The agreement holds for both pairs, indicating that the IR10-based reconstruction does not introduce systematic vertical artefacts within the gap region, even in the marginal convergence-angle case. By integrating the SYN4/IR10 concept into an open-source ASP-based workflow, this work provides a practical and reproducible solution for recovering scientific value from RED4-affected HiRISE stereo observations. The independent HRSC validation confirms that the reconstructed topography is consistent with external reference data across the gap region.

A high-temperature, induction furnace to investigate magma ocean evaporation with experiments up to 3000°C

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Keywords: high-temperature experiments, W emissivity, partitioning coefficients.

Many differentiated, terrestrial planetary bodies are depleted in moderately volatile elements (MVE) relative to primitive meteorites (chondrites) or estimates of a bulk Solar system composition. Mass-dependent fractionation of isotopes between those differentiated bodies and chondrites appears associated to this MVE depletion (Sossi et al., 2025). Loss of (silicate) vapour associated with magma (oceans) from the surface of planetary bodies during major melting episodes is one hypothesis to explain this relative depletion (e.g., Hin et al., 2017; Calogero et al., 2025). However, models apparently supporting that hypothesis rely on elemental partition coefficients and isotopic fractionation factors between vapour and liquid that are poorly calibrated for such conditions or have never even been investigated experimentally.

We use a custom-designed, induction furnace capable of reaching 3000°C to determine elemental and isotopic distributions between silicate liquid and coexisting vapour over a range of temperatures and (One issue to overcome when using temperatures determined by pyrometers are material and temperature-dependent emissivities. For this project, we have calibrated our furnace for experiments with tungsten crucibles, as these can withstand temperatures up to 3000°C. Using a variety of metals and oxides with known melting points as temperature calibrants, we confirm literature observations that W emissivity near 1.4 µm wavelength decreases with increasing temperature from 1000°C to about 2000°C (Ushiki et al., 2021), nearly halving in our case. Increasing temperature even further, however, we find that the emissivity significantly increases again. The variations in emissivity over the investigated temperature range would lead to apparent temperatures that are offset from actual temperatures by up to 550°C if these changes in emissivity are not taken into account.

Initial experiments with coexisting silicate liquid and vapour are performed with a synthetic starting glass with an anorthite-diopside eutectic composition, doped with MVE. The W crucibles are sealed using a laser welder to create a closed system for liquid and vapour, thus allowing for equilibrium to be attained. To mimick conditions relevant to magma ocean formation and potential vapour loss on growing planetesimals in the early Solar system, air is evacuated from the crucible and replaced with ~5 mbar He using a valve system, before initiating an experiment.

Calogero M.A. et al. (2025) - Can impact-induced heating drive moderately volatile element loss?. Earth Planet. Sci. Lett., 669, 119580, https://doi.org/10.1016/j.epsl.2025.119580.

Hin R.C. et al. (2017) - Magnesium isotope evidence that accretional vapour loss shapes planetary compositions. Nature, 549(7673), 511-515, https://doi.org/10.1038/nature23899.

Sossi P.A. et al. (2025) - Physicochemical Controls on the Compositions of the Earth and Planets. Space Sci. Rev., 221(8), 118, https://doi.org/10.1007/s11214-025-01243-w.

Ushiki T. et al. (2021) - Expanded two-color thermography considering temperature-dependent emissivity of tungsten for ITER divertor infrared thermography. Fusion Eng. Des., 168, 112665, https://doi.org/10.1016/j.fusengdes.2021.112665.

Bernard Crater (Mars): Constraints from terrestrial analogues on the origin of hectometric mound-like edifices

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Keywords: Mars, small volcanism, terrestrial analogues.

Hectometric mound-like edifices on the floor of Bernard Crater (Terra Sirenum, southern Martian highlands) display morphologies that overlap with both sedimentary and volcanic landforms, preventing direct genetic interpretation. This study investigates whether these features are consistent with sedimentary extrusion or small-scale igneous volcanism, also through comparison with terrestrial analogues.

Bernard Crater is located within a structurally controlled basin affected by Tharsis-related stresses, where fracture systems may have provided pathways for subsurface ascent (Hauber et al., 2010; Tanaka et al., 2014). The crater floor represents a resurfaced Amazonian surface hosting a distinct population of 182 mound-like edifices.

Mapped mounds are unevenly distributed and form clustered and aligned populations across the crater floor. Linear alignments display a dominant NNW-SSE orientation consistent with local and regional structural trends, indicating tectonic control on emplacement. Morphometric analysis defines a population of narrow-ranged parameters, with basal diameters of ~150-400 m, heights of ~15-40 m, and slopes of ~3-6°, consistent with constructional geometries.

Comparison with terrestrial analogues highlights strong similarities with monogenetic volcanic fields (e.g., Iceland, Hawaii, Parícutin, Uinkaret/Tuweep, El Pinacate), where small-volume cones are aligned along structural features and exhibit comparable morphometric scaling. In contrast, sedimentary candidate analogues show broader geometries and higher morphological variability, whereas maar-caldera systems from the Bracciano and Albano volcanic districts provide useful comparisons for larger collapse-like depressions. Larger circular depressions identified within Bernard Crater display degraded morphologies comparable to volcanic collapse structures (Cole et al., 2005).

THEMIS IR Nighttime data indicate that mound clusters and caldera-like structures occur within low thermal inertia domains, consistent with poorly consolidated or fragmental surface materials including possible volcanic tephra-like deposits. Crater size-frequency distributions constrain resurfacing of the crater floor to the Amazonian (~250-500 Ma), suggesting that mound emplacement may have been associated with late-stage resurfacing (Mangold et al., 2010).

Although morphology alone is insufficient to unambiguously determine mounds' origin, the combined evidence from morphometry, spatial organization, structural context, thermophysical properties, and terrestrial analogue comparison supports an interpretation in which the Bernard Crater mound population represents small-scale monogenetic volcanic constructs emplaced along tectonically controlled pathways.

Cole J. et al. (2005) - Calderas and caldera structures: a review. Earth-Sci. Rev., 69(1-2), 1-26, https://doi.org/10.1016/j.earscirev.2004.06.004.

Hauber E. et al. (2010) - Structural evolution of rift zones on Mars: Insights from analogue modelling. Tectonophysics, 480(1-4), 149-163, https://doi.org/10.1016/j.tecto.2009.09.020.

Mangold N. et al. (2010) - A Late Amazonian alteration layer related to local volcanism on Mars. Icarus, 207(1), 265-276, https://doi.org/10.1016/j.icarus.2009.10.015.

Tanaka K.L. et al. (2014) - The digital global geologic map of Mars: Chronostratigraphic ages, topographic and crater morphologic characteristics, and updated resurfacing history. Planet. Space Sci., 95, 11-24, https://doi.org/10.1016/j.pss.2013.03.006.

Comparative mineralogy of the Makgadikgadi Pans and Martian hypersaline environments using PRISMA and CRISM hyperspectral data

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Keywords: planetary geology, hyperspectral remote sensing, Martian analogues.

The Makgadikgadi Basin in Botswana represents one of the largest evaporitic systems on Earth and is considered an important terrestrial analogue for Martian playa and hypersaline environments (Franchi et al., 2020; Kahsay et al., 2024). The basin is characterised by evaporitic crusts, authigenic clay minerals, polygonal fractures, layered deposits and groundwater-controlled geomorphological processes comparable to those observed in Martian paleolake basins and playa environments (Franchi et al., 2020). The study area mainly focuses on the Ntwetwe and Sua pans, where previous investigations identified evaporitic minerals, authigenic clays and geomorphological features analogous to Martian playa deposits (Franchi et al., 2020; Kahsay et al., 2024). These environments provide ideal conditions for investigating clay mineral formation and preservation within hypersaline systems. This study investigates the surface mineralogy of the Makgadikgadi Pans using hyperspectral remote sensing data from the ASI (*Agenzia Spaziale Italiana*) PRISMA (*PRecursore IperSpettrale della Missione Applicativa*) mission and compares the results with hypersaline environments on Mars analysed using Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) data. The mineralogical analysis focuses on the identification and distribution of clay minerals and evaporitic phases within the pans. Preliminary spectral analysis reveals the presence of clay minerals including montmorillonite, illite, glauconite, and evaporites such as thenardite and trona, which are associated with hypersaline depositional conditions and groundwater activity within the basin (Kahsay et al., 2024; Zinzi et al., 2025). PRISMA hyperspectral data were processed and analysed in ENVI to identify diagnostic spectral absorption features associated with clay minerals and evaporitic phases within the Makgadikgadi Pans. Clay mineral distribution maps were generated to investigate mineralogical variations across the basin and their relationship to evaporitic and hydrological processes. Particular attention was given to authigenic clay-rich areas associated with groundwater upwelling and evaporitic crust development. Similar hydrated minerals and phyllosilicates have been identified on Mars using CRISM data in locations such as Jezero Crater and Gale Crater (Zinzi et al., 2025; Motlhasedi et al., in press). CRISM data from these Martian paleolake environments were analysed for comparison with the terrestrial spectral signatures obtained from PRISMA. Previous studies identified Fe/Mg smectites, carbonates and hydrated minerals within these Martian environments (Motlhasedi et al., in press), providing a framework for comparative hyperspectral analysis between Earth and Mars. This comparative investigation contributes to understanding aqueous alteration, evaporitic processes and clay mineral formation within hypersaline environments on both Earth and Mars.

Franchi F. et al. (2020) - Layered mound, inverted channels and polygonal fractures from the Makgadikgadi pan (Botswana): Possible analogues for Martian aqueous morphologies. Planet. Sp. Sci., 192, 105048, https://doi.org/10.1016/j.pss.2020.105048.

Kahsay T.H. et al. (2024) - The astrobiological potential of the Makgadikgadi Basin, Botswana: Field analogue for planetary exploration. Planet. Sp. Sci., 249, 105943, https://doi.org/10.1016/j.pss.2024.105943.

Motlhasedi A.J. et al. (in press) - Investigation of a potential endorheic basin on Mars in the Terra Cimmeria. Icarus.

Zinzi A. et al. (2025) - Terrestrial and Martian Paleo-Hydrologic Environment Systematic Comparison with ASI PRISMA and NASA CRISM Hyperspectral Instruments. Remote Sens., 17, 758, https://doi.org/10.3390/rs17050758.

Constraining metal-silicate relationships in the Mineo pallasite

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Keywords: Mineo pallasite, main group pallasites, metal-silicate relationships.

Pallasites are rare stony-iron meteorites composed of olivine crystals embedded within a metallic Fe-Ni matrix and are commonly interpreted as samples derived from the core-mantle boundary of differentiated planetesimals (Greenwood et al., 2006). Despite decades of study, their origin remains controversial, with competing models suggesting impact-induced mixing between core metal and mantle silicates, ferrovolcanic processes, or the incorporation of materials from multiple parent bodies (Yang et al., 2010). Main Group pallasites (PMG) provide key constraints on differentiation, collisional evolution and metal-silicate interactions during the early stages of Solar System formation.

The Mineo pallasite, which fell in Sicily in 1826, represents one of only four witnessed pallasite falls worldwide and the only witnessed pallasite fall recovered in Italy (Zucchini et al., 2018). Previous mineralogical and geochemical investigations classified Mineo as a PMG pallasite and highlighted significant chemical and textural heterogeneities within olivine crystals, suggesting a complex formation history potentially related to large-scale impact processes and incomplete metal-silicate mixing (Zucchini et al., 2018; Ricci et al., 2022). In particular, the coexistence of chemically heterogeneous angular olivines and geochemical similarities with IIIAB iron meteorites raises the possibility that Mineo may preserve features consistent with both classical PMG meteorites and impact-mixed metal-silicate assemblages.

Here we present new preliminary oxygen isotope data obtained through laser fluorination analyses performed at The Open University, together with an ongoing investigation focused on the metallic phases of the Mineo pallasite. Oxygen isotope measurements yield $\delta^{17}O$ = 1.32‰, $\delta^{18}O$ = 2.89‰ and $\Delta^{17}O$ = -0.19‰, consistent with the isotopic field of Main Group pallasites and supporting a genetic affinity with the PMG parent body. However, the coexistence of PMG-like oxygen isotopic signatures with previously documented petrographic and chemical heterogeneities suggests that Mineo may preserve evidence of localized disequilibrium processes associated with impact-related assembly.

To investigate these processes, ongoing analyses focus on kamacite, plessite and metal-olivine interface regions to evaluate the chemical homogeneity of the metallic component, characterize possible intra-metal heterogeneities and test for evidence of incomplete equilibration or mixing between distinct metallic reservoirs. The metallic component may preserve direct evidence of differentiation, re-equilibration and impact-related mixing processes. This study aims to assess whether Mineo represents a chemically disturbed PMG pallasite derived from a single differentiated parent body or instead preserves evidence of impact-induced metal-silicate reassembly processes.

Greenwood R.C. et al. (2006) - Oxygen isotope variation in stony-iron meteorites. Science, 313(5794), 1763-1765, https://doi.org/10.1126/science.1128865.

Ricci L. et al. (2022) - The Achievements of the RockStar Group (Perugia) on Astrophysical Modelling and Pallasite Geochemistry. Universe, 8(3), 156, https://doi.org/10.3390/universe8030156.

Yang J. et al. (2010) - Main-group pallasites: Thermal history, relationship to IIIAB irons, and origin. Geochim. Cosmochim. Ac., 74(15), 4471-4492, https://doi.org/10.1016/j.gca.2010.04.016.

Zucchini A. et al. (2018) - Chemical and mineralogical characterization of the Mineo (Sicily, Italy) pallasite: A unique sample. Meteorit. Planet. Sci., 53(2), 268-283, https://doi.org/10.1111/maps.13002.

Experimental petrology to produce and characterize simulants for Martian lavas: Insights on rheology and spectral identification of mineral phases

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Keywords: Martian simulants, reflectance spectroscopy, volcanic rocks.

The most common rocks on terrestrial planets are volcanic-magmatic rocks, consisting of lava flows and pyroclasts with glassy and crystalline silicate phases. Mars, the most geologically diverse terrestrial planet after Earth, hosts magmatic rocks ranging from ultramafic/basaltic to alkaline/trachyandesitic compositions (McSween, 2015). Understanding how chemical composition and phase assemblage (crystalline and amorphous) influence the spectral response of volcanic rocks is pivotal to interpret remotely sensed spectra used in planetary geology. We synthesized Martian simulants with two putative Martian compositions, performed cooling experiments, and carried out rheological, mineralogical and spectral characterization to provide reference data for interpreting geological processes on Mars.

Samples were prepared by mixing powdered oxides to mimic volcanic compositions from Gusev and Gale craters (McSween, 2015). Powders were molten at 1450°C and quickly cooled to produce glasses. Three cooling experiments per glass were conducted using a Gero HTRV 70-250/18 furnace equipped with an Anton Paar rheometer (Vetere et al., 2021). Samples were cooled at 100°C/h from superliquidus temperature, with viscosity monitored to identify three crystallization stages: nucleation onset, crystal growth, and advanced crystallization. Mineralogical characterization was performed by X-ray powder diffraction (XRPD) with quantitative phase analysis (QPA) via Rietveld refinement using internal standards to quantify amorphous content.

Reflectance spectra were collected at the Cold Surface Spectroscopy (CSS) facility (IPAG, Grenoble, France) using the SHINE Spectro-Gonio Radiometer equipped with the CarboN-IR cryogenic chamber. Spectra were acquired in the 1-4.2 μm range at temperatures between 105 and 290 K.

Ongoing low-temperature spectral characterization will clarify the influence of temperature on silicate phase detection. Preliminary results show that samples with identical bulk composition but different mineralogical assemblage exhibit markedly different spectral responses: VNIR spectra are dominated by iron-related phases, while MIR spectra reflect Si-bearing phases. The complex interaction among mineral and amorphous phases makes spectral features difficult to interpret, highlighting the need for a broader compositional study.

McSween H.Y. (2015) - Petrology on Mars. Amer. Mineral., 100(11-12), 2380-2395, https://doi.org/10.2138/am-2015-5257.

Vetere F. et al. (2021) - Rheological evolution of eruptible Basaltic-Andesite Magmas under dynamic conditions: The importance of plagioclase growth rates. J. Volcanol. Geoth- Res., 420, 107411, https://doi.org/10.1016/j.jvolgeores.2021.107411.

Investigating the evolution of Venusian rifts through integrated observations and modelling

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Keywords: Venus rift, topography, gravity.

Recent geodynamical modelling and observational evidence indicate that Venus may still experience tectonic-like processes, such as rifts (Gülcher et al., 2025). In fact, the surface of Venus is characterized by a global network of structures (chasmata), extending for thousands of kilometres, similar to terrestrial rifts (Brossier et al., 2022). This surface deformation is believed to be primarily driven by mantle convection and plume-lithosphere interactions. Yet their driving mechanisms, temporal evolution, and lithospheric structure remain poorly understood because of the sparse observational constraints. Investigating the evolution of Venusian chasmata is therefore essential to understanding Venus' interior dynamics and history.

Here, we used a forward 2D numerical model Regorda et al. (2023) to constrain the rates, durations, and lithospheric structures of extensional processes, integrating observational evidence from topography and gravity anomalies to improve our understanding of Venusian rifting. In particular, we tested different extensional velocities and lithospheric and crustal thicknesses.

For comparison with natural observation, we extracted topographic and gravity profiles spaced every 50 km along 30 Venusian rift axis. To minimize 3D effects, we extracted subsets consisting of at least 3 topographic profiles from each rift, evaluating their homogeneity and, therefore, limiting 3D effects. For this analysis, we used the normalized mean absolute error and the Pearson correlation index to provide a robust evaluation of the similarities of the topographic profile between the average extracted and each profile of the subsets, and therefore consider their homogeneity.

We observed that models with a lithospheric thickness of 100 km and a crustal thickness of 15 km show the best topographic fit with observations, with the exception of rifts located in the Thetis Regio. In addition, we recognised one group of rifts with a duration between 2 and 5 Myr and an extension velocity of 1 or 2 cm/yr, and one group with a duration between 10 and 12.5 Myr and an extension velocity of 0.5 or 1 cm/yr. Finally, we were able to identify an asynchronous evolution along the Dali chasma and a variation of the crustal thickness along the axis of one portion of the Hecaete Chasma.

Brossier J. et al. (2022) - Extended rift-associated volcanism in Ganis chasma, venus detected from magellan radar emissivity. Geophys. Res. Lett., 49(15), e2022GL099765, https://doi.org/10.1029/2022GL099765.

Gülcher A.J. et al. (2025) - Dynamics of venusian rifts and their interactions with plumes and intrusions. Earth Planet. Sci. Lett., 667, 119514, https://doi.org/10.1016/j.epsl.2025.119514.

Regorda A. et al. (2023) - Rifting venus: Insights from numerical modeling. J. Geophys. Res.-Planet., 128(3), e2022JE007588, https://doi.org/10.1029/2022JE007588.

Spectral characterization of synthetic silicate glasses analogous to Lunar basalts

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Keywords: Moon, planetology, spectroscopy.

Volcanic glasses are widespread on the Moon and represent an important component of both pyroclastic deposits and the lunar regolith. Despite their relevance for the interpretation of remote sensing observations, amorphous silicate materials remain poorly represented in planetary spectral libraries compared to crystalline phases. In this work, we present a combined Visible-Near Infrared (VNIR, 400-2500 nm) and Mid-Infrared (MIR, 3000-25000 nm) spectral characterization of synthetic silicate glasses representative of lunar mafic to ultramafic compositions.

Four lunar analogue compositions derived from Apollo samples were synthesized in the laboratory: a high-Ti mare basalt (MB), a low-Ti basalt (LTB), a KREEP basalt (KB), and an Apollo 15 green glass analogue (GG). The glasses were separated into four grain size fractions (In the VNIR range, all samples show weak and broad absorption bands near ~1100 nm and ~1900 nm, attributed to Fe^{2+} electronic transitions. Compared to crystalline materials, these absorptions are toned down and poorly resolved, reflecting the amorphous structure of the glasses. Spectral slopes and albedo are strongly controlled by grain size, with finer fractions generally displaying higher reflectance and steeper VIS slopes. However, MB shows an anomalous behaviour, with increasing albedo toward coarser fractions and flattened VNIR slopes. Compositional effects were investigated through the SAT parameter (SiO_2+Al_2O_3+TiO_2), the SCFM index, and iron content, although grain size appears to dominate VNIR spectral variability.

In the MIR range, spectral behaviour is mainly controlled by vibrational processes within the silicate framework. The Christiansen Feature (CF) systematically shifts toward shorter wavelengths with increasing grain size and shows a strong correlation with silicate network polymerization parameters, especially SAT and SiO_2 content. In contrast, the Reststrahlen band peak (RB_{peak}) position displays a weaker and more scattered compositional dependence. A weak Transparency Feature (TF) is observed only in the finest grain size fractions, confirming the strong grain size control on this spectral feature.

Overall, the results demonstrate that MIR spectral parameters provide more robust compositional constraints than VNIR spectral properties. This work contributes to improving spectral libraries of amorphous planetary materials and supports future investigations of glass-rich volcanic and impact deposits on the Moon and other rocky bodies.

Electron Backscattered Diffraction (EBSD) analysis of the Scalea (L5) meteorite

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Keywords: Scalea, meteorite, EBSD.

Electron backscatter diffraction (EBSD) has been demonstrated to be a valuable technique for unraveling the deformation and thermal histories of metamorphosed ordinary chondrites (Ruzicka & Hugo, 2018; Hugo et al., 2020; Macente et al., 2025). Here, we report preliminary EBSD analyses of Scalea meteorite, an L5 ordinary chondrite fell on September 11, 2024, in Scalea, Italy (Moggi Cecchi et al., 2026). This study aims to investigate its shock and thermal metamorphic history, with implications for analogous chondrite parent bodies.

A centimetric fragment was embedded in epoxy resin as a thick section and polished using progressively finer abrasive papers and diamond paste. To remove surface defects, the sample was polished for ~4 hour with 0.06 μm colloidal silica using a AMT Qpol Vibro. Residual polishing paste was removed in a pure ethanol ultrasonic bath. Carbon coating was not applied in order to improve the quality of EBSD pattern acquisition. The section was analyzed with a Hitachi SU8700 VP equipped with a high-performance CMOS Oxford Symmetry S2 EBSD system, located at the MEMA laboratory, University of Firenze, Italy. Analyses were performed at 20 kV and a nominal current of 10 nA, and step size of ~2 μm with a standard tilt angle of 70° under low vacuum condition. Kikuchi patterns were collected and processed using Oxford Instruments AZtecCrystal.

The Scalea meteorite shows a brecciated texture, composed of two distinct lithologies: a fine-grained low-Ca pyroxene-rich lithology (~30-40 μm) and a medium-grained olivine-rich aggregate lithology (~100-400 μm) (Moggi Cecchi et al., 2026). We analyzed a potential contact between these lithologies and found distinct crystallographic deformation and orientation patterns. The inverse pole figure (IPF) map shows that pyroxene grains in the low-Ca pyroxene lithology display an overall preferred crystallographic orientation, unlike the olivine-rich lithology, where grain orientations are randomly scattered. This trend is also accompanied by distinct grain reference orientation deviation angles (GROD-angles), a parameter used to estimate crystal deformation, which are more pronounced in the low-Ca pyroxene lithology ($GROD_{pyroxene}$ ~0.9°) than in the olivine-rich lithology ($GROD_{pyroxene}$ ~0.5°). This suggests that the two lithologies may have experienced different deformation and thermal histories. Further investigation of the Scalea meteorite is important for advancing our understanding of the complexity of chondrite aggregation and the metamorphic history of primitive asteroids.

Hugo R.C. et al. (2020) - Mesoscale and microscale shock effects in the LL 6 S4 chondrites Saint-Séverin and Elbert: A tale of two breccias. Meteorit. Planet. Sci., 55(6), 1418-1438, https://doi.org/10.1111/maps.13304.

Macente A. et al. (2025) - The petrology of the Ozerki meteorite constrained by electron backscatter diffraction and X-ray computed tomography. Meteorit. Planet. Sci., 60(5), 1095-1118, https://doi.org/10.1111/maps.14344.

Moggi Cecchi V. et al. (2026) - Description and characterization of the Scalea ordinary chondrite, a new Italian fall meteorite. 57th LPSC, 1533.

Ruzicka A.M. & Hugo R.C. (2018) - Electron backscatter diffraction (EBSD) study of seven heavily metamorphosed chondrites: Deformation systematics and variations in pre-shock temperature and post-shock annealing. Geochim. Cosmochim. Ac., 234, 115-147, https://doi.org/10.1016/j.gca.2018.05.014.

Reconstructing the geological evolution of Eld Mound in Becquerel Crater, Mars

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Keywords: Mars, interior layered deposits, geological mapping.

The interior layered deposits (ILDs) of Becquerel Crater preserve important evidence of past sedimentary, climatic, and possibly endogenic processes on Mars. Previous studies have suggested that these deposits formed through combinations of aeolian deposition, groundwater-related activity, evaporitic processes, and subsequent erosional reworking (Lewis et al., 2008; Cadieux & Kah, 2015; Schmidt et al., 2022; Pondrelli et al., 2015). However, the specific genetic mechanisms controlling the formation and long-term evolution of Eld Mound, a large ILD located inside Becquerel, remain in debate.

This study first aims to reconstruct the geological evolution of Eld Mound through detailed geological mapping, geomorphological analysis, stratigraphic observations, and topographic characterization using Context Camera (CTX) imagery and High Resolution Stereo Camera (HRSC) datasets. Topographic profiling and slope analysis is used to characterize layer continuity, mound asymmetry, structural organization, and evidence of differential erosion. These observations are then integrated with geological mapping and available mineralogical information to identify spatial relationships between composition and morphology and inform evolutionary interpretation.

The study further explores potential alternative genetic mechanisms involved in the development of Eld Mound. In particular, we discuss whether regional structural deformation and possible endogenic activity associated with crustal weakening following impact processes could have influenced mound evolution and stratigraphic architecture. Preliminary observations suggest that variations in layer expression, mound geometry, and erosional style may reflect multiple stages of more localised deposition, deformation, and resurfacing rather than a crater-wide formation process.

Cadieux S.B. & Kah L.C. (2015) - To what extent can intracrater layered deposits that lack clear sedimentary textures be used to infer depositional environments? Icarus, 248, 526-538, https://doi.org/10.1016/j.icarus.2014.11.004.

Lewis K.W. et al. (2008) - Quasi-periodic bedding in the sedimentary rock record of Mars. Science, 322(5907), 1532-1535, https://doi.org/10.1126/science.1161870.

Pondrelli M. et al. (2015) - Equatorial layered deposits in Arabia Terra, Mars: Facies and process variability. GSA Bulletin, 127(7-8), 1064-1089.

Schmidt G. et al. (2022) - Protracted hydrogeological activity in Arabia Terra, Mars: Evidence from the structure and mineralogy of the layered deposits of Becquerel crater. J. Geophys. Res., 127, https://doi.org/10.1029/2022JE007320.

Formation of lunar anorthosites through serial-like magmatism

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Keywords: lunar anorthosites, serial magmatism, mineral chemistry.

The lunar magma ocean (LMO) model, originally developed from studies of Apollo samples, remains a cornerstone for understanding the Moon's early differentiation. However, increasing evidence for compositional heterogeneity within the lunar crust challenges the classical view of an anorthositic crust formed solely by flotation of plagioclase from a globally homogeneous magma ocean.

We investigate the major- and trace-element compositions of plagioclase, pyroxene, olivine, and glass in the lunar polymictic feldspathic breccia NWA 13859. Olivine and pyroxene display a wide range of Mg# (42-91), contrasting with plagioclase narrow anorthite content (An_{95-98}) and uniform REE concentrations. Melts calculated to be in equilibrium with plagioclase show correlated compatible elements (e.g., Sr and Ba) consistent with fractional crystallization, whereas decoupled incompatible element ratios (e.g., Th/Sm and Zr/Sm), together with plagioclase REE and major-element systematics, indicate the involvement of additional processes. Geochemical modelling indicates that the chemical variations of NWA 13859, and more broadly of lunar anorthosites, require an initial fractional crystallization of mantle-derived melts before either mixing with variably evolved LMO residual melts or assimilating their fractionated products.

We suggest that partial melts of KREEP-free LMO mantle cumulates produced by mantle overturn evolve through fractional crystallization before interacting with LMO residual melts or their fractionated products at crustal levels and generate lunar anorthosites. This hybrid scenario reconciles compositional, petrological, and geochemical constraints and supports a serial-like magmatism framework for the formation of lunar highlands anorthosites.

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S4.

From magma genesis to eruptive dynamics: multidisciplinary perspectives on volcanic systems

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Experimental insights into Pressure-Temperature-H_2O controls on the crystallization of tephri-phonolitic magmas from the Ventotene Volcanic System

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Keywords: experimental petrology, phaser elations, Ventotene.

The investigation of intensive parameters (temperature, pressure and volatile content) that control magma storage and evolution within magma reservoirs is essential for interpreting eruptive dynamics, as they exert a control on phase equilibrium and crystallization pathways in alkaline magmas. In this study, we report phase equilibrium experiments performed on a tephri-phonolitic composition (MD1), representative of the magma erupted as juvenile pyroclasts during the Parata Grande caldera-forming eruption of Ventotene volcano (Pontian Islands). Crystallization experiments were carried out at 600 and 300 MPa across temperatures between 840-1050°C, under variable H_2O contents. All experiments included a fixed-duration supra-liquidus heating step to eliminate any crystal nuclei that could have influenced the crystallization kinetics. At 600 MPa, under H_2O-undersaturated conditions, apatite and Fe-Ti oxides crystallize at 1050°C, followed, at decreasing temperature, by clinopyroxene, biotite, plagioclase, and K-feldspar. Under H_2O-oversaturated conditions, a similar paragenesis (clinopyroxene + biotite + plagioclase + apatite + Fe-Ti oxides) is obtained and, at the temperature of 840°C, amphibole is present instead of K-feldspar, emphasizing the influence of water activity on phase stability in evolved alkaline magmas. The differentiation pathway of the experimental residual glasses is similar for both the H_2O-undersaturated and H_2O-supersaturated experiments, showing a shift in composition from phonolite to trachyte with decreasing temperature. At 300 MPa and H_2O-oversaturated conditions, the paragenesis of sub-liquidus experiments is composed of clinopyroxene, biotite, and Fe-Ti oxides, with minimal modal variations until the appearance of plagioclase at 850°C (neither K-feldspar nor amphibole crystallize). The glass composition is consistently trachytic at 950 and 900°C (the high degree of crystallization at 850°C prevented the analysis of the residual glass in this experiment).

Overall, these results provide new constraints on the crystallization pathways of tephri-phonolitic magmas at mid- to deep-crustal pressures and emphasize the combined roles of pressure and water content in controlling minerals stability and crystallization sequences. This work improves our understanding of differentiation processes in alkaline magmas and offers an experimental framework to interpret mineral assemblages and reconstruct pre-eruptive storage conditions at Ventotene volcano, with possible implications for analogous alkaline magmatic systems (e.g., Campi Flegrei).

Multi-level magma storage and recharge processes associated with the 1928 AD lateral eruption of Mount Etna (Italy)

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Keywords: Etna, igneous, petrology.

Mount Etna's 1928 lateral eruption and resulting destruction of the town of Mascali represents one of the most disastrous flank eruptions on the volcano in recent history. The start of the eruption was signalled by explosive activity at the Northeast Crater, followed by rapid fissure propagation downslope along the NE Rift Zone and emission of multiple lava flows. In this study, the textural, petrological, geochemical and thermobarometric investigations of lava samples taken from the 1928 flow field, both proximal and distal, aim to reconstruct plumbing system dynamics during the eruption. Although erupted trachybasalts feature minimal variability in terms of whole-rock major-element composition, mineral phases (olivine, clinopyroxene, and plagioclase) show complex zoning patterns deriving from open-system processes. Clinopyroxene-only thermobarometry and hygrometry indicate two main levels of magma storage, consisting of a (i) deep reservoir (270-330 MPa), where primitive clinopyroxene (Mg# up to 79) formed at 1070-1075ºC from a hydrous trachybasaltic magma (3.3 wt.% H_2O) and a (ii) shallower reservoir (130-165 MPa), where evolved clinopyroxene crystallised (Mg# 70-75) at 1055-1070ºC from a slightly more evolved trachybasaltic melt with comparable water content (2.8 wt.%). In clinopyroxene crystsals, concentric zoning patterns, resorbed evolved cores, and primitive overgrowths yielding similar pressures coherent with the deep reservoir suggest coexisting yet compositionally distinct melts within the deeper reservoir. Complementary evidence of magma recharge and crystal recycling is also observed in olivine, which shows primitive cores (up to Fo_{82}), commonly resorbed, crystallised at 1090-1110ºC. However, homogeneous evolved olivine phenocrysts (Fo_{70}) formed at 1047-1060ºC. Repeated magma recharge recharge in the shallow reservoir is also indicated by reverse zoning and bands of more primitive material. Plagioclase thermometry and hygrometry provide consistent results, whereby An-rich cores (An_{61-88}) record higher temperatures (1055-1063ºC) and H_2O contents of 2.4-3 wt.%, indicative of formation in the deep reservoir with olivine and clinopyroxene. Instead, crystal rims and groundmass microlites record lower temperatures (1005-1038ºC) and lower H_2O in the melt (0.5-0.9 wt.%), reflecting degassing-driven crystallisation. These observations allow for the reconstruction of a vertically developed plumbing system formed of a deep reservoir undergoing periodic magma recharge, promoting mixing as well as crystal dissolution and recycling, and a shallower reservoir, acting as a zone of magma storage, differentiation, and degassing. These results highlight how multi-level magmatic ponding and recharge processes governed the eruptive dynamics of lateral eruptions on the volcano.

Understanding volcanic risk perception in the Vesuvius Red Zone: Knowledge gaps, trust and preparedness

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Keywords: volcanic risk perception, volcanic hazard communication, Vesuvius.

The social and demographic complexity of the Vesuvius area, and its exposure to volcanic hazard, highlight the need to strengthen knowledge, communication, and preparedness for a potential emergency. Approximately 670,000 people live in the red zone and would require preventive evacuation in the event of renewed volcanic activity. To address this scenario, the National Emergency Plan for the Vesuvius Area (NEPVA) was first issued in 1995 and subsequently updated between 2001 and 2015. The plan is based on a maximum expected sub-Plinian eruption scenario and requires the preventive evacuation of residents from the red zone before the onset of the eruption.

Risk perception is a key predictor of protective behaviour and therefore a critical factor in crisis-management effectiveness. This study examines volcanic risk perception among lower- and upper-secondary school students from five municipalities in the Vesuvius red zone (Portici, Torre del Greco, Pollena Trocchia, Cercola, and San Giuseppe Vesuviano). A survey carried out in 2024 involved 2,451 students and assessed knowledge, preparedness, education, information sources, trust, and self-efficacy.

Results show that students generally recognize volcanic risk and express moderate concern, while also perceiving high levels of hazard and vulnerability. In this sense, volcanic risk is perceived as concrete and locally relevant. Nevertheless, important gaps remain in the understanding of volcanic processes and hazards, particularly the confusion between the effects of volcanic gases and those of pyroclastic density currents.

These findings confirm the strong link between risk perception, expected emergency behavior, and the quality of available information. The main information channels remain the media, although students report limited trust in them, followed by informal sources such as family members and acquaintances. Risk education should therefore build on the relatively high trust placed in scientists and Civil Protection through coordinated educational programs involving schools, institutions, and local stakeholders. Schools and public outreach initiatives should play a central role in improving knowledge of the NEPVA, strengthening confidence in the emergency plan, and supporting more effective responses during crises.

Uncertainty about the ability to forecast a future Vesuvius eruption remains a major issue: approximately half of the surveyed students doubt that the population could be evacuated in time. Warning time is therefore perceived as one of the most critical aspects of the NEPVA, while inaccurate forecasts could increase the risk of false alarms. Overall, the results are consistent with previous studies and underline the need for a cooperative, multidisciplinary, and long-term commitment to volcanic risk education. Such an effort must involve all stakeholders, especially local communities, whose awareness and active participation are essential for the success of the Emergency Plan.

Petrology of the 1909 El Chinyero eruption (Tenerife, Canary Islands): Reconstructing magmatic processes from textural and compositional study of mineral phases

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Keywords: Tenerife, plumbing system, volcanic risk.

Effusive eruptions emitting basic lava flows along rift systems may pose a significant hazard to surrounding populated areas, especially when eruptive fissures or vents are located at low altitude on the flank of the volcano.

With the aim of reconstructing the pre-eruptive dynamics of basanite/tephrite eruptions, this study focuses on the last eruptive episode recorded in Tenerife (Canary Islands), in 1909 CE, along the NW rift of the Teide volcano, which caused the formation of a scoria cone, the emplacement of a 10^7 m^3 lava field with an average effusion rate of approximately 11.5 m^3/s and the dispersion of significant ash volumes on the island (Di Roberto et al., 2016).

The combination of whole-rock chemistry and detailed textural and compositional micro-analyses performed on samples from different portions of the lava field (at the vent, front and several intermediate locations) allowed the reconstruction of the architecture of the plumbing system feeding the eruption. The Chinyero lavas have a tephritic composition with Na-affinity (1.5-1.6 wt.% K_2O, 4.0-4.4 wt.% Na_2O), and MgO contents of 4.6-5.3 wt.%. They are variably vesiculated, and have predominantly porphyritic textures with clinopyroxene, olivine and plagioclase phenocrysts (up to 1 mm in size) embedded in a hypocrystalline to microlitic groundmass composed of olivine, clinopyroxene and acicular-shaped plagioclase.

Electron probe microanalyses of mineral phases indicate a strong zoning pattern in the phenocryst populations, suggesting complex crystallisation dynamics. Clinopyroxene displays massive sector zoning and subordinate step, normal and reverse zoning, defined by the alternation of two different diopsidic compositions easily distinguished by their Mg# and Cr_2O_3 values (Mg# = 74-82; Cr_2O_3 = 0.11-0.45 wt.% vs. Mg# = 68-79; $Cr_2O_3 \leq 0.09$ wt.%), while maintaining similar CaO concentrations (22-23 wt.%). Olivine phenocrysts are characterised by the sole presence of normal zonation with Fo content of 79-84 mol% in the cores and 74-80 mol% in the rims, with NiO following the same trend (0.13-0.25 wt.% in cores and ≤0.08 wt.% in rims). Glass analyses revealed tephritic and foiditic compositions in some intermediate glass samples, whereas all the remaining samples showed a phonolitic composition.

Thermobarometry and hygrometry modelling confirms the complex history of crystallisation recorded by mineral phases, enabling the reconstruction of the pre-eruptive dynamics of magma storage, ascent and crystallisation during the last eruption which took place in Tenerife. This enables the improvement of existing models of volcanic risk evaluation related to effusive eruptions.

Di Roberto A. et al. (2016) - The 1909 Chinyero eruption on Tenerife (Canary Islands): insights from historical accounts, and tephrostratigraphic and geochemical data. Bull. Volcanol., 78, 88, https://doi.org/10.1007/s00445-016-1083-7.

Phonolite-hosted ultramafic xenoliths from Mayotte (Comores archipelago) and their fluid inclusions record: Clues on the architecture of a trans-lithospheric plumbing system

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Keywords: fluid inclusions, phonolite genesis, trans-lithospheric plumbing system.

Combining the geochemistry of gas emissions in active volcanic regions with the signature of mineral-hosted fluid inclusions is the next frontier in volcano monitoring and geodynamics. Indeed, it can provide important clues on the mobility of fluids through the lithosphere and the ponding/degassing path of magmas underneath active volcanoes.

Here, new mineral and fluid inclusion chemistry data on a unique suite of phonolite-hosted ultramafic xenoliths from Petite Terre (Mayotte) were used to investigate the processes responsible for magma ponding and differentiation in a trans-lithospheric plumbing system, which on 2018-2021 produced the Fani Maoré cone and lava field, one of the largest submarine eruptions ever documented.

The ultramafic xenoliths are fragment of a cold and refractory lithospheric mantle, not affected by metasomatic processes, and minerals entrap 0.04 to 0.22 vol.% of fluid inclusions, aligned on dominantly secondary trails. The He-Ne isotopicsignature of fluid inclusions bear witness to the primitive, mantle-derived signature of fluids, displaying a SCLM-MORB-like fingerprint, in overlap to that of mineral-hosted fluid inclusions in olivine phenocrysts and surface gas emissions at La Grille and Karthala volcanoes (Grande Comore). On the other hand, the $^{4}He/^{40}Ar^{*}$ and He/CO_2 ratios of the fluid inclusion entail the entrapment of fluids during degassing of the host phonolite magma at Petite Terre. Combining our data with mineral-based T-P estimates, we show that: i) basanite to tephrite magmas erupted at Fani Maoré in 2018-2021 and the xenoliths-bearing phonolites erupted at Petit Terre followed different T-P and degassing paths during ascent to the surface; ii) rapidly ascending phonolite magmas producing explosive volcanism at Petit Terre could have formed already at P of 0.7-1.0 GPa or even deeper, in a mature trans-lithospheric plumbing system located beneath Mayotte.

The 2014-2020 explosive activity at Kuchinoerabujima Volcano: A phreatic or a phreatomagmatic crisis?

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Keywords: explosive volcanism, phreatic eruptions, phreatomagmatic eruptions.

Phreatic eruptions are explosive events generated by the rapid flashing of subsurface water into steam, without the direct involvement of new magma. These eruptions are particularly difficult to forecast and may result in sudden explosions producing ballistic ejecta and pyroclastic density currents capable of affecting areas up to a few km from the vent. At active volcanoes, hydrothermal systems hosting water and pressurized fluids may promote recurrent phreatic activity, either independently or in connection with magmatic unrest. A continuous range of activity exists between purely phreatic and phreatomagmatic event, in which variable amounts of juvenile magma can be involved in the activity.

Here we present data on stratigraphy, texture, and composition of the deposits and eruptive products emplaced during the 2014-2020 eruptive activity of Kuchinoerabujima volcano (Japan). The presence of an extensive documentation of the activity, both from official activity reports and monitoring camera footages makes this eruption crisis an optimal case study for describing and interpreting this type of activity.

The 2014-2020 deposits consist of multiple discrete pyroclastic beds with limited dispersal, extending 1 to 2.5 km from the active Shindake crater. Proximal outcrops are characterized by meter-thick breccias and poorly sorted tuff breccias, locally preserved at medial distances. Medial sections mainly contain massive to cross-stratified ash-rich deposits interbedded with a clast-supported lapilli layer, whereas distal sites are dominated by thin, massive to occasionally crudely laminated ash beds. Dense, altered lithic clasts dominate all facies. Based on sedimentological features, facies relationships and bed contacts, six lithostratigraphic units (A to F) were distinguished and correlated with specific eruptive episodes documented between 2014 and 2020.

Petrographic and SEM observations, coupled with component analysis, show the whole 2014-2020 succession is dominated by hydrothermally altered lithic clasts (>50 vol.%) containing silica, alunite, pyrite, and clay minerals, together with up to 30 vol.% of partially altered glass fragments.

Small amounts of unaltered glass fragments (1-10 vol.%), only present in the ash fraction, challenge the interpretation of the sequence as related to phreatomagmatic, rather than purely phreatic, activity. These fragments display a microlite-rich groundmass, formed of feldspar and pyroxene crystals, generally accompanied by tridymite and cristobalite. Groundmass glass compositions cluster in the high-silica rhyolite field, with a few clasts showing a dacitic composition. The glass fragments have always a very low to null vesicularity, suggesting that they did not contribute to the explosivity of the eruptions. We suggest that these clasts possibly represent the fragmentation of small, shallow intruding magma bodies, which intersected the hydrothermal system, creating the conditions for fluid overpressure and explosion. This mechanism is different from typical phreatomagmatic or magmatic activity, dominated by magma decompression, vesiculation and fragmentation. These findings raise a fundamental question regarding the nature of phreatic activity: should it be defined by the total absence of magma in the ejecta, or simply by the lack of an active magmatic role in the eruptive mechanism?

Shear-induced crystallization as a trigger for rapid solidification of basalts: Implications for basaltic Plinian eruption

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Keywords: magma rheology shear-induced crystallization, basaltic Plinian eruptions.

The eruptive style of mafic volcanoes is critically influenced by magma rheology, which is dynamically modulated by crystallization during cooling and decompression of ascending magma. Although the role of undercooling is well established, the influence of deformation on crystallization kinetics in magmas remains poorly constrained. In this study, we experimentally investigate the rheological and textural evolution of Mt. Etna trachybasalt under isothermal conditions (1170°C) using concentric cylinder rheometry at varying shear rates (up to 10 s^{-1}). Real-time viscosity monitoring reveals that stirring exerts a fundamental influence in enhancing magma solidification due to crystallization, shortening the incubation time of nucleation and the time needed to reach thermomechanical equilibrium. Crystal textures confirm that stirring shifts crystallization from growth-dominated to nucleation-dominated regimes, with nucleation rates increasing by up to two orders of magnitude at the highest shear rate. Electron back-scatter diffraction analysis of the experimental samples indicates a non-linear structural response to deformation. Low-to-intermediate shear rates (0.1-1 s^{-1}) induce a moderate degree of crystals preferred orientation, while higher shear rate (10 s^{-1}) produces chaotic, isotropic textures due to rapid and spatially dispersed nucleation. These findings outline that deformation actively drives crystallization, dramatically accelerating magma solidification. We discuss how shear-enhanced crystallization is a key mechanism in volcanic systems, facilitating the attainment of rheological thresholds that trigger transitions in eruptive style. These deformation-driven effects offer new constraints for the understanding of basaltic Plinian eruption trigger mechanisms, identifying a threshold above which microlite production and magma strengthening can be significantly accelerated during ascent.

From melt structure to eruptive dynamics: Experimental and synchrotron constraints on magma crystallisation and rheology

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Keywords: magma, eruption, crystallization.

The physicochemical response of magmas to the thermal, barometric, and redox perturbations experienced during ascent is mediated by melt structure, which in turn governs melt viscosity, magma transport, outgassing efficiency, fragmentation conditions, and eruptive style. Despite decades of experimental work, the relationships between melt composition, structure, crystallisation kinetics, and rheological evolution remain incompletely understood, particularly for the disequilibrium conditions that characterise syn-eruptive processes.

This contribution provides an overview of recent experimental and synchrotron-based research aimed at bridging the gap between melt structure and eruptive dynamics. A central theme is that melt composition exerts a first-order control not only on liquid viscosity but also on the tendency of a magma to crystallise during ascent. By combining thermal analysis, vibrational spectroscopies, and synchrotron-based techniques, it is possible to track how silicate melts evolve structurally during magma transport and eruption, and to identify the compositional parameters that govern crystallisation onset and extent across this entire temperature range. Key physicochemical parameters emerge as variables that precondition melts for contrasting crystallisation behaviours: from structural stability and glass-forming ability to rapid and pervasive crystal nucleation.

These constraints feed directly into the reconstruction of magma ascent dynamics. Crystallisation during ascent affects rheology through multiple, coupled mechanisms: the physical effect of suspended crystals, the chemical fractionation of the residual liquid, and the provision of crystal-melt interfaces that promote heterogeneous bubble nucleation. Incorporating composition-dependent crystallisation kinetics into numerical conduit-flow models yields substantially different predictions for viscosity evolution, outgassing, and fragmentation compared to crystal-free scenarios, offering new insight into why chemically similar magmatic systems can produce dramatically different eruptive behaviours. These results underscore the importance of a multipronged approach, integrating experimental petrology, glass science, synchrotron techniques, and numerical modelling, for advancing our ability to interpret the petrological and textural record of volcanic products and to constrain the processes that govern eruption dynamics.

The long-lasting, multistage activity of the Astroni volcano (Campi Flegrei, Italy): New evidence from petrological and chemostratigraphic data

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Keywords: Campi Flegrei, Astroni volcano, chemostratigraphy.

The Astroni volcano is atypical within the Campi Flegrei district, where most volcanic centres are monogenetic. It consists of a 1.5 km wide tuff ring formed during repeated eruptions between ca. 4.6 and 4.0 ka. The products emplaced during its activity offer a rare opportunity to investigate the temporal evolution of a relatively long-lived volcanic system from various perspectives. These include pre- to syn-eruptive magma chamber processes, as well as eruptive and emplacement dynamics. Building on a recent revision of the Astroni stratigraphic framework, which identified eight distinctive eruptive units and five laterally traceable unconformity surfaces marking phases of volcanic quiescence, the preliminary results of a detailed petrological and chemostratigraphic study of the Astroni deposits are presented here. Most of the stratigraphic sequence (Units I-VI) is made of pyroclastic density current and minor fallout deposits dominated by highly vesicular juvenile clasts, with low crystal content and relatively uniform feldspar-rich paragenesis. The topmost levels include a small lava dome/plug with associated welded scoria deposits emplaced inside the crater (Unit VII), and a succession of fine-grained stratified ash deposits (Unit VIII). The two topmost units are stratigraphically separated by the deposits of the nearby Fossa Lupara crater (about 1 km NW of the Astroni edifice). Juvenile compositions of the Astroni units are consistently trachytic/phonolitic, showing relatively narrow ranges for most major oxides (e.g. 58.2-60.2 wt.% SiO_2, 0.48-0.58 wt.% TiO_2, 3.01-3.82 wt.% CaO, 0.72-1.31 wt.% MgO). Trace elements are relatively more variable, especially Sr (428-734 ppm), Zr (371-462 ppm) and Ba (424-1169 ppm). The Fossa Lupara juvenile clasts are slightly, though systematically less evolved, with e.g. 56.5-59.2 wt.% SiO_2, 0.53-0.65 wt.% TiO_2, 3.34-4.70 wt.% CaO, 1.06-1.7 wt.% MgO, 723-943 ppm Sr, 311-388 ppm Zr and 1026-1571 ppm Ba. An overall trend of decreasing degree of evolution is observed throughout the Astroni sequence and within most eruptive units, based on trace element contents and ratios. In more detail, Units I and II are homogeneous and strongly evolved in composition, whereas Units III to VII show subtle but consistent trends of decreasing degree of evolution with increasing stratigraphic height. These findings, slightly differing from those of previous literature, indicate a plumbing system involving either 1) multiple independent reservoirs feeding individual eruptive units or 2) a single reservoir subject to periodic recharges by less evolved magmas, possibly concomitant to phases of volcanic quiescence.

Seamounts geomorphic analysis: Growth and destruction modes of the Italian Sea submarine volcanoes

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Keywords: lateral collapse, vent cone, fissure ridge.

The morphology of subaerial volcano is studied through techniques and methods, which cannot be applied in the submarine environment. In addition, the study of ongoing activity in the submarine environment is difficult. Thus, the great improvements of quantitative analysis of subaerial volcanoes are not matched by similar developments in the study of their submarine counterparts. Nonetheless, the recent boost in the imaging potential of marine geophysical instrumentation has led to a better understanding of submarine volcanic landscapes. Multibeam bathymetry and reflectivity data are central to this growing resolution capacity and foster the development of quantitative investigations. In the Italian seas, the use of multibeam bathymetric systems started in the 90's, when, the volcanic seamounts of the Tyrrhenian Sea were initially mapped. Recently, the seamounts have been re-surveyed using higher resolution multibeam and sub-bottom profiler instruments in the frame of the MER (Marine Ecosystem Restoration) ISPRA project, which led to the acquisition of over 13,000 km^2 of sonified seafloor. Beside the geophysical data, direct observations of the submarine landscapes and seafloor sampling were conducted using ROVs. The analysis of the data allows at first, the determination of the relative importance of magmatic and tectonic processes in the evolution of the submarine volcanoes. At a smaller scale, the single elements which contribute to the shaping of the submarine seamounts can be quantified. Fissure ridges and alignments of vent cones are the elemental constructional structures, showing that single small eruptions result in thicknesses up to 100 m and volume in the order of 10^6 m^3. The evolution of conical seamounts results from the repeated, hundreds of m-scale, shifting of summit emission centres, in connection with lateral collapses involving 10^6-10^7 m^3 of material, a dimensional range similar to that of landslides accompanying short-lived eruptive phases. Lava lobes with length of 10's of m surround some of the elemental geomorphic elements, but larger lava fields which occupy the whole flank of the volcano, with length up to some kms and estimated volume in the order of 10^6-10^7 m^3 are also observed. Morphologies consisting of chutes and ridges, channels, bedforms and shallow-seated landslides are widespread, hinting at the importance of volcaniclastic and pyroclastic processes in the growth and degradation of the seamounts. All the above elements outline the magnitude of the growth and destruction processes in the regular evolution of the seamount. However, collapses involving large sectors of the volcanoes, resulting in debris avalanche deposits, are also observed. They affect 10^{-1} to 10^1 km^3 of material and cause the complete reorganization of the magmatic system, with possible implications on the deep plumbing system, as shown by the creation of new emission sites and changes in the morphology of the volcanic buildings.

Multi-parametric recording of multi-vent activity at Stromboli volcano (Italy)

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Keywords: strombolian activity, eruptive dynamics, shallow pressure source.

Strombolian activity is characterized by rhythmic explosions of variable intensity, commonly associated with the emission of scoriaceous lapilli and the formation of a convective plume that can rise approximately 100-200 m above the vent (Taddeucci et al., 2013). The strombolian activity observed at Stromboli in October 2023 was occurring from three vents: the S vent was characterized by ash-rich explosions, whereas the N1_1 and N1_2 vents, located approximately 10-20 m apart, frequently generated nearly simultaneous ash-poor explosions, together with spattering and puffing activity, particularly at N1_2 vent. Over four consecutive days, we monitored the activity of the three vents using the SKATE (Setup for Kinematic Acquisitions of Transient Eruptions) system. The setup includes a high-definition high-speed camera recording 30-second videos at 250 frames per second (FPS), a thermal infrared camera continuously acquiring data at 16 FPS, and a broadband microphone continuously recording at 20 kHz. Preliminary analysis of the thermal camera recordings enabled a qualitative classification of explosion types at each vent and also provided a continuous record of activity at all vents, expressed as peaks in brightness temperature within a defined control area. From these data, a set of quantitative parameters was derived to characterize eruptive dynamics during the acquisition period, including explosion duration, mean inter-event time, and hourly explosion frequency. From the high speed camera (focused on N1_1 and N1_2 vents) and the microfone we obtained the exit velocity, size and number of the pyroclasts, the amplitude and mean frequency of the acoustic radiation of the explosions, respectively, as well as the ejection onset to acoustic arrival time delay. The correlations among the calculated parameters, particularly the direct correlation in the kinetic energy of the total ejecta from N1_1 and N1_2 during simultaneous eruptions, suggest a common shallow pressure source that maintained a stable partitioning of energy between the two vents. Despite this, the two vents display distinct eruptive and acoustic behaviors, likely reflecting differences in shallow conduit geometry and gas flux conditions (Gaudin et al., 2017; Spina et al., 2017).

Gaudin D. et al. (2017) - Integrating puffing and explosions in a general scheme for Strombolian-style activity. J. Geophys. Res.-Sol. Ea., 122(3), 1860-1875, https://doi.org/10.1002/2016JB013707.

Spina L. et al. (2017) - Time-series analysis of fissure-fed multi-vent activity: a snapshot from the July 2014 eruption of Etna volcano (Italy). Bull. Volcanol., 79(7), 51, https://doi.org/10.1007/s00445-017-1132-x.

Taddeucci J. et al. (2013) - Linked frequency and intensity of persistent volcanic activity at Stromboli (Italy). Geophys. Res. Lett., 40(13), 3384-3388. https://doi.org/10.1002/grl.

Analysis of the 1917 eruption of San Salvador Volcano, Republic of El Salvador, Centro-America

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Keywords: document analysis, geochemical study, eruption reconstruction.

This study focuses on the analysis of the eruption of 7 June of 1917 at San Salvador Volcanic complex. This eruption occurred in the evening of seventh of June and was directly triggered by an earthquake less than two hours before. The eruption was mainly fissural and lavic in the NNW slope of San Salvador volcanic complex and successively nested in the crater of Boquerón Edifice. This lead first to the total evaporation of a crater lake and then to the emission of a limited volume of pyroclastic outside of the crater and the building of a small strombolian cone in the bottom of the crater of Boquerón. The association of earthquake and eruption produced around 1050 fatalities, most of them (>90%) attributed to the earthquake, in a moment when San Salvador (capital of El Salvador Republic) and surroundings had perhaps 60.000 inhabitants, while today probably are over 1,750.000. The earthquake destroyed most of the buildings in the city (perhaps as much as 80% of the total). In addition to the enormous growth of the capital in the last century, it should be noted that while the eruption developed on the NW flank of the volcanic complex, the capital is mainly located to the south of it, where there are other peripheral volcanic edifices, including a maar.

While in the last three decades an important volume of research has been conducted on the volcanic hazards related to the former explosive activity of San Salvador volcano, much less attention has been devoted to the effusive one. A lavic eruption similar to the 1917 one might originate important damage to the administrative and economic life of El Salvador republic, as well as an important risk to the population. In spite of a large amount of dispersed information, the dominant narrative throughout the last century about the development of the 1917 eruption is tainted by one of the earliest descriptions, which contains errors and gaps in information. A first goal of our study is to spurge all these errors, as well as to fill the gaps in information in aspects relevant (chemical composition and crystallinity and total volume of lave emitted, velocity of expansion, placement and evolving of vents at the flank of the volcano during the eruption) in order to understand the associated hazard.

The second goal of this study is related to the significance of these basic-intermediate lavic eruption in the construction of a small to medium (around 1.400 m of vertical development) basaltic-andesite basaltic stratovolcano. San Salvador volcanic complex can be considered representative of a large number of similar active arc basic volcanoes outcropping in the frontal pacific coast (from the Tacaná volcano in Mexico-Guatemala border sector till La Yeguada volcano in Panamá). This volcanic front is related to the subduction of the Cocos plate under the Caribean one. The eruption of 1917 can be considered representative of a large number of similar eruptions that in a large part built similar sized stratovolcanoes, like Volcán San Vicente or Volcán San Miguel at El Salvador.

Inversion of fluvial network for tracing magma emplacement

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Keywords: magmatism, river inversion, Larderello.

We demonstrate how surface analyses can be used to identify actively emplacing magma bodies at middle/shallow crustal levels along with their long-term evolution. We invert the river network to extract spatially explicit maps of rock-uplift rates from topographic data, representing a parallel significant advantage over previous methods in imaging blind magma intrusions. Based on the plethora of geological and geophysical data, we select the Larderello-Travale-Magmatic-System in the Northern-Apennines (Italy), where a low shear-wave velocity anomaly from ambient-noise-tomography reveals a large subsurface partial melt body. The combination of our pattern of rock-uplift rates with ambient-noise-tomography allows us to document a correlation in space and wavelength between subsurface magmatic processes and surface topographic responses. We estimate a cumulative uplift of about 300 meters over 1.2 Ma, corresponding to an accommodation space volume of ca 400 km^3. On these bases, we therefore propose a long-term evolutionary model for magma emplacement beneath the LTMS, describing the topographic-magmatic features and attempting to quantify magma injection rates.

This study also documents how river network inversion models can serve early-stage exploration of geothermal green-fields fed by crustal magmatic intrusions, thus representing a non-invasive, environmentally sustainable and extremely low-cost tool.

Deciphering magma dynamics beneath Mt. Etna through crystal records and monitoring signals during 2022-23 period

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Keywords: volcanic tremor, petrology, SO_2 flux.

We present a multidisciplinary study investigating the volcanic activity of Etna's South-East Crater (SEC) during March 2022 - August 2023. Over this period, the SEC experienced two long-lasting effusive phases, the first occurring in May-June 2022 and the second between November 2022 and February 2023. Moreover, lava fountains occurred on May 21 and August 13-14, 2023. Magma dynamics driving these different eruptive phases were investigated by integrating the compositional and temporal record of olivine in Etna volcanic products with measurements of plume SO_2 flux and volcanic tremor amplitude and source location. The analysis of olivine zoning and related diffusion timescales made it possible to recognize main phases of magma intrusion and storage at different crustal levels, which overall showed good correlation with episodes of volcanic unrest linked to magma and gas migration through the shallow conduits. Specifically, volcanic tremor and SO_2 flux increased markedly in early May 2022 as fresh, volatile-rich magma rose toward the uppermost section of the plumbing system, at depths shallower than 2 km beneath the summit area, ultimately supplying the early effusive phase of May-June 2022. Months later, new magmatic inputs from deeper reservoirs remobilized the residual melt previously emplaced in the upper plumbing system, and prompted the onset of the second effusive phase in November 2022. The development of lava fountains in May and August 2023 followed the activation of very deep magmatic reservoirs, identified at depths greater than 9 km beneath the summit area. Lava fountains were likely triggered by the rapid ascent of primitive magmas, accompanied by substantial volatile release. By integrating multiple datasets, we were able to identify recurrent magmatic processes driving volcanic activity and controlling eruptive styles.

Timescales of magma-mush dynamics and eruption-triggering processes constrained using multi-mineral diffusion chronometry

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Keywords: mush systems, crystal cargo, diffusion chronometry.

Crystal mush systems - crystal-rich magmatic systems containing variable proportions of interstitial melt - play a fundamental role in controlling magma storage, differentiation, remobilisation, and eruption. These systems evolve through complex interaction among crystallisation, melt extraction, magma recharge, mush remobilisation and rejuvenation. The crystal cargo of volcanic rocks preserves a detailed record of these processes, as minerals with diverse origins, textures, and age distribution archive the history of magma-mush dynamics occurring in the volcano plumbing system prior to eruption.

Elemental diffusion chronometry has emerged as one of the most powerful tools for quantifying the timescales of pre-eruptive magmatic processes. By exploiting chemical gradients preserved within zoned crystals and between crystals and surrounding melt, diffusion chronometry provides direct constraints on the timing of magma recharge, mush remobilisation, crystal recycling, and eruption triggering. Durations of pre-eruptive magmatic processes are quite variable and are system-dependent. Timescales of magma storage between magma intrusion and eruption is relative short (from a few days to a few decades) for basaltic systems, but much longer (decades to millennia) for silicic systems.

The short pre-eruptive timescales recorded in mafic systems frequently correlate with monitoring signals such as seismic unrest, gas emissions, and ground deformation, highlighting the growing importance of diffusion chronometry for volcano forecasting and hazard assessment (Petrone et al., 2022; Hughes et al., 2025). Timescales of magma remobilisation and pre-existing crystals remobilisation, retrieved from the internal portions of chemically zoned crystals, provide information on the longevity of crystal mushes and are shedding new light, particularly on basaltic crystal mushes (Schiavon et al., 2025), which may persist longer than previously hypothesised.

Here, using recent case studies from basaltic and intermediate volcanoes, I explore how diffusion chronometry provides time-resolved insights into pre-eruptive magma dynamics and crystal-mush evolution. Emphasis is placed on multi-mineral approaches and interdisciplinary studies that integrate diffusion chronometry with real-time volcano observations and isotope geochemistry to better constrain magma storage conditions, remobilisation processes, mush longevity, and eruption triggering mechanisms.

Hughes G.E. et al. (2025) - Linking monitoring data and timescales of mafic recharge during the 2013-17 eruption at Volcán de Colima, Mexico. J. Volcanol. Geotherm. Res., 460, https://doi.org/10.1016/j.jvolgeores.2025.108285.

Petrone C.M. et al. (2022) - Mush rejuvenation controlling intense explosive eruptions at basaltic volcanoes: the 2019 paroxysmal events at Stromboli (Italy). Nat. Commun., 13, 7717, https://doi.org/10.1038/s41467-022-35405-z.

Schiavon B. et al (2025) - Multiple mush generations provide insights into the longevity of open-conduit basaltic volcanoes. Sci. Rep., https://doi.org/10.1038/s41598-025-07005-6.

So close, so far: Contrasting magmatic evolution of The Pleiades and Mount Melbourne volcanoes (Antarctica)

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Keywords: Antarctica, mantle melting, plumbing system.

The Pleiades and Mount Melbourne volcanic fields, located roughly 180 km apart in northern Victoria Land (Antarctica), provide an opportunity to investigate how mantle melting and glacial loading regimes influence magma intrusion and evolution in the crust. Despite sharing the same regional tectonic setting related to the Cenozoic lithospheric rifting, the two volcanic fields present distinct compositional and volcanological features. The Pleiades Volcanic Field, composed of apparently monogenetic centres, erupted mildly and strongly alkaline magmas characterised by a continuous compositional evolutionary trend from alkali basalts to trachytes. In contrast, the Mount Melbourne system is a long-lived central stratovolcano surrounded by older peripheral centres (oldest products dated at 4.1 Ma), which erupted alkaline magmas showing discontinuous chemical trends, dominated by basaltic and trachytic compositions.

Geochemical and isotopic data from the Pleiades indicate that both mildly and strongly alkaline series derive from a common parental magma but evolve along distinct pathways: the strongly alkaline trend is dominated by fractional crystallisation, whereas the mildly alkaline one reflects the combined effects of crystallisation, crustal assimilation, and magma mixing. Geochronological constraints indicate that during the significant crustal assimilation occurred during the last glacial period (In contrast, the trace-element signatures of mafic glasses erupted throughout the activity of Mount Melbourne suggest a combination of decreasing degree of partial melting and progressive modification of the mantle source. This scenario points to a substantial control of mantle melting conditions on the magmatic evolution of the Mount Melbourne system.

The comparison between the Pleiades and Mount Melbourne volcanic fields highlights how volcanic systems formed within the same geodynamic province can develop different magmatic characters, in response to varying mantle melting conditions and crustal architecture. These differences may be further enhanced by the contrasting effects of glacial loading on the two Antarctic volcanic systems. The Pleiades, located closer to the polar plateau, were subjected to thicker glacial cover, which may have enhanced a prolonged magma storage and mixing-assimilation processes. In contrast, the coastal position of Mount Melbourne likely reduced the impact of glacial load on crustal magmatic evolution, and the observed geochemical variations are attributed primarily to temporal modifications in the mantle melting conditions. These working hypotheses underscore how distinct combinations of deep and shallow processes can shape divergent volcanic and magmatic evolutions.

A crystal-chemical window on pulsed basaltic magmatism during early back-arc basin evolution: The case of the ODP Leg 107-site 655 (Tyrrhenian Sea)

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Keywords: basalts, igneous crystals, Tyrrhenian Sea.

Textures and compositions of the igneous minerals carried in basaltic lavas can provide important insights into the sub-volcanic pre-eruptive processes, which are obscured by the relatively uniform bulk chemistry of the erupted basalts.

In this study, we present textural information and chemical analyses for minerals from 11 samples spanning a 116 m-thick sequence of pillow lava flows drilled in the central portion of the Tyrrhenian Sea back-arc basin (ODP Leg 107, Site 655), whose opening is linked to extensional movements within the framework of the Eurasia-Africa convergence. The drilled sequence consists of geochemically well-characterized basalts with a monotonous mid-oceanic ridge chemical affinity, emplaced during magmatic activity associated with the initial seafloor-spreading stage (4-3 Ma) of the Tyrrhenian back-arc basin (Beccaluva et al., 1990).

The chemical and textural variations exhibited by the crystals hosted in the basaltic pillow lava sequence represent an archive of magmatic processes that occurred during the initial seafloor-spreading stage of the Tyrrhenian back-arc basin. The lava samples are weakly porphyritic, with olivine-plagioclase and olivine-plagioclase-clinopyroxene phyric types found alternating along the sequence. The groundmass in all the samples consists of microlites of the phenocryst phases, opaques, and altered interstitial glass. The co-crystallized plagioclase and clinopyroxene microlites exhibit a range of textures comparable to those observed in the groundmass of mid-oceanic ridge basalts, reflecting variable cooling rates within the hosted pillow basalt. Olivine is partially to completely replaced by Fe-hydroxides and clays in most of the basaltic lava samples, whereas clinopyroxene phenocrysts with resorbed features are restricted to the lower portion of the drilled sequence.

The variability observed in crystal habit, zoning patterns, and resorption features, both within individual crystals and among basaltic lava samples, documents the role of processes other than fractional crystallization in the formation of the ultimately erupted crystal cargo. This is confirmed by mineral-melt equilibrium modelling, which identifies several plagioclase and clinopyroxene compositions that are in chemical disequilibrium with the host melt. The in-equilibrium crystal-melt pairs constrain crystallization temperature range of 1050-1150°C and pressures consistent with the 6 km-thick oceanic crust geophysically detected beneath this portion of the Tyrrhenian Sea.

The compositional distribution of the ubiquitous plagioclase crystals documents temporal changes in the crystal population and suggests that the basaltic lavas derived from magma pulses that locally interacted with regions of an already-formed transcrustal magmatic plumbing system. Results of geospeedometric investigation, in progress on the plagioclase phenocrysts, are necessary to provide constraints on the timescales of the feeding magma pulses.

Beccaluva L. et al. (1990) - Geochemistry and mineralogy of volcanic rocks from ODP Sites 650, 651, 655, and 654 in the Tyrrhenian Sea. In: Kastens K.A. & Mascle J. (Eds.), Proc. ODP, Sci. Results, 107, 49-47, https://doi.org/10.2973/odp.proc.sr.107.140.1990.

Inferences on the hydrothermal system involved in the recent phreatic activity of Shindake volcano (Kuchinoerabujima island, Japan) from the study of lithic clasts

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Keywords: Shindake volcano, phreatic eruption, hydrothermal alteration.

Phreatic eruptions are steam-driven explosive events produced by the rapid pressurization and vaporization of shallow groundwater or hydrothermal fluids. Although they are often small in volume, these eruptions are difficult to forecast because they can occur suddenly, after the failure of pressurized and hydrothermally altered shallow aquifers. In this context, lithic fragments are important because they can preserve information on the rocks disrupted during the eruption, the alteration facies, the fluid-rock interaction processes, and the physical conditions of the hydrothermal system before failure. For this reason, the study of altered lithics can help reconstruct the processes that prepare hydrothermal systems for phreatic explosions and improve the assessment of related hazards.

This work presents a preliminary study of lithic material erupted during the 2014-2020 eruptive cycle of Kuchinoerabujima volcano, Japan. Kuchinoerabujima is an active volcanic island located in the northern Ryukyu Arc, about 80 km south of Kyushu. The volcanic edifice is mainly composed of andesitic lava flows and pyroclastic deposits. Furudake and Shindake are the Holocene eruptive centres, but all historically documented eruptions occurred at Shindake. Recent activity has been dominated by phreatic and phreatomagmatic eruptions, indicating the interaction between a shallow magmatic system, groundwater, and an active hydrothermal system. The 2014-2015 activity was preceded by long-term unrest, including ground deformation, shallow seismicity, stronger fumarolic activity, and increased gas emissions. The following 2018-2019 activity evolved from inflation, degassing, and intermittent ash emissions to explosive phreatomagmatic eruptions, with ballistic ejecta and pyroclastic density currents affecting the proximal areas of the volcano.

To investigate the hydrothermally altered lithics, the collected samples were first described macroscopically and then analysed by optical petrography, SEM-EDS, Raman spectroscopy, and EMPA. These analyses were used to define the main textures, the degree of alteration, the hydrothermal alteration facies, and the chemistry of selected sulfide phases. The results show that the analysed lithics are mainly affected by silicic and advanced argillic alteration, with mineral assemblages including alunite, pyrite, clay minerals, and silica polymorphs such as tridymite. Overall, these data suggest that the investigated lithic fragments record the involvement of a shallow active high-sulfidation-type hydrothermal system in the recent explosive activity of Shindake volcano.

Automated thin section classification of volcanic textures using multiband optical imaging

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Keywords: image analysis, volcanic textures, Chinyero eruption.

Thin section analysis is a fundamental technique in rock microscopy aimed to the first identification and characterization of rock phases. In volcanic studies, textural analysis plays a crucial role in reconstructing magmatic processes and eruptive dynamics. In particular, quantifying the spatial distribution, size, shape, orientation, and number density of vesicles and crystals is essential for a robust interpretation of volcanic textures and can provide key constraints on degassing processes and magma ascent mechanisms.

Recent advances in high-resolution optical scanning, combined with back-scattered electron imaging and X-ray elemental mapping, enable a more comprehensive characterization of mineral phases and rock textures (Blundy & Cashman, 2008). Furthermore, automated image analysis workflows allow for more objective quantification of textural parameters, reducing operator dependency (Shea et al., 2010; Visalli et al., 2025).

In this study, we implemented a novel image analysis workflow that integrates high-resolution plane-polarized and cross-polarized optical scans to generate a 15-band multivariate raster dataset. This dataset combines the native red, green, and blue channels with additional features derived from band ratios and differences, as well as standard deviation layers to enhance textural discrimination. Furthermore, a principal component analysis was applied to this dataset, and the most informative principal components were selected as the input image to be processed with the Micro-Fabric Analyzer (Visalli et al., 2021). The workflow was tested on porphyritic tephrites collected from the lava flows belonging to the 1909 Chinyero eruption, which represents the last effusive event produced by the Teide volcano (Tenerife, Canary Islands). Results showed improved segmentation of the main phases compared with workflows based on thresholding algorithms of single images, enabling discrimination among glass, vesicle, and crystalline phases and the derivation of crystal and vesicle size parameters useful for assessing the crystallinity and vesicularity of the investigated samples.

Blundy J.D. & Cashman K.V. (2008) - Petrologic Reconstruction of Magmatic System Variables and Processes. Rev. Mineral. Geochem., 69, 179-239, https://doi.org/10.2138/rmg.2008.69.6.

Shea T. et al. (2010) - Textural studies of vesicles in volcanic rocks: An integrated methodology. J. Volcanol. Geoth. Res., 190, 271-289, https://doi.org/10.1016/j.jvolgeores.2009.12.003.

Visalli R. et al. (2021) - Micro-Fabric Analyzer (MFA): A New Semiautomated ArcGIS-Based Edge Detector for Quantitative Microstructural Analysis of Rock Thin-Sections. ISPRS Int. J. Geo-Inf., 10(2), 51, https://doi.org/10.3390/ijgi10020051.

Visalli R. et al. (2025) - Image-assisted textural analysis of plagioclase crystals in volcanic rocks: an application to lavas erupted on 2021 at Pacaya volcano, Guatemala. Front. Earth Sci., 13, https://doi.org/10.3389/feart.2025.1527797.

S5.

Minerals and synthetic analogues at non-ambient conditions: From theory to experiment

CONVENERS & CHAIRPERSONS:

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Evolution of the dynamic response in cupropearceite, $[Cu_6As_2S_7][Ag_9CuS_4]$

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Keywords: high temperature, diffuse scattering, disorder.

Minerals of the pearceite-polybasite group have drawn considerable attention (e.g., Bindi et al., 2006) in mineralogy and material sciences due to their physical properties, such as fast ion conduction, and structural complexity. They have general formula $[M_6T_2X_7][M_{10}X_4]$ with M = Ag and Cu, T = As and Sb, and X = S, Se and Te, and occur in three different polytypes, with the trigonal high-temperature *Tac* one usually showing fast-ion conductivity (Bindi et al., 2006). Its structural complexity is associated to extensive twinning, pseudosymmetry, coexistence of different polytypes, and strong diffuse scattering (DS) features. So far, their DS was characterized only by electron diffraction at selected T, i.e. room T, 90K and 4.2K (Withers et al., 2008; Bindi et al., 2013) and related to the presence of two mutually incommensurable substructures (Withers et al., 2008; Welberry & Paściak, 2011). However, a comprehensive answer on the observed aperiodic order, i.e, incommensurate vs. composite modulated structure (Bindi et al., 2013) is still lacking, together with the evolution of the modulation vector with T. To further explore the evolution of the dynamic response as a function of temperature, we collected single-crystal X-ray DS data at ID28 (ESRF) on a crystal of cupropearceite-*Tac* from 100 to 325K. The DS features in the *hk*0 plane clearly decrease approaching the phase transition, as expected when going towards more ordered polytypes. However, the diffuse signatures in the *hhl* plane reduce at a slower rate, suggesting the occurrence of at least two contributions to the DS, which are difficult to disentangle and whose origin needs to be clarified. To better interpret the source of the disorder, newly developed approaches to the analysis of DS, such as the 3D-ΔPDF and Independent Component Analysis, are tested and discussed.

Bindi L. et al. (2006) - Fast ion conduction character and ionic phase-transitions in disordered crystals: the complex case of the minerals of the pearceite-polybasite group. Phys. Chem. Miner., 33, 677-690.

Bindi L. et al. (2013) - The composite modulated structure of cupropearceite and cupropolybasite and its behavior toward low temperature. Am. Mineral., 98(7), 1279-1284.

Welberry T. & Paściak M. (2011) - Monte Carlo and Molecular Dynamics Simulation of Disorder in the Ag^+ Fast Ion Conductors Pearceite and Polybasite. Metall. Mater. Trans. A, 42, 6-13.

Withers R.L. et al. (2008) - A composite modulated structure mechanism for Ag+ fast ion conduction in pearceite and polybasite mineral solid electrolytes. Solid State Ionics, 179(37), 2080-2089.

The Olivine-in-Diamond System: Shedding Light on Diamond Formation Conditions

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Keywords: diamond, elastic, geobarometry, olivine.

The study of inclusions and defects in diamond can offer fundamental insights into the mechanisms of plate tectonics, as well as Earth's carbon and volatile cycles, assuming the depth and temperature of diamond growth are known. While pure diamond itself does not provide clear indicators regarding the pressure and temperature of its formation, this information can theoretically be determined by measuring the stress state of minerals trapped as inclusions during diamond growth (Angel et al., 2022). Olivine represents one of the most abundant mineral phases found within diamonds. However, most of these entrapped inclusions are surrounded by fractures and exhibit evidence of fluid rims (Nimis et al., 2016). As a result, the calculated residual pressures are anomalously low, suggesting that diamond growth and olivine entrapment occurred outside the diamond stability field (Angel et al., 2022). This apparent contradiction emphasises the need to investigate the mechanisms driving the release of residual inclusion pressure. These factors are not accounted for by the simple elastic geobarometry model successfully used for inclusions in garnets from ultra-high-pressure metamorphic rocks (Murri et al., 2018; 2022).

For this purpose, we investigate the effects of non-elastic deformations for olivine inclusions in diamond by performing Raman spectroscopy at high temperature combined with thermo-mechanical modelling. Furthermore, we outline possible approaches to identify and quantify the key mechanisms responsible for low inclusion pressures, ultimately enabling a more accurate assessment of the entrapment conditions for most diamond inclusions.

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Angel R.J. et al. (2022) - Crystallographic methods for non-destructive characterization of mineral inclusions in diamonds. Revi. Mineral. Geochem., 88(1), 257-305, https://doi.org/10.2138/rmg.2022.88.05.

Murri M. et al. (2018) - Raman elastic geobarometry for anisotropic mineral inclusions. Am. Mineral., 103(11), 1869-1872, https://doi.org/10.2138/am-2018-6625CCBY.

Murri M. et al. (2022) - The role of symmetry-breaking strains on quartz inclusions in anisotropic hosts: Implications for Raman elastic geobarometry. Lithos, 422, 106716, https://doi.org/10.1016/j.lithos.2022.106716.

Nimis P. et al. (2016) - First evidence of hydrous silicic fluid films around solid inclusions in gem-quality diamonds. Lithos, 260, 384-389, https://doi.org/10.1016/j.lithos.2016.05.019.

Mineral behaviour across environments: insights from first-principles simulations

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Keywords: first-principle modelling, lattice dynamics, mineral-surface interactions.

Understanding the physical and chemical behaviour of minerals across a wide range of thermodynamic conditions requires a detailed knowledge of their structural, vibrational, and electronic properties, and of their evolution under external stimuli such as pressure, temperature, and chemical environment. In this context, first-principles simulations have become a powerful and versatile tool for bridging the gap between atomistic models and experimental observations, enabling the investigation of mineral properties from deep Earth conditions to surface and interface processes.

In the present contribution, selected case studies are presented to illustrate how density-functional theory (DFT), combined with lattice dynamics and thermodynamic modelling, can be used to explore mineral behaviour across different physical and environmental conditions. First, the polymorphic transition of ZnS from the Sphalerite to the rock-salt structure is investigated by means of phonon dispersion analysis and the quasi-harmonic approximation, providing insights into the role of vibrational contributions and elastic properties in determining phase stability under pressure and temperature conditions relevant to the Earth's interior (Ulian & Valdrè, 2019).

A second example focuses on the pressure-dependent structural and elastic behaviour of Phlogopite, a layered phyllosilicate of geological relevance. First-principles calculations reveal a strongly anisotropic compressibility and elastic response, governed by the interplay between interlayer interactions and in-plane bonding, and allow the determination of the full elastic tensor, which is difficult to obtain experimentally (Ulian et al., 2026a). In addition, the effect of Fe/Mg substitution in exfoliated monolayers is explored in terms of electronic structure modulation, highlighting possible implications for dielectric and semiconducting applications of 2D mineral analogues (Ulian & Valdrè, 2023).

Finally, the interaction between biomolecules and mineral surfaces is investigated through a combined DFT and atomic force microscopy approach, focusing on the adsorption of phospholipids on the chlorite surfaces. The simulations provide atomistic insight into adsorption geometries, binding mechanisms, and energetics, showing how surface chemistry and charge distribution control the formation of stable hybrid organic-inorganic interfaces (Ulian et al., 2026b).

In summary, these case studies demonstrate how first-principles modelling offers a unified framework for understanding mineral behaviour across a broad spectrum of conditions, from high-pressure bulk geo-processes to surface interactions relevant to environmental and biological systems, highlighting its key role in complementing and guiding experimental investigations.

Ulian G. & Valdrè G. (2019) - Thermomechanical, electronic and thermodynamic properties of ZnS cubic polymorphs: an *ab initio* investigation on the zinc-blende-rock-salt phase transition. Acta Cryst. B, 75(6), 1042-1059, https://doi.org/10.1107/S2052520619012630.

Ulian G. & Valdrè G. (2023) - Crystal-chemical, vibrational and electronic properties of 1M-phlogopite $K(Mg,Fe)_3Si_3AlO_{10}(OH)_2$ from Density Functional Theory simulations. Appl. Clay Sci., 246, 107166, https://doi.org/10.1016/j.clay.2023.107166.

Ulian G. et al. (2026a) - High-pressure behaviour and elastic constants of 1M and 2M_1 polytypes of phlogopite $KMg_3Si_3AlO_{10}(OH)_2$. Solid Earth, 17(3), 601-616, https://doi.org/10.5194/se-17-601-2026.

Ulian G. et al. (2026b) - Adsorption of phospholipids onto layered silicate surface: the case of clinochlore. Appl. Clay Sci., 279, 108053, https://doi.org/10.1016/j.clay.2025.108053.

Stress-induced plastic deformation in garnet measured via Raman spectroscopy

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Keywords: Raman spectroscopy, pseudotachylytes, deformation.

Most of the energy released during an earthquake is dissipated within the fault zone through frictional heating, microfracturing, and plastic deformation, while only a smaller fraction is radiated as seismic waves. Recently, the generation of plastic deformation caused by seismic-rupture propagation has been quantified with High-Resolution Electron Backscatter Diffraction (HR-EBSD), which reveals a progressive increase in dislocation density in wall-rock minerals as the distance to the slip zone decreases (Toffol et al., 2024). In this contribution, we explore the potential of Raman spectroscopy for quantifying microscale plastic deformation, as an approach alternative to HR-EBSD. The Raman-active phonon modes of pristine garnet (cubic symmetry *Ia*3*d*) are $3A_{1g}+8E_g+14T_{2g}$. The three fully symmetrical modes A_{1g}, which occur near 350, 556, and 914 cm^{-1} in almandine-rich compositions (Kolesov & Geiger, 1998), appear exclusively in parallel-polarized (HH) spectra (i.e. polarization of the incident light E_i parallel to the polarization of scattered light E_s), independently of the crystal orientation with respect to E_i. Therefore, the A_{1g} must not appear in the cross polarized spectra (VH, i.e. E_i ^ E_s) of undeformed garnet and the intensity depolarization ratio (I_{VH}/I_{HH}) should remain negligibly small. Hence, I_{VH}/I_{HH} values higher than the experimental "zero" value are due to point-symmetry reduction of garnet caused by external anisotropic stress fields (Campomenosi et al., 2020).

We show that anomalously high depolarization ratio I_{VH}/I_{HH} can be used to detect plastic deformation in wall-rock garnet. We measured the depolarization ratio of fractured garnets at increasing distances from a pseudotachylyte vein in the hanging wall of the Woodroffe Thrust (Musgrave Ranges, central Australia), in the same areas previously investigated by Mancktelow et al. (2022) and by Toffol et al. (2024). Zones of high dislocation density in HR-EBSD maps consistently coincide with strong deviations from cubic symmetry in garnet, expressed by $(I_{VH}/I_{HH})_{914}$ values that substantially exceed the instrumental baseline. Importantly, the peak positions of all Raman modes remain constant, indicating negligible elastic strain and therefore the absence of significant elastic stresses acting on the garnet grains (Campomenosi et al., 2020). Although HR-EBSD generally offers higher spatial resolution than confocal Raman spectroscopy, our results demonstrate that Raman spectroscopy provides a rapid and reliable complementary tool for identifying stress-induced plastic deformation in garnet. It also has the advantage of requiring less thorough polishing of the sample and faster data processing, making it widely applicable to fault rocks compared to HR-EBSD.

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Campomenosi N. et al. (2020) - Using polarized Raman spectroscopy to study the stress gradient in mineral systems with anomalous birefringence. Contrib. Mineral. Petrol., 175, 16, https://doi.org/10.1007/s00410-019-1651-x.

Kolesov B. & Geiger C. (1998) - Raman spectra of silicate garnets. Phys. Chem. Min., 25, 142-151, https://doi.org/10.1007/s002690050097.

Mancktelow N.S. et al. (2022) - Time-lapse record of an earthquake in the dry felsic lower continental crust preserved in a pseudotachylyte-bearing fault. J. Geophys. Res.-Sol. Ea., 127, e2021JB022878, https://doi.org/10.1029/2021JB022878.

Toffol G. et al. (2024) - On-fault earthquake energy density partitioning from shocked garnet in an exhumed seismic midcrustal fault. Sci. Adv., 10, eadi8533, http://doi.org/0.1126/sciadv.adi8533.

Polyhedral distortions beyond quadratic elongation and angle variance in the Crystal Palace program

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Keywords: polyhedra, crystal structures, distortions.

It was the careful examination of the coordination environment of the atoms in the structure of wadsleyite that led Joe Smyth (1987) to propose it as a major host for water in the mantle. This is a classic illustration of the fact that many properties of mineral and inorganic crystal structures depend on the detailed coordination of their atoms and distortions. Robinson et al. (1971) defined the parameters of quadratic elongation and bond angle variance as measures of atomic coordination distortion. These measures rely on purely geometrical principles without crystal chemical assumptions and have been very widely used for the last half century. However, they have several limitations; they are only defined for tetrahedral and octahedral coordination, they cannot be used to describe the distortions of vacant sites in which there is no central cation, and they do not separate out the distortions arising from displacement of the central cation from those arising from the deviation of the positions of the ligands from a regular polyhedron.

Makovicky & Balić-Žunić (1998) showed that all of these shortcomings are overcome by using the concept of the centroid of the ligands, which is the point with smallest variance of distances to them. It can be defined for any polyhedron. Use of the centroid allows the bond length and angle distortions due to the distortion of the ligand positions from a regular polyhedron to be distinguished from those arising from the displacement of the cation from the centroid of the ligands. The asphericity parameter quantifies the distribution of the ligand distances from centroid - how much they differ from being equal. The centroid volume distortion (CVD) measures the angular distortion of the ligands from a perfect polyhedron. These two parameters can be used for both occupied and vacant polyhedra. In occupied polyhedra the offset of the central atom from the centroid is quantified by the eccentricity parameter and its contribution to the distortions of the ligand-cation-ligand bond angles is characterised by the atom volume distortion (AVD) parameter. These parameters are now calculated by the Crystal Palace program (Angel et al., 2025) from input cif files for multiple structures and will be illustrated in this presentation by examples from Joe Smyth's work.

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Angel R.J. et al. (2025) - Uncertainties of recalculated bond lengths, angles and polyhedral volumes as implemented in the Crystal Palace program for parametric crystal structure analysis. Acta Crystallogr. A, 81, 202-210, https://doi.org/10.1107/S2053273325002682.

Makovicky E. & Balić-Žunić T. (1998) - New measure of distortion for coordination polyhedra. Acta Crystallogr. B, 54, 766-773, https://doi.org/10.1107/S0108768198003905.

Robinson K. et al. (1971) - Quadratic elongation: a quantitative measure of distortion in coordination polyhedra. Science, 172, 567-570, https://doi.org/10.1126/science.172.3983.567.

Smyth J.R. (1987) - Beta-Mg_2SiO_4 - a potential host for water in the mantle. Amer. Mineral., 72, 1051-1055.

Thermal activation of charge carriers in Fe^{2+}-bearing richterite detected by Raman spectroscopy

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Keywords: richterite, Raman spectroscopy, polaron conductivity.

Understanding large-scale geological processes requires investigating mineral properties under non-ambient conditions. Amphiboles (general formula $AB_2C_5T_8O_{22}W_2$) considerably contribute to volatiles cycling and lithospheric high-conductivity anomalies in the mid-crust and subduction zones, given their abundance and the role of Fe^{2+}-bearing minerals in charge transport. While electrical conductivity measurements have suggested the formation of polarons (conduction electrons coupled with longitudinal optical phonons) at high temperatures (HT), direct evidence has only recently been provided by Raman spectroscopy through the detection of resonance Raman scattering and the reversible delocalization of H^+ cations (Mihailova et al., 2021).

Richterite, a Na-Ca amphibole occurring in metasomatized mantle, can incorporate considerable amount of ^{A}K. It is stable over a wide pressure (up to 12-13 GPa) and temperature (up to 1400 K) range, making it particularly relevant to subduction processes and mantle conductivity anomalies. Previous studies of a synthetic sample along the potassium ferro-richterite - riebeckite join demonstrated polaron formation also in this material (Bernardini et al., 2024). However, natural amphiboles in these geological settings are typically Mg-rich. Hence, the aim of this contribution is to understand the effect of ^{C}Mg as well as of A-site cations on the formation of charge carriers at HT in natural Na-Ca amphiboles. We have analysed K- and Fe^{2+}-bearing amphibole specimen on the richterite - ferri-winchite join (generalized formula $^{A}(Na_{1-x}£_x)^{B}(NaCa)^{C}(Mg_{5-x}Fe^{3+}_x)Si_8O_{22}(OH)_2$, $0 \leq x \leq 1$) from Siilinjärvi, Finland, using in situ HT Raman spectroscopy, both in air (Böttger, 2025) and under vacuum (~10^{-4} bar), coupled with direct-current conductivity measurements. Electron delocalization from FeO_6 octahedra begins at ~900 K, followed by electron ejection from the crystal at ~950 K. These results indicate that ^{C}Mg increases the activation temperature of polaron formation, whereas the semi-occupied A site does not affect the polaron dipole moment (Mihailova et al., 2022). At ~1100-1150 K, progressive delocalization of H^+ cations from the W-site occurs, with partial recovery upon cooling, indicating mobilization of H^+ at HT. Under vacuum, both polaron formation and H^+ delocalization occur at T approximately 150 K higher than in air, indicating that the absence of oxygen raises the energy barrier required for these processes. Direct-current experiments show strong anisotropy of the polaron conductivity; however, the low Fe content reduces the polaron concentration and consequently lowers electrical conductivity.

These findings improve our knowledge of the crystal-chemical processes controlling geophysical anomalies in subduction zones, contributing to improved models of lithospheric dynamics.

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Bernardini S. et al. (2024) - The effect of A-site cations on charge-carrier mobility in Fe-rich amphiboles. Am. Mineral., 109, 1545-1553, https://doi.org/10.2138/am-2023-9138.

Böttger F. (2025) - Hochtemperaturverhalten von eisenhaltigem Richterit mithilfe von Ramanspektroskopie. Bachelor thesis, University of Hamburg, Germany.

Mihailova B. et al. (2021) - Atomistic insight into lithospheric conductivity revealed by phonon-electron excitations in hydrous iron-bearing silicates. Commun. Mater., 2, 57, https://doi.org/10.1038/s43246-021-00161-y.

Mihailova B. et al. (2022) - Polarons in Rock-Forming Minerals: Physical Implications. Condens. Matter, 7(4), 68, https://doi.org/10.3390/condmat7040068.

Atomic dynamics of coesite under non-ambient conditions revisited

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Keywords: coesite, Raman spectroscopy, HF-DFT.

Coesite crystals were studied at high pressures and high temperatures by in situ Raman spectroscopy and ab initio calculations. Phonon assignment of detected Raman-active modes has been carried out by comparing the measured and calculated wavenumbers as well as their pressure derivatives. The phonon compressibility of several low-energy modes changes above 6 GPa and we show that this behaviour reflects the way atomic displacement vectors of such phonon modes reorient due to structural changes occurring in coesite with increasing pressure. High-temperature experiments of coesite show that most low-energy phonon modes soften following a non-linear trend with a significant decrement in its temperature derivative above ~900 K. Because coesite is expected to undergo congruent melting above 800-900 K (Bourova et al., 2006), we suggest that these anomalies may reflect the response of atomic dynamics to the thermodynamic metastability of coesite under overheated conditions. Finally, the mode Grüneisen parameters of the most intense coesite Raman peaks were calculated from both high-pressure and high-temperature experimental data. At ambient conditions, the low-energy modes show a large difference between isobaric (g_P) and isothermal (g_T) mode Grüneisen parameters with $g_T >> g_P$. However, high temperature significantly reduces g_P while high pressure slightly increases g_T of most phonon modes. Therefore, combined high pressure and temperature experiments are necessary to better understand the correlation between the coesite intrinsic anharmonicity and its thermodynamic stability.

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Bourova E. et al. (2006) - Coesite (SiO_2) as an extreme case of superheated crystal: An X-ray diffraction study up to 1776 K. Chem. Geol., 229(1-3), 57-63, https://doi.org/10.1016/j.chemgeo.2006.01.011.

Alkali-Cl modification of magmatic sulfide liquids and its implications for metal transport across the lithosphere

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Keywords: sulfide liquid, mafic-ultramafic systems, alkalis.

Magmatic sulfide liquids are the principal carriers of chalcophile metals such as Ni, Cu, Au and the platinum group elements, yet the physical mechanisms allowing dense sulfide melts to be extracted from the mantle and transported through the crust remain incompletely understood. Here we present a series of high-pressure and high-temperature experiments investigating the interaction between Fe-Ni-Cu sulfide liquids and alkali- and chlorine-bearing components under magmatic conditions to investigate the role of salts and carbonates in modifying sulfide liquid physical properties. Experiments were conducted between 0.15-1 GPa and 300-1300°C using sulfide-, silicate- and carbonate-bearing systems under mantle-like oxygen fugacities (Zhang et al. 2024; Cottrell et al. 2025). Experimental products were analysed using SEM, EPMA and Raman spectroscopy to constrain alkali and halogen incorporation, sulfide melting behaviour and the physical consequences of alkali enrichment in sulfide liquids. The experiments demonstrate that sulfide liquids can dissolve measurable concentrations of Na, K and Cl at magmatic temperatures, even in the presence of competing silicate and carbonate melts. Alkali contents of residual sulfide liquids commonly reach several wt.%, with K remaining more compatible than Na under hydrous conditions. Alkali and halogen incorporation is strongly temperature dependent but only weakly pressure dependent, indicating that these components may remain dissolved in sulfide liquids throughout much of the lithospheric continuum provided temperatures remain sufficiently high. Raman spectra of quenched sulfide liquids show no evidence for preserved carbonate or sulfate complexes, suggesting that alkalis are structurally dispersed within the sulfide liquid rather than occurring as discrete oxysalt phases. Dedicated melting experiments further demonstrate that alkalis and halogens act as effective fluxes for sulfide liquids. Relative to pure FeS systems (Boehler, 1992; Urakawa et al. 2004), alkali-bearing compositions depress sulfide melting temperatures by up to ~100°C, extending the temperature interval over which sulfide liquids remain molten, mobile and capable of differentiation. This behaviour has important implications for mantle melting, as alkali-bearing sulfides may be extracted from fertile mantle domains at lower thermal thresholds than predicted for simple Fe-S systems. Alkali incorporation also modifies sulfide liquid density. Using measured alkali contents and BSE-derived phase proportions, we estimate that alkali-bearing residual sulfide liquids attain densities of ~3.4-3.5 g cm^{-3}, decreasing further to ~3.1-3.3 g cm^{-3}, when internal porosity is considered. Mixing with coexisting FeS-rich sulfide liquid results in a bulk sulfide globule density reduction of ~7-10%. Although modest, such reductions may significantly increase sulfide residence time and transport distance in crystal-rich magmas. These effects are expected to be strongest for Cu-rich residual sulfide liquids, which preferentially concentrate alkalis and host the bulk of Cu and precious metals in natural systems. During cooling and crystallisation, alkalis and halogens are expelled from sulfide liquids into surrounding silicate minerals and fluids, producing alkali- and Cl-rich halos commonly observed around magmatic sulfides. We propose that transient alkali-halogen enrichment of sulfide liquids links mantle melting, sulfide transport, crustal differentiation and magmatic-hydrothermal mineralisation within a single lithosphere-scale metallogenic framework.

High-pressure spin transition and compressional behavior of Fe- and Ni-bearing monosulfide solid solutions

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Keywords: spin-transition , high-pressure, monosulfide solid solution.

Monosulfide solid solutions (mss) with a metal-to-sulfur ratio of 1:1 represent major sulfide phases in the Earth's upper mantle and are commonly found as inclusions in diamonds and mantle-derived rocks (Stachel & Harris, 2008; Beyer et al., 2022). Their compositions commonly involve Fe, Ni, Cu, and Co, forming extensive solid solutions. The presence of transition metals in these phases may trigger pressure-induced electronic transitions (Lavina et al., 2010), associated with anomalous elastic and structural behavior under deep Earth conditions.

In this study, Fe-Cu and Ni-Cu mss end-members ($(Fe_{0.90}Cu_{0.08})S$ and $(Ni_{0.92}Cu_{0.08})S$ respectively) were synthesized at 5.2 GPa and 1000°C using a multianvil apparatus. Their high-pressure behavior was investigated up to apx. 9 GPa by synchrotron single-crystal X-ray diffraction in diamond anvil cells. Synchrotron Mössbauer source spectroscopy was also performed on the Fe-bearing sample.

Fe-bearing mss exhibits a pronounced elastic anomaly from 3-5 to 6 GPa, characterized by enhanced compressibility and a volume decrease associated with a pressure-induced high-spin to low-spin transition of Fe. Specifically, the room-pressure high-spin configuration is characterized by a 6% volume excess compared to the volume expected extrapolating the low-spin equation of state. Mössbauer spectroscopy independently confirmed the occurrence of a continuous electronic transition. In contrast, the Fe-free Ni-Cu mss displays smooth compression without detectable anomalies, demonstrating that the observed behavior is intrinsically linked to the electronic state of iron.

Comparison with natural troilite (FeS) and pyrrhotite (Fe_7S_8) highlights the strong influence of spin transitions on the compressional properties of Fe-bearing sulfides, consistent with previous observations on FeS systems. These findings demonstrate that electronic spin transitions significantly affect the density and elastic behavior of mantle sulfides and must be explicitly considered when estimating trapping pressures of sulfide inclusions in diamonds (Gilder et al., 2011) and modeling the physical properties of sulfide-bearing assemblages in planetary interiors.

Beyer C. et al. (2022) - High-pressure phase relations in the system Fe-Ni-Cu-S up to 14 GPa: Implications for the stability of sulfides in the earth's upper mantle. Contrib. Mineral. Petr., 177(10), 99, https://doi.org/10.1007/s00410-022-01966-x.

Gilder S.A. et al. (2011) - Anatomy of a pressure-induced, ferromagnetic-to-paramagnetic transition in pyrrhotite: Implications for the formation pressure of diamonds. J. Geophys. Res.-Sol. Ea., 116, B10101, https://doi.org/10.1029/2011JB008292.

Lavina B. et al. (2010) - Effect of dilution on the spin pairing transition in rhombohedral carbonates. High Pressure Res., 30(2), 224-229, https://doi.org/10.1080/08957959.2010.485391.

Stachel T. & Harris J.W. (2008) - The origin of cratonic diamonds-constraints from mineral inclusions. Ore Geol. Rev., 34(1-2), 5-32, https://doi.org/10.1016/j.oregeorev.2007.05.002.

Alkaline earth sulfides in Mercury's mantle: Thermodynamic properties and implications for interior structure and thermal evolution

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Keywords: Mercury, alkaline earth sulfides, ab-initio calculations.

Oldhamite (CaS) and niningerite (MgS) are alkaline earth sulfides stable under highly reducing conditions and crystallizing in the cubic NaCl-type structure (B1). These phases, extremely rare in terrestrial rocks, are commonly found in extraterrestrial materials such as enstatite chondrites and aubrites, and may also occur in reduced planetary interiors, including Mercury's mantle. The high-pressure/high-temperature (HP-HT) behavior of CaS and MgS is still poorly constrained due to the lack of comprehensive thermodynamic and thermoelastic data, particularly because these phases are highly unstable under terrestrial conditions and experimental constraints, especially for MgS, remain very limited. In this work, we perform ab initio density functional theory calculations (DFT) within the framework of the quasi-harmonic approximation (QHA) to determine reliable thermophysical properties of CaS and MgS under Mercury's mantle P-T conditions (i.e., up to 10 GPa and 2200 K). We assessed the performance of seven exchange-correlation functionals through comparison with available experimental data. Among the tested functionals, B3LYP provides the highest accuracy. Thermodynamic properties of CaS and MgS were computed at ambient and HP-HT conditions through phonon dispersion calculations. Additionally, temperature- and pressure-dependent thermal expansivity was determined through calculation of mode Grüneisen parameters. Thermodynamic properties of CaS are consistent with the few available experimental and previously calculated data. For MgS, where experimental constraints are currently lacking, we provide novel values for thermoelastic parameters. Notably, MgS exhibits high volume thermal expansivity, potentially influencing Mercury's mantle convection regime and thermal evolution, and contributing to the interpretation of the planet's global contraction history and its surface tectonic features. The construction of reliable thermodynamic databases for CaS and MgS using ab initio calculations provides new insights on phase stability in reduced planetary interiors, enabling improved constraints on modal abundances of alkaline earth sulfides in Mercury's mantle and complementing new geophysical and geochemical informations on its internal structure as expected from the joint ESA-JAXA BepiColombo mission.

Phase transitions in benitoite at high-pressure

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Keywords: benitoite, high-pressure, phase transitions.

The rare cyclosilicate benitoite (ideally $BaTiSi_3O_9$) represents a fundamental structural analogue for high-pressure (HP) silicate and carbonate systems, primarily due to its uncommon framework of three-membered silicate rings. Among silicates, this $[Si_3O_9]^{6-}$ topology is shared only by $CaSiO_3$ pseudowollastonite, making benitoite an ideal comparative system for investigating the mineralogy of the Earth's interior (Yang & Prewitt, 1999). This study explores the structural evolution and compressional behaviour of benitoite via synchrotron single-crystal X-ray diffraction up to 22.3 GPa. Our experimental data reveal a complex polymorphic sequence involving three distinct phase transitions: to benitoite-II at ~4.2 GPa, to benitoite-III at ~12.7 GPa, and finally to benitoite-IV at ~16.7 GPa. The crystal structures of the previously unknown polymorphs benitoite-III (space group $Pbn2_1$) and benitoite-IV (space group $R32$) were solved and refined. The structural transformation is governed by a progressive distortion of the Si_3O_9 rings and TiO_6 octahedra, alongside an increase in the Ba coordination number. Notably, benitoite-IV exhibits a unique ring configuration where the tetrahedral bases become nearly parallel, leading to a marked increase in overall density. This densification mechanism closely mirrors the behaviour observed in the $CaSiO_3$ system, where the HP-polymorphs breyite and parabreyite - both featuring distorted three-fold rings - are significantly denser than low-pressure pseudowollastonite. Ultimately, these findings provide critical insights into the stabilization of three-membered rings under extreme conditions and offer a robust structural model to interpret the behaviour of high-pressure carbonates containing sp^3-hybridized carbon.

Yang H. & Prewitt T.C. (1999) - Crystal structure and compressibility of a two-layer polytype of pseudowollastonite ($CaSiO_3$), Am. Mineral., 84, 1902-1905, https://doi.org/10.2138/am-1999-11-1224.

Mineral physics of a new perovskitoid structure for photovoltaic applications

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Keywords: high pressure, band gap, phase transitions.

Organometal halide perovskites (OMHPs) have emerged as highly promising materials for the ecological transition, owing to their low production costs, outstanding optoelectronic properties, and the possibility of finely tuning their characteristics through targeted design and synthetic strategies. Recently, a class of OMHPs in which triphenylsulfonium [$(Ph)_3S^+$] or trimethylsulfonium [$(CH_3)_3S^+$] are chosen as the organic cations, combined with lead- or bismuth-halide frameworks, has attracted growing attention. Their bulky (sterically large), hydrophobic, and positively charged nature allows them to optimize perovskite morphology, passivate bulk defects, and exhibit good moisture stability. These large cations generally form low-dimensional (0D, 1D or 2D) perovskite-like structures.

In this context, the present work investigates the structural and functional role of the triphenylsulfonium cation in lead-halide (I, Br, Cl) perovskite systems, with particular emphasis on the interplay between crystal chemistry, weak interactions, and optoelectronic behavior.

A series of novel OMHPs was synthesized via different solution-based approaches, including low-temperature aqueous precipitation, crystallization from volatile polar solvents, and slow evaporation from dimethylformamide (DMF). These methods yielded multiple new perovskite-like phases, with distinct structural arrangements. In most cases, the cystallized compounds were effimerous under room conditions, and just in a few cases we were able to isolate good crystals to refine their crystal structures. One of the most promising run products is a new bulky triphenylsulfonium lead iodide-DMF complex $(Ph)_3S[Pb_2I_5(DMF)]$ that was well stabilized by the fine tuning of the synthesis procedure, and structurally characterized by single-crystal X-ray diffraction. It crystallizes in the monoclinic space group $P2_1/n$ (No. 14), with unit cell parameters a = 9.3128(3) Å, b = 23.5999(9) Å, c = 14.1518(5) Å, β = 96.9090(10)°, and Z = 4.

The crystal structure reveals a one-dimensional perovskite-like framework based on lead-iodide units, where Pb^{2+} centers are coordinated by iodide anions and a DMF molecule, forming distorted octahedral environments. These octahedra connect into chains, generating a 1D inorganic backbone. The role of the coordinated DMF is interesting as it might play a key role in reducing the dimensionality and stabilizing the structure.

Vibrational spectroscopic data are presented to supports the crystallographic model, together with theoretically calculated band gap of the newly crystallized $(Ph)_3S[Pb_2I_5(DMF)]$ that results to be 2.30 eV at room conditions. High-pressure experiments and theoretical calculations are presented to investigate phase stability, potential memory effects upon decompression, and the evolution of electronic and transport properties. Preliminary results indicate the likely presence of phase transition and decrease in band gap during compression, resulting in a complete metallic transition at extreme conditions.

These studies aim to deepen the understanding of structure-property relationships in sulfonium-based OMHPs and to assess their potential for advanced optoelectronic and energy applications.

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Low-temperature structure evolution of sodium carbonate from 293 to 80 K

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Keywords: natrite, synthetic, low-temperatures.

Sodium carbonate, Na_2CO_3, naturally occurring as the mineral natrite, is a benchmark compound in aperiodic crystallography and one of the earliest structures described through the superspace approach. Its room-temperature γ phase is characterized by an incommensurately modulated monoclinic structure, whereas upon cooling, a commensurate lock-in δ phase has been reported (Dusek et al., 2003; de Pater & Helmholdt, 1979). However, the low-temperature behaviour of Na_2CO_3 remains poorly constrained: diffraction data below room temperature are scarce, and the γ → δ transformation has proven elusive, being detected only in some studies (Dusek et al., 2003; de Pater & Helmholdt, 1979).

Here we present a temperature-dependent powder X-ray diffraction study of synthetic Na_2CO_3 from room temperature down to 80 K, aimed at clarifying the structural evolution of this archetypal modulated carbonate under non-ambient conditions. The incommensurate γ phase remains stable down to 150 K. At 125 K, new satellite reflections appear and can be indexed by a commensurate modulation vector q = (1/6, 0, 1/3), marking the onset of the δ phase. The transformation is not expressed through changes of intensities of the main reflections, since γ and δ share the same monoclinic average cell.

Below 125 K, the γ and δ phases coexist down to 80 K, with a progressive increase in δ-satellite intensity upon cooling. The analysis of temperature-dependent line broadening, particularly for *hkl*0 reflections, reveals the build-up of a microstrain in the γ phase followed by partial relaxation in the lock-in regime. This behaviour may be interpreted in terms of the formation of commensurate domains and the localization of strain at domain walls.

The possible structural mechanisms driving the transition are taken into consideration in light of the main hypotheses previously proposed in the literature (Dusek et al., 2003; Arakcheeva & Chapuis, 2005; Arakcheeva et al., 2010), including changes in C-Na coordination, carbonate-group tilting, and local bonding requirements around the Na sites. By revisiting these interpretations within a new low-temperature dataset, this study contributes to a more comprehensive understanding of the γ → δ transformation in Na_2CO_3 and of the mechanisms governing lock-in transitions in this modulated mineral.

Arakcheeva A. & Chapuis G. (2005) - A reinterpretation of the phase transitions in Na_2CO_3. Acta Crystallogr. B, 61, 601-607, https://doi.org/10.1107/S0108768105033008.

Arakcheeva A. et al. (2010) - The incommensurately modulated structures of natural natrite at 120 and 293 K from synchrotron X-ray data. Am. Mineral., 95, 574-581, https://doi.org/ 10.2138/am.2010.3384.

de Pater C.J. & Helmholdt R.B. (1979) - Incommensurate structural phase transformation in Na_2CO_3. Phys. Rev. B, 19, 5735-5745, https://doi.org/10.1103/PhysRevB.19.5735.

Dusek M. et al. (2003) - Sodium carbonate revisited. Acta Crystallogr. B, 59, 337-352, https://doi.org/10.1107/S0108768103009017.

Raman high-pressure phase transitions in Ba, Sr, and Pb feldspars

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Keywords: high-pressure, Raman spectroscopy, feldspars.

Exchange of larger cations, like Sr, Pb or Ba for Ca in anorthite promotes the transition from triclinic *P*-1 to a monoclinic *I*2/*c* structure, which is the phase at room conditions for Sr-, Pb- and $BaAl_2Si_2O_8$ feldspars. At high pressure we observe a transition to a $P2_1/c$ space group, at 6.6, 7.9 and 5.8 GPa, for Sr-, Pb- and $BaAl_2Si_2O_8$ feldspars, respectively (Curetti et al., 2016). In all, the transition was first order, with discontinuous character; moreover a change in compressional behaviour occurred in the *I*2/*c* symmetry at about 4 GPa, which hindered the fitting of an equation of state for the whole *I*2/c pressure range. Suggestion for a second phase transition at higher pressure in $PbAl_2Si_2O_8$ feldspar were provided by previous synchrotron investigations, but also in recent work on the Ba and Sr feldspar analogues with paracelsian-structure as well as in anorthite (Tribaudino et al., 1999; Pakhomova et al., 2020; Gorelova et al., 2021). In anorthite a phase transition at about 10 GPa was ascribed to changes in the coordination symmetry of some Al tetrahedral sites, becoming more 5-fold at the highest pressures.

Here we provide spectroscopic evidence for the *I*2/*c* - $P2_1/c$ transitions in Sr-, Ba-, Pb- feldspars, and discuss possible presence of the transition to a higher pressure phase with higher coordination close to 9-10 GPa. Synthetic Sr, Ba and Pb feldspars, the latter in an ordered and Al/Si disordered configuration were compressed in a diamond anvil cell, up to 11 GPa, measuring the Raman spectra at steps of about 0.5 GPa. In all samples evidence for the *I*2/*c* - $P2_1/c$ transition was provided by splitting of peaks and appearance of new peaks at the transition pressures; the peak at 505 cm^{-1}, which is the strongest in feldspar Raman spectrum was found to show a strong shift at the transition of about 8 cm^{-1}, highlighting the first order type of the transition; in disordered Pb feldspar however suggestion of a more continuous behaviour is present. In all samples at about 4 GPa a change in slope of several peaks, was observed, which suggests the presence of an isosymmetric transition within the *I*2/*c* symmetry. At pressure above 8-10 GPa the presence of new peaks and a shift in the others indicates the possible presence of a second phase transition.

The similar pressure at which the transition occurs in the three phases suggests that the transitions are driven completely by changes in the tetrahedral framework, as previously found for anorthite. The model of the transition for increasing coordination of the tetrahedral cation was discussed.

Curetti N. et al. (2016) - High-pressure structural configuration and phase transition in celsian, $BaAl_2Si_2O_8$. Phys. Chem. Min., 44(3), 181-192, https://doi.org/10.1007/s00269-016-0847-0.

Gorelova L.A. et al. (2021) - Crystal structure evolution of slawsonite $SrAl_2Si_2O_8$ and paracelsian $BaAl_2Si_2O_8$ upon compression and decompression. J. Phys. Chem. C, 125(23), 13014-13023, https://doi.org/10.1021/acs.jpcc.1c02949.

Pakhomova A. et al. (2020) - Polymorphism of feldspars above 10 GPa. Nat. Commun., 11, 2721, https://doi.org/10.1038/s41467-020-16547-4.

Tribaudino M. et al. (1999) - High pressure behaviour of lead feldspar ($PbAl_2Si_2O_8$). Phys. Chem. Min., 26(5), 367-374, https://doi.org/10.1007/s002690050196.

Investigating mineral rheology through host-inclusion systems

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Keywords: host-inclusion systems, mineral rheology, raman spectroscopy.

Deciphering Earth's geodynamic processes requires a comprehensive understanding of mineral deformation under varying conditions. Traditional experimental methods depend on idealised synthetic materials, which can fail to capture natural systems' structural defects and chemical heterogeneities. Our alternative approach is to study mineral inclusions trapped in host crystals, which serve as naturally pre-stressed microenvironments, providing direct insight into mineral rheology. Using Raman spectroscopy, we can quantify residual pressures in inclusions across diverse P-T conditions to investigate how internal stress states influence the plastic behaviour of the host mineral. By focusing on zircon and quartz inclusions within garnet, we demonstrate how this technique offers a robust framework for assessing rock-forming mineral mechanics, with significant implications for rheological modelling and geodynamic interpretations.

Exploring the structural complexity of feldspathoids at non-ambient conditions: The case of leucite and kalsilite

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Keywords: leucite, kalsilite, phase transition.

Leucite ($KAlSi_2O_6$) is a key feldspathoid for modeling alkaline, potassium-rich magmatic systems. While its polymorphic behavior is well-documented at high temperature or high pressure alone (Lange et al., 1986; Hatch et al., 1990; Palmer et al., 1997; Gatta et al., 2008), its structural response to simultaneous high pressure (P) and high temperature (T) remains less explored. In this study, we investigated the P-T behavior of leucite through in situ single-crystal and powder synchrotron X-ray diffraction.

Initial single-crystal experiments (P02.2 at PETRA-III and ID15B at ESRF) revealed an unexpected transition from the tetragonal $I4_1/a$ polymorph toward a trigonal form (R-3) at pressures above 2.2-2.5 GPa. This trigonal phase, never reported before, is characterized by a significantly higher structural complexity, with two independent K sites and four tetrahedral sites. Further experiments conducted at the ID06 beamline (ESRF) using a Large Volume Press (LVP) confirmed this phase transition. The LVP data demonstrate that the transformation is reproducible and have allowed for the first time the determination of a clear phase stability field under combined P-T conditions.

This trend toward structural complexity appears to be a common feature among feldspathoids. Parallel investigations on kalsilite ($KAlSiO_4$) have similarly identified new high-pressure phases. Notably, preliminary single-crystal XRD data on kalsilite at high-P and ambient-T show a polymorph characterized by a complex supercell, whereas XRD data at combined P-Tshow a transition toward a polymorph metrically analogous to nepheline ($c' = 2c$). Together, these findings underscore the necessity of high-resolution in situ crystallography to understand the sophisticated structural rearrangements that govern the stability of alkali-bearing framework silicates in the Earth's interior.

Gatta G.D. et al. (2008) - Leucite at high pressure: Elastic behavior, phase stability, and petrological implications. Am. Mineral., 93, 1588-1596, https://doi.org/10.2138/am.2008.2932.

Hatch D.M. et al. (1990) - Phase transitions in leucite, $KAlSi_2O_6$. Phys. Chem. Minerals, 17, 220-227, https://doi.org/10.1007/BF00201453.

Lange R.A. et al. (1986) - Phase transitions in leucite ($KAlSi_2O_6$), orthorhombic $KAlSiO_4$, and their iron analogues ($KFeSi_2O_6$, $KFeSiO_4$). Am. Mineral., 71, 937-945.

Palmer D.C. et al. (1997) - Structural behavior, crystal chemistry, and phase transitions in substituted leucite: High-resolution neutron powder diffraction studies. Am. Mineral., 82, 16-29, https://doi.org/10.2138/am-1997-1-203.

Redox processes and conductivity phenomena in Fe-bearing hydrous silicates

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Keywords: amphibole, biotite, high-temperature Raman spectroscopy.

To understand key phenomena in the mid-crust and subduction zones, including volatile-element cycling triggered by mineral transformations and reduction-oxidation (redox) processes, we need to better understand the properties of rocks and hence, the properties of the constituent minerals under non-ambient conditions. In fact, the redox processes consist of electron cycling and hence, they can significantly contribute to the well-known and yet poorly understood lithospheric conductivity. There are two main concepts about the dominant component of the lithospheric conductivity: (i) ionic conductivity of aqueous fluids at mineral-grain boundaries, formed as the result of metasomatic processes, and inherent conductivity of rock-forming minerals, including electronic-polaron conductivity as well as diffusion of H^+ and heavy cations. Recently, it was shown that conductive fluids alone cannot explain the anomalously high anisotropic conductivity in the mantle wedge (Yoshino et al., 2006), which has triggered even higher scientific interest on the mechanism of formation of intrinsic charge carriers in rock forming minerals. Given that temperature rather than pressure is the major factor influencing the transport phenomena in silicates, this calls for in situ high-temperature studies of rock-forming minerals, in particular, of iron-bearing hydrous silicates, because they can oxidize and dehydrogenize without a structural collapse, i.e. they can contribute to both water and electron cycling, delivering both H^+ and e^- in the lithospheric rocks. However, the research is commonly focused on the final oxidation and dehydrogenation state, and the preceding processes are ignored. The role of atomic dynamics to trigger the delocalization and subsequent ejection of e^- and H^+ is also neglected. Moreover, polaron conductivity has been suggested to exist in amphiboles and phyllosilicates but only recently, by using Raman spectroscopy, a method sensitive to both electron and phonon excitations, we have provided a direct proof for the formation of thermally activated small polarons in amphiboles, arising from the coupling between polar optical phonons and electron transitions within $Fe^{2+}O_6$ octahedra (Mihailova et al. 2021 and 2022; Bernardini et al. 2005).

In this contribution, thermally induced transformation processes and activation of charge carriers in representative Fe^{2+}-bearing amphibole and biotite species will be discussed, based on the results from in situ high-temperature Raman scattering coupled with direct-current electrical-conduction experiments.

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Bernardini S. et al. (2025) - The effect of anisotropic electrical conductivity of amphiboles on geophysical anomalies observed in subduction zones. Sci. Rep., 15, 14244, https://doi.org/10.1038/s41598-025-98025-9.

Mihailova B. et al. (2021) - Atomistic insight into lithospheric conductivity revealed by phonon-electron excitations in hydrous iron-bearing silicates. Commun. Mater, 2, 57/1-10, https://doi.org/10.1038/s43246-021-00161-y.

Mihailova B. et al. (2022) - Polarons in rock-forming minerals: physical implications. Condens. Matter, 7, 68, https://www.mdpi.com/2410-3896/7/4/68.

Yoshino T. et al. (2006) - Hydrous olivine unable to account for conductivity anomaly at the top of the asthenosphere. Nature, 443, 973-976, https://doi.org/10.1038/nature05223.

Ab initio investigation of the thermodynamic, thermoelastic and structural properties of dolomite $CaMg(CO_3)_2$

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Keywords: dolomite, ab initio model, thermodynamic properties.

Dolomite, $CaMg(CO_3)_2$, is a double carbonate mineral crystallizing in the trigonal system (space group *R*-3). As one of the most abundant constituents of the Earth's crust, it plays a fundamental role in the global carbon cycle, acting as a primary vehicle for carbon transport and recycling into the deep mantle (Kerrick & Connolly, 2001). Despite its geological prevalence, dolomite remains a subject of intense debate due to the long-standing difficulty in replicating its low-temperature precipitation at rates consistent with the geological record (Kim et al., 2023). Understanding its thermodynamic stability and lattice dynamics is therefore crucial to clarifying the mechanisms governing its deposition and persistence across diverse geological environments. In this work, thermodynamic, thermoelastic and structural properties of dolomite under the combined effects of temperature and pressure are investigated employing an ab initio theoretical approach. Simulations were performed using CRYSTAL23 software package (Erba et al., 2023), with hybrid functional. The theoretical framework is based on the quasi-harmonic approximation (QHA) which integrates equation of state (EoS) results the phonon dispersion relations calculated at various unit cell volumes (pressures). The static EoS parameters at 0 K, derived from a third order Birch-Murnaghan yielded a bulk modulus K_0 = 91.31 GPa, a pressure derivative K' = 4.33 and an equilibrium volume V_0 = 323.420 Å^3. A wide range of properties was systematically analyzed, including the volumetric thermal expansion coefficient (α_V), the isothermal (K_T) and adiabatic (K_S) bulk moduli, and the isobaric heat capacity (C_p). The thermodynamic properties were calculated by fitting phonon frequencies with a third order polynomial function and within a temperature range of 0-800 K and pressures of 0-8 GPa, consistent with the experimental breakdown limits of dolomite. Preliminary data has shown a good agreement with the experimental findings. The calculated crystallographic cell parameters show excellent agreement with high-PT experimental data (Martinez et al., 1996). Specifically, at T = 298.1 K, the unit cell volume deviates from experimental values by -0.6%. Both the calculated isothermal bulk modulus (K_{0T} = 101.2 GPa and the average volumetric thermal expansion coefficient ($\alpha_{298\text{-}800K} = 2.3 \times 10^{-5}$ K^{-1}) show robust agreement with experimental data. Vibrational spectroscopy analysis under pressure further confirms the accuracy of the model, showing a general shift toward higher frequencies in line with experimental observations. These findings demonstrate that the hybrid functional approach within the QHA framework provides a robust predictive tool for the thermodynamic modeling of carbonates under geophysical conditions.

Erba A. et al. (2023) - CRYSTAL23: A Program for Computational Solid State Physics and Chemistry. J. Chem. Theory Comput., 19, 6891-6932, https://doi.org/10.1021/acs.jctc.2c00958.

Kerrick D.M. & Connolly J.A.D. (2001) - Metamorphic devolatilization of subducted marine sediments and the transport of volatiles into the Earth's mantle. Nature, 411, 293-296, https://doi.org/10.1038/35077056.

Kim J. et al. (2023) - Dissolution enables dolomite crystal growth near ambient conditions. Science, 382, 915-920, https://doi.org/10.1126/science.adi3690.

Martinez I. et al. (1996) - In situ X-ray diffraction of aragonite and dolomite at high pressure and high temperature; evidence for dolomite breakdown to aragonite and magnesite. Am. Mineral., 81, 611-624, https://doi.org/10.2138/am-1996-5-608.

Multi-technique characterization of natural and synthetic ferroan dolomites: From morphology to surface chemistry

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Keywords: ferroan dolomite, multi-analytical characterization, surface chemistry.

Dolomite $CaMg(CO_3)_2$ is one of the most abundant carbonates in Earth, remaining stable across a broad range of pressures and temperatures and playing a key role in the deep-mantle CO_2 cycle (Merlini et al., 2012). Despite its prevalence in the ancient sedimentary record, the debate on abiotic depositional mechanisms remains ongoing (Kim et al., 2023). This study presents a comprehensive characterization of iron-bearing dolomites to evaluate how iron incorporation alters the properties of the pure stoichiometric end-member, analyzing for the first time two distinct natural samples of ferroan dolomites through several techniques to provide a novel mineralogical dataset. A sample from Traversella mountains (Ivrea, Italy), representing a dolomitic marble protolith replaced by magmatic fluids (Vander Auwera & Verkaeren, 1993), and another from Valenciana mine (Guanajuato, Mexico), formed as late-stage epithermal cavity filling from hydrothermal fluids (Petruk & Owens, 1974), were investigated and compared with a synthetic analogue to understand the effect of Fe^{2+}/Mg^{2+} substitutions on the crystallographic cell parameters, vibrational and thermal properties. X-ray diffraction analysis (XRD) at ambient conditions revealed similar chemistry yielding formulas of $Ca_{0.98}Mn_{0.02}Mg_{0.81}Fe_{0.19}(CO_3)_2$ (Traversella) and $CaMg_{0.90}Fe_{0.10}(CO_3)_2$ (Guanajuato). Energy dispersive X-ray spectroscopy (EDS) and X-ray fluorescence (XRF) analyses showed higher heavy metal contamination (Mn, Pb, and Zn) in the Guanajuato specimen, corroborating the distinct geological complexities associated with the formation of these carbonates. Vibrational spectroscopy analyses (IR and Raman) revealed no significant deviation from the typical spectrum of the synthetic counterpart. Specifically, the carbonate symmetric stretching mode was identified at 1094 cm^{-1} via Raman spectroscopy while the asymmetric stretching at 1423 cm^{-1} via IR. Despite a slightly higher iron content in the Traversella structure, no significant differences were observed in thermal stability, with all samples exhibiting a characteristic endothermic decomposition peak around 730°C under an N_2 atmosphere. Surface chemical analysis with X-ray photoelectron spectroscopy (XPS) highlighted comparable surface compositions between the two natural specimens confirming the presence of iron (Fe 2p) on both surfaces. These observations provide a valuable dataset for understanding how and to what extent iron incorporation modifies the physico-chemical properties of dolomites compared to the pure end-member. This comparative study can be particularly insightful when examining samples with contrasting geological histories, offering a valuable mineralogical framework to support petrographic and tectonic analyses.

Kim J. et al. (2023) - Dissolution enables dolomite crystal growth near ambient conditions. Science, 382, 915-920, https://doi.org/10.1126/science.adi3690.

Merlini M. et al. (2012) - Structures of dolomite at ultrahigh pressure and their influence on the deep carbon cycle. Proc. Natl. Acad. Sci., 109, 13509-13514, https://doi.org/10.1073/pnas.1201336109.

Petruk W. & Owens D. (1974) - Some Mineralogical Characteristics of the Silver Deposits in the Guanajuato Mining District, Mexico. Econ. Geol., 69, 1078-1085, https://doi.org/10.2113/gsecongeo.69.7.1078.

Vander Auwera J. & Verkaeren J. (1993) - Occurrence of Contrasting skarn formations in dolomites of the Traversella deposit (Ivrea, Italy). Geol. Rundsch., 82, 726-740, https://doi.org/10.1007/BF00191499.

Experimental challenges in constraining sulfur behavior under HP-HT conditions: Current advances and future perspectives

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Keywords: sulfur, experiments, subduction zones.

Sulfur plays a fundamental role in deep Earth geochemical cycles. In subduction zone settings, the transfer of sulfur-bearing (SOH) fluids controls mantle redox conditions, metal transport, and ore-forming processes. Despite its importance, the behavior of such fluids under conditions typical of Earth's interior, i.e. high-pressure and high-temperature (HP-HT), remains poorly constrained. Current models for sulfur mobility and speciation largely rely on indirect petrological observations and thermodynamic modelling, whereas direct experimental constraints are still scarce (Secchiari et al., 2025). These limitations mainly arise from the intrinsic experimental difficulties associated with SOH fluids. In particular, the synthesis, preservation, and measurement of ultra-low fluid volumes in experimental capsules are complicated by the high reactivity of sulfur species, which may induce fluid-capsule interaction, chemical re-equilibration during quenching, volatile loss, and post-run modifications of fluid composition.

In this contribution, we present recent methodological and analytical advances aimed at constraining SOH fluid behavior under HP-HT conditions. A series of experiments was conducted using a piston-cylinder apparatus under geologically relevant sub-arc conditions (P = 3 GPa, T = 700°C), with controlled redox conditions and variable run durations. The resulting volatile species were analyzed using the unique capsule-piercing device coupled with a quadrupole mass spectrometer (QMS) available at the University of Milan. To further investigate material resistance, capsule integrity, and fluid-capsule interaction, our experimental approach was integrated for the first time with X-ray Micro-Computed Tomography (μCT), allowing non-destructive 3D characterization of capsules and run products before and after experiments.

Our results confirm that the bulk fluid composition can be preserved during synthesis, quenching, and fluid analysis, validating thermodynamic predictions. However, they also demonstrate that fluid preservation and capsule resistance remain the major limiting factors in SOH systems. Capsule weakening and volatile diffusion become increasingly critical with longer run durations and increasing sulfur activity. These observations highlight that the main challenge is no longer the production or detection of sulfur species themselves but rather preserving the synthetized fluid composition until analysis. Ongoing methodological developments, including alternative capsule materials and experimental set up, as well as improved extraction procedures, represent promising steps toward robust experimental constraints on sulfur transport and speciation in deep Earth fluids.

Secchiari A. et al. (2025) - Analytical protocol for measuring micro-molar quantities of sulfur volatile species in experimental high pressure and temperature fluids. Commun. Chem., 8, 19, https://doi.org/10.1038/s42004-024-01370-5.

Effect of Mg substitution in hydroxyapatite (OHAp) on crystallographic structure, elastic and vibrational properties

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Keywords: hydroxyapatite, Density Functional Theory, magnesium doping.

Hydroxyapatite (OHAp), $Ca_{10}(PO_4)_6(OH)_2$, constitutes the primary inorganic component of vertebrate hard tissues and serves as a fundamental mineral phase in geological environments. In biological systems, the incorporation of foreign ions such as Mg^{2+} significantly influences crystal growth, morphology, elastic behaviour, and biomineralization processes (Bigi et al., 1993). Due to its smaller ionic radius compared to calcium, magnesium substitution within specific crystallographic sites induces local distortions (Makshakova et al., 2022). However, the atomistic mechanisms underlying Mg incorporation and its effect on the elastic behaviour of the apatite lattice remain only partially understood, particularly in relation to crystallographic symmetry and directional mechanical properties. The present study investigates the structural, elastic and vibrational properties of Mg-substituted hydroxyapatite using Density Functional Theory (DFT) at the B3LYP level with the CRYSTAL23 code (Erba et al., 2023). To isolate site-specific effects, a 10% substitution level (one Mg atom per cell) was modeled within the crystallographic Ca positions, allowing the full elastic tensor to be determined without higher-symmetry constraints. The results show that Mg incorporation induces moderate structural distortions and a contraction of the lattice, associated with the smaller ionic radius of Mg^{2+} compared to Ca^{2+}, in agreement with previous findings. Vibrational (infrared and Raman) properties are only moderately affected, with small frequency shifts and broadening of the phosphate stretching modes in the Raman and infrared spectra due to symmetry breaking and activation of additional vibrational modes. However, the Mg^{2+}/Ca^{2+} substitutions have large impact on the mechanical properties of the mineral, highlighting a clear decoupling between volumetric and deviatoric responses. Specifically, the polycrystalline bulk modulus (K_0) remains largely unaffected with values for Mg-substituted models (~114-123 GPa) consistent with stoichiometric OHAp (121.2 GPa). Whereas the shear (μ) and Young's moduli increase substantially, from 44.9 GPa to 53.3-57.0 GPa and from 120.1 GPa to 147 GPa respectively. These results indicate an enhanced resistance to shape deformation, an effect accompanied by a marked reduction in elastic anisotropy despite the lowering of crystallographic symmetry. Ultimately, this work offers a clear atomistic framework for Mg-substitution in hydroxyapatite, demonstrating how symmetry dictates directional elastic properties. These insights are fundamental for interpreting and designing Mg-containing biological apatites with tailored mechanical and structural stability.

Bigi A. et al. (1993) - Magnesium influence on hydroxyapatite crystallization. J. Inorg. Biochem., 49, 69-78, https://doi.org/10.1016/0162-0134(93)80049-F.

Erba A. et al. (2023) - CRYSTAL23: A Program for Computational Solid State Physics and Chemistry. J. Chem. Theory Comput., 19, 6891-6932, https://doi.org/10.1021/acs.jctc.2c00958.

Makshakova O.N. et al. (2022) - The mutual incorporation of Mg^{2+} and CO_3^{2-} into hydroxyapatite: a DFT study. Materials, 15, 9046, https://doi.org/10.3390/ma15249046.

High pressure polymorphic transitions in ordered and disordered carbonates belonging to the Ca-Mg-Fe series

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Keywords: carbonates, cation disorder, extreme conditions.

The influence of chemical composition and cation disorder on the phase stability of Ca-Mg-Fe carbonates at high pressure has been extensively investigated because of its relevance to the deep carbon cycle (e.g., Merlini et al., 2016). Both parameters strongly affect carbonate stability. In particular, Mg incorporation progressively stabilizes ambient-pressure polymorphs to higher pressures: transitions to calcite-II, dolomite-II, and magnesite-II occur at about 1.5 GPa, 14-18 GPa, and 80 GPa, respectively. Similar trends were observed for higher-pressure transitions. When Fe enters the structure, however, the effect of Mg-Fe substitution on ankerite stability remains poorly constrained, and literature data often provide conflicting interpretations.

A second key factor controlling carbonate behavior under non-ambient conditions is cation disorder. Naturally occurring *R*-3 carbonates display ordered cation alternation between structural layers. At high temperature, cations progressively redistribute among available sites, producing disordered structures (Reeder & Wenk, 1983). The order-disorder transition temperature, marking the change from *R*-3 (dolomite-like) to *R*-3*c* (calcite-like), depends strongly on composition. For example, i.e., transition occurs at ~1200°C in dolomite and decreases with increasing Fe content (Zucchini et al., 2025a). Preliminary studies up to 25 GPa showed that ordered dolomite and ankerite undergo a phase-I to phase-II transition, whereas disordered samples do not (Zucchini et al., 2025b).

We therefore investigated a wide compositional range within the Ca-Mg-Fe system and extend the explored pressure range beyond the commonly studied 0-25 GPa interval.

Here we report results from synchrotron single-crystal X-ray diffraction experiments performed at high pressure on Ca-Mg-Fe carbonates ranging from calcite ($CaCO_3$) to dolomite [$CaMg(CO_3)_2$] and ankerite [$Ca(Mg_{1-x}Fe_x)(CO_3)_2$, 0 Results show for the first time that disordered carbonates can also undergo phase transitions, although at higher pressures than ordered equivalents. In particular, disordered ankerite with 0.3 Fe a.p.f.u. transforms into a new triclinic polymorph, whereas no transition was observed up to ~50 GPa for disordered ankerite with 0.7 Fe a.p.f.u.

Previous studies demonstrated that both order-disorder and high-pressure transitions strongly affect ankerite compressibility (Zucchini et al., 2025b): ordered ankerite and ankerite-II are the most and least compressible structures, respectively, while disordered ankerite shows intermediate behavior. Ongoing studies on elasticity under non-ambient conditions will also clarify the role of anisotropy in both (dis)ordered ankerite and ankerite-II, potentially explaining seismic-wave anomalies in the mantle wedge.

Overall, both literature data and new results indicate that Fe stabilizes low-pressure carbonate structures even in disordered systems, with important implications for the compressibility and elasticity of mantle carbonates.

Merlini M. et al. (2016) - High-temperature and high-pressure behavior of carbonates in the ternary diagram $CaCO_3$-$MgCO_3$-$FeCO_3$. Am. Mineral., 101, 1423-1430, http://dx.doi.org/10.2138/am-2016-5458.

Reeder R.J. & Wenk H.R. (1983) - Structure refinements of some thermally disordered dolomites. Am. Mineral., 68, 769-777.

Zucchini A. et al. (2025a) - Cation disordering in ankerite as a function of Fe content. Eur. J. Mineral., 37, 577-589, https://doi.org/10.5194/ejm-37-577-2025.

Zucchini A. et al. (2025b) - Influence of cation disorder on the mineral physics of ankerite. Am. Mineral., 110, 908-918, https://doi.org/10.2138/am-2024-9495.

S6.

Integrating multidisciplinary observations to track mantle dynamics from ocean domains to arc systems

CONVENERS & CHAIRPERSON

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Marine terraces and Quaternary surface uplift of the Central-Southern Andes: New constraints from a 100 km coastal stretch around 30°S

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Keywords: marine terraces, flat-slab subduction, coastal uplift and deformation.

The Pampean flat-slab segment of the Andes in Central-Southern Chile is characterized by a strong interplate coupling between the subducting Nazca and the overriding South America plates. The subduction of the Nazca Plate beneath the South American plate makes this segment of the Chilean coast seismically active, with recent major events of M > 8 occurred in years 1906, 1943, 1985 and 2015.

To investigate the relationships among subduction and tectonic processes affecting the overriding plate we are carrying out a tectonic geomorphology analysis of the Andean segment around 30°S. The study is based on the analysis and dating of marine terraces, which provide crucial constraints to the timing and rates of coastal uplift.

The coastal stretch we are studying, c. 100 km in length, consists of a succession of rocky headlands bearing flights of shore platforms, and bays underlain by Neogene marine to alluvial sediments that feature arrangements of terraces marked by shell-rich shore deposits. The lower marine terraces are easily identified while the higher terraces appear as rather uniform, slightly seaward-dipping surfaces incised by the drainage net. As a result, the identification of the marine terraces is quite complicated debate exists on the inferred rates of uplift and on whether the terraces are tectonically deformed or not.

To investigate the marine terrace arrangement we carried out a detailed geomorphological analysis based on the construction of a dense net of topographic profiles both across and along the terraced surfaces, constrained by GPS measures and field analyses aimed at reconstructing the morpho-stratigrapic setting of the depositional marine terraces at selected sites, sampling for amino-acid racemization measurements and OSL.

The topography analysis has allowed the identification of a distinct flight of marine terraces both in the headlands and the bays. The terraces range in elevation from c. 10 m to 150-200 m. The AAR measurements on different taxa are overall consistent with the morpho-stratigraphic framework reconstructed to date and support field evidence of cross-cutting of older depositional terraces by younger shore platforms.

Along the entire coastal stretch, marine terraces of comparable sizes occur at similar elevation, suggesting an overall homogeneous behaviour of the study region. Within such a framework, there is evidence of deformation of the marine terraces that, in some areas, appear both displaced by faults and tilted, with vertical offsets decreasing with relative terrace ages. Overall our results indicate that, despite the significant distance that separates the coastal sector from the trench, due to the strong coupling between the subducting and overriding plates, the upper plate morphology of the Central-Southern Andes displays evidence of the ongoing subduction not only in terms of uplift but also in terms of differential vertical motions.

Melt/rock ratio as the primary controlling factor on the geochemistry of mantle-impregnating melts in the Oman Ophiolite

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Keywords: lithospheric mantle, MORB melt impregnation, melt-rock interaction.

The lithospheric mantle exposed in the Oman ophiolite preserves a complex record of melt migration and intrusion, involving melts with different geochemical signatures. Nevertheless, only few studies have centered on the evolution of the lithospheric mantle and detailed petro-chemical works are still very limited (e.g. Battifora et al., 2026). This study focuses on plagioclase-bearing impregnation structures recorded in the Oman harzburgites and dunites, aiming to document the shallow melt percolation event involved in the evolution of this lithospheric mantle sector, and the control, at the microscale, of the melt/rock ratio on the geochemical signature of the impregnating melts. Studied impregnation structures consist of various modal proportions of interstitial plagioclase (Plag), clinopyroxene (Cpx), and orthopyroxene (Opx) in a dunitic or harzburgitic host rock, forming impregnated dunites and harzburgites, respectively. The high TiO_2 contents of spinel (0.06-0.74 wt.%) in impregnated lithotypes, as well as the texture of interstitial minerals, indicate interaction of dunites and harzburgites with percolating melts crystallizing plagioclase and pyroxenes. The Na_2O (0.01-0.43 wt.%) contents of interstitial Cpx and An (An = Ca/Ca+Na = 85-98 mol%) values in coexisting Plag are inversely correlated and highlight a general depleted geochemical signature of all impregnating melts. Trace element compositions of computed melts in equilibrium with Cpx from impregnated lithotypes show variable Light (L-) Rare Earth Elements (REE) depletion. Namely, some computed melts show L- to Heavy (H-) REE ratios (La_N/Yb_N = 0.22-0.78; C1-normalized) similar to the Oman V1 (Geotimes) lavas and the Oman lower crustal gabbros, whereas other computed melts exhibit very low L-/H-REE ratios (La_N/Yb_N = 0.05-0.15; C1-normalized), evidencing a significant depletion in highly incompatible trace elements (La_N = 0.26-2.55; C1-normalized). Geochemical modelling indicates that impregnating melts, characterized by different geochemical signatures, are genetically correlated. The observed geochemical heterogeneity reflects the variation of the melt/rock ratio during interaction between MORB-type melts and the host residual mantle, rather than the occurrence of unaggregated melts characterized by primary depletion in incompatible trace elements. This in turn demonstrates how the melt/rock ratio plays a primary control in modifying the geochemical signature of melts percolating throughout the lithospheric mantle, originating strongly depleted signature. Understanding such processes is key to assessing the role of mantle-impregnating melts in the geochemical budget of the overlying Oman Moho Transition Zone and oceanic crust, thus adding an important piece to the complex accretional history of the Oman oceanic lithosphere.

Battifora C. et al. (2026) - Deciphering Melt Percolation through Mantle Microstructures: Evidence from Oman Harzburgites. J. Petrol., 67(5), egag037, https://doi.org/10.1093/petrology/egag037.

Water in the deep (and not so deep) Earth

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Keywords: hydrogen speciation, mantle water storage, mantle xenoliths.

Hydrogen, incorporated as hydroxyl, has long been recognized to be an ubiquituous trace component of most mantle minerals (Bell & Rossman, 1992). Xenoliths from the cratonic keels host up to 200-250 hundreds of parts per million by weight of water (ppm wt. H_2O). While in the convecting mantle, the water content measured in Mid Ocean Ridge Basalts (MORBs) also points out to a few hundreds of ppm wt. H_2O in their source at about 100 km depth. Deeper, the low seismic velocities atop the transition zone are unanimously interpreted as due to melting, especially dehydration melting, due to the high water content in the material ascending from the transition zone (estimates range from 0.2 to 1 wt.% H_2O see Andrault & Bolfan-Casanova, 2022). For the rest of the deeper part of the Earth, the lower mantle, the latest constraints on the actual water content point out to 0.06 wt.% H_2O in a pyrolitic-shallow lower mantle, that is ~1.26 (0.2) ocean masses.

Because the Earth's mantle gets more and more reducing with increasing pressure (Frost & McCammon, 2008), the speciation of H is expected to change as a function of depth, going from H_2O and OH- under oxidizing conditions to H_2 under reducing conditions. And indeed, recently, we have discovered H_2 in natural omphacite from eclogite xenoliths brought up by kimberlites (Moine et al., 2020), in agreement with previous experimental observations. Due to the difficulty in detecting H_2, with spectroscopy, it is possible that the H storage of the mantle has therefore been largely under-estimated in previous studies of mantle xenoliths. I will discuss this too.

Andrault D. & Bolfan-Casanova N. (2022) - Mantle rain toward the Earth's surface: A model for the internal cycle of water. Phys. Earth Planet. Int., 322, 106815, https://doi.org/10.1016/j.pepi.2021.106815.

Bell D.R. & Rossman G.R. (1992) - Water in Earth's Mantle: The Role of Nominally Anhydrous Minerals. Science, 255, 1391-1397, https://doi.org/10.1126/science.255.5050.1391.

Frost D.J. & McCammon C.A. (2008) - The Redox State of Earth's Mantle. Annu. Rev. Earth Pl. Sc., 36, 389-420, https://doi.org/10.1146/annurev.earth.36.031207.124322.

Moine B. et al. (2020) - Molecular hydrogen in minerals as a clue to interpret ∂D variations in the mantle. Nat. Commun., 11, 3604, https://doi.org/10.1038/s41467-020-17442-8.

Cryptic incompatible trace element enrichment in orthopyroxene from abyssal harzburgites: Evidence for transient MORB melt-rock interaction

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Keywords: melt-mantle reaction, trace elements, abyssal peridotite.

Abyssal peridotites are residues of partial melting of the oceanic mantle beneath mid-ocean ridges. However, following melt depletion, these rocks may also undergo variable degrees of mineralogical and/or chemical refertilization through interaction with migrating melts, commonly crystallizing clinopyroxene and plagioclase. Depleted harzburgites, thereby, are regarded as refractory mantle residues. However, whether harzburgites can also record processes beyond simple melt extraction is still debated. Here, we solve this issue integrating new experimental constraints with petrological observations on depleted harzburgites from the Charlie-Gibbs Transform Zone (Reykjanes Ridge, SW of Iceland), where these harzburgites are associated to refertilized lherzolites (Sanfilippo et al., 2024). Orthopyroxenes from Charlie-Gibbs harzburgites display refractory major element compositions (X_{Mg} = 0.91-0.92, Al = 0.095-0.158 a.p.f.u., Ti Cr (0.30-0.43), consistent with moderately high degrees of melt extraction (F = 12-16%). Despite their refractory major element compositions, orthopyroxenes display preferential enrichments in highly incompatible trace elements, as for instance the increase of LREEs from core to rim of large porphyroclasts (Ce_N/Sm_N = 0.39-0.50 in cores; 0.65-1.35 in rims). These orthopyroxenes represent the most LREE-enriched compositions so far reported in abyssal harzburgites and are associated with relatively flat trace element patterns in the rare clinopyroxenes (Ce_N/Sm_N = 0.84-1.10). Experimental results of basalt-harzburgite reaction at 1.5 GPa and 1300°C indicate that this decoupling between major and trace element compositions in orthopyroxene can result from open-system reactive melt percolation. Geochemical modelling, combining experimentally-derived orthopyroxene/melt partition coefficients and textural constraints, suggests that the cryptic incompatible element enrichment observed in Charlie-Gibbs orthopyroxenes is best explained by reactive percolation of transient MORB-like melts through a previously depleted mantle harzburgite.

Sanfilippo A. et al. (2024) - Upwelling of melt-depleted mantle under Iceland. Nat. Geosci., 17(10), 1046-1052, https://doi.org/10.1038/s41561-024-01532-z.

In-situ B isotopes in ophicarbonates: Unravelling hydrothermal systems and their implications for subduction processes

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Keywords: ophicarbonates, B isotope, hydrothermal system.

In submarine-hydrothermal systems, fluid-rock interactions play a pivotal role in fostering life on rocky planets. Carbonated-ultramafic rocks (i.e., ophicarbonates) represent an important witness of such environments, and their study may provide new insights into hydrothermal processes. This contribution reports *in-situ* trace element concentrations and the first in-situ boron isotope analyses ($\delta^{11}B$) of serpentines from the Ligurian N. Apennine (Italy) ophicarbonates, which represent non-subducted remnants of Jurassic ultramafic-hosted hydrothermal system (Cannaò et al., 2024). The increasing inventory of several fluid-mobile elements (e.g., B, Li, As, Sb, Sr, U) associated with the REE budget variability in serpentines from ophicarbonates compared to those in pure serpentinites suggest that chemical changes during the evolution of the hydrothermal system exert a relevant influence on the geochemistry of serpentines. Pure serpentinites, which are considered the protoliths of the ophicarbonates, show positive $\delta^{11}B$ signatures from +15.8 to +35.0‰, falling in the range of present-day oceanic serpentinites and ophiolite-derived serpentinites. The $\delta^{11}B$ imprint of serpentines in ophicarbonates clusters at +10.2 ±2.2‰ (2SD) and -5.7 ±1.5‰ (2SD). Remarkably, this is the first report of oceanic serpentines showing negative B isotope compositions. The positive $\delta^{11}B$ data likely reflect inheritance from the precursor serpentinite, while the negative $\delta^{11}B$ values are here related to the hydrothermal process(es). Modeling results show how the variations in pH and the different $\delta^{11}B$ composition of hydrothermal vent fluids at different T can affect the $\delta^{11}B$ imprint of serpentines. This novel approach provides valuable new insights into the variations and controls on the physicochemical conditions of fluid-rock interaction during the progressive evolution of a long-lived fossil ultramafic-hosted hydrothermal system. The use of in-situ techniques is particularly well suited for the analysis of oceanic samples, as it enables high-resolution, spatially precise chemical and isotopic analyses while maximizing the information obtained from the small rock aliquots typically recovered during oceanic expeditions. The B isotope variability reported by the N. Apennines ophicarbonates is also shared by their high-pressure counterparts (Cannaò, 2025), suggesting that the imprint acquired under oceanic conditions can be transferred to depth, thereby influencing the deep Earth's geochemical refertilization.

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Cannaò E. et al. (2024) - Fossil hydrothermal oceanic systems through in-situ B isotopes in ophicarbonates (N. Apennines, Italy). Chem. Geol., 645, 121899, https://doi.org/10.1016/j.chemgeo.2023.121899.

Cannaò E. (2025) - Subducted ophicarbonates as source for B-bearing diamond formation. Chem. Geol., 680, 122693, https://doi.org/10.1016/j.chemgeo.2025.122693.

Two decades of integrated geophysical exploration at Brothers volcano: Advancing global understanding of submarine arc magmatic-hydrothermal systems

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Keywords: submarine arc volcanism, integrated geophysics, hydrothermal systems.

Brothers volcano of the southern Kermadec arc, offshore New Zealand, is globally one of the best-studied submarine arc volcanoes and a case study site for exploring coupling between magmatism, hydrothermal circulation, and seafloor mineralization (de Ronde et al., 2011). Over the last two decades, integrated geophysical exploration has provided a three-dimensional view of Brothers volcano, revealing how volcanic architecture, permeability, heat transfer and alteration interact across different spatial and temporal scales. Here we present results from 20 years of shipborne, near-seafloor and drilling-based investigations, including magnetic anomalies, heat flow, seismic imaging, high-resolution bathymetry, paleomagnetism and IODP drilling (Caratori Tontini et al., 2019; de Ronde et al., 2019). These results show that the present hydrothermal system is strongly influenced by a ~3-3.5 km-wide caldera, with focused permeability along its ~290-530 m-high walls, and by resurgent volcanism associated with hydrothermal activity at two post-collapse volcanic cones. In particular:

- Bathymetry and backscatter maps define structures and faults as well as vent-field morphology;
- Seismic data image internal structures and subseafloor pathways;
- Heat-flow observations and magnetic anomalies indicate deep fluid circulation at ~1-2 km depth overprinted by shallow convection cells of ~100-200 m depth;
- Magnetic and paleomagnetic data show hydrothermal demagnetization, alteration, remanence acquisition and geologically recent (~3-4 ka) volcanic activity.

IODP Expedition 376 drilled five sites, U1527-U1531, reaching up to 453 mbsf and sampling a >300 m-thick demagnetized interval that links geophysical anomalies to lithology, alteration, physical properties and mineralization processes (de Ronde et al., 2019; Caratori Tontini et al., 2023). The coexistence of distinct hydrothermal domains at Brothers volcano provides a rare opportunity to link fluid pathways, heat transfer, alteration and mineralization to the geodynamic and magmatic evolution of a submarine arc volcano. This variability demonstrates that submarine arc hydrothermal systems are dynamic and spatially heterogeneous, governed by interactions between magma supply, volcano-tectonic evolution, and structurally controlled permeability. The integrated geophysical record of Brothers volcano is globally relevant, offering a basis for comparison with other submarine arc volcanoes, ancient volcanic-hosted massive sulfide deposits and subaerial epithermal environments. In summary, Brothers volcano shows how multidisciplinary geophysical exploration can constrain the coupling among volcanic structure, permeability evolution, hydrothermal circulation, alteration and mineralization in submarine arc settings.

Caratori Tontini F. et al. (2019) - Heat flow and near-seafloor magnetic anomalies highlight hydrothermal circulation at Brothers Volcano caldera, southern Kermadec Arc, New Zealand. Geophys. Res. Lett., 46(14), 8252-8260, https://doi.org/10.1029/2019GL083517.1.

Caratori Tontini F. et al. (2023) - Effects of hydrothermal alteration and mineralization on the paleomagnetic properties of rocks from IODP Expedition 376 at Brothers Volcano. Econ. Geol., 118(7), 1605-1627, https://doi.org/10.5382/econgeo.5008.

de Ronde C.E.J et al. (2011) - Submarine hydrothermal activity and gold-rich mineralization at Brothers Volcano, Kermadec Arc, New Zealand. Miner. Deposita, 46, 541-584, https://doi.org/10.1007/s00126-011-0345-8.

de Ronde C.E.J. et al. (2019) - Critical role of caldera collapse in the formation of seafloor mineralization: The case of Brothers volcano. Geology, 47(8), 762-766, https://doi.org/10.1130/G46047.

Early-stage evolution of supra-subduction zone ophiolite in Khalsi-Chilling area, Indus Suture Zone, Ladakh Himalaya: Insights from Cr-spinel mineral chemistry

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Keywords: Cr-spinel, ophiolite, supra-subduction zone.

The peridotites associated with the Indus Suture Zone, Ladakh Himalaya in and around the Khalsi-Chilling area are mostly serpentinized. The serpentinite masses after peridotites include disseminated accessory chromian-spinel (Cr-spinel). Mineral chemistry of the Cr-spinel of the Khalsi-Chilling has been presented in the current study to understand the petrogenesis of the peridotites and the geotectonic evolution of the ophiolitic belt during the early stage of subduction in the Neo-Tethyan ocean. Spinel has a pristine chemical composition at the core.

The relic olivines with high forsterite (Fo_{90-92}) and low MnO (≤ 0.20) composition are similar to mantle olivines. The mineral chemistry of the Cr-spinel core reveals that spinel is genetically classified into two groups that is, 1) Al-rich spinel-bearing serpentinites (Cr# 0.15-0.37), which are similar to abyssal peridotites (MORB-tholeiite affinity) and 2) Al-poor spinel-bearing serpentinites (Cr# 0.43-0.55), which are attributed to overlapped fields of forearc and abyssal peridotites. The Al-rich spinel serpentinized peridotites were formed by 7-17% partial melting of the fertile mantle during the early stage of proto-arc spreading, accompanied by subduction initiation in the Neo-Tethyan realm. The low equilibrium temperature (703-774°C) of the Al-rich spinel hosted within serpentinized peridotites, compared to those within the abyssal peridotites, indicates the involvement of water supplied from the subducted slab. The estimated moderate-to-high degree of partial melting (20-30%) of the protoliths hosting Al-poor spinel reflects the abundance of water derived from the subducted slab during progressive subduction.

CO_2-CO fluids and redox disequilibrium in metasomatised oceanic mantle peridotites from Sal, Cape Verde

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Keywords: carbon supersaturation, mantle metasomatism and redox, oceanic lithosphere deep carbon cycle.

The redox evolution of the deep oceanic lithospheric mantle remains largely unconstrained because mantle xenoliths rarely preserve evidence from depths exceeding 60-70 km. We investigated the speciation and redox behaviour of carbon-bearing fluids in spinel peridotite xenoliths from Sal Island (Cape Verde), equilibrated at 2.2-3.5 GPa (up to 106 km of depth) and metasomatic temperatures of 1140-1200°C. Raman spectroscopy of 152 fluid-rich melt inclusions identifies CO_2-CO-(N_2) fluids with XCO up to 0.22 in metasomatised ultrarefractory harzburgites.

The CO_2-CO fluids are carbon-supersaturated, with aC up to ~3.5 and metastable within the graphite stability field, yet graphite is absent both in most fluid inclusions and host peridotites. Fluid and mineral oxybarometry reveal strong redox heterogeneity during metasomatism. Rock fO_2 ranges from ΔFMQ -3.7 in the least metasomatised harzburgites to ΔFMQ +0.5 in oxidised metasomatic domains, whereas coexisting CO-rich fluids reach ΔFMQ -3.4. These variations define a redox gradient extending across nearly four log units within the deep lithosphere and demonstrate that carbon saturation and fluid-rock redox equilibrium were not attained simultaneously during metasomatic reactions.

Thermodynamic analysis of the anhydrous C-O system indicates that, below the CCO buffer, carbon saturation and fluid-rock redox equilibrium are mutually exclusive conditions. Open-system modelling further shows that suppression of graphite precipitation is required to reproduce the observed coexistence of metastable CO_2-CO fluids and highly oxidised metasomatic assemblages beyond the CCO and EMOG/EDDOG buffers. In contrast, the more fertile lherzolites, characterised by higher redox capacity and fO_2 near the CCO buffer, preserve CO_2-dominated fluids that did not enter the carbon-supersaturation regime.

These observations indicate that the deep oceanic lithosphere beneath Cape Verde evolved through incomplete carbonate-rich metasomatic reactions operating under strong local redox disequilibrium. Under these conditions, carbon remained mobile as metastable CO_2-CO fluids rather than being efficiently sequestered as graphite. Thus, Sal mantle xenoliths suggest that carbon transfer through the deep oceanic lithosphere may be governed by reaction kinetics and transient redox heterogeneities rather than equilibrium buffering alone.

Metasomatic carbon enrichment in oceanic mantle peridotites from Sal (Cape Verde)

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Keywords: ocean island mantle, silicate-carbonate metasomatic melt, carbon cycle.

The deep oceanic lithospheric mantle remains poorly characterised because mantle xenoliths rarely sample depths greater than 60-70 km. We investigated the petrology and metasomatic evolution of spinel peridotite xenoliths from Sal Island (Cape Verde), which record equilibration at 2.2-3.5 GPa and provide direct constraints on the evolution of the deep oceanic lithosphere beneath an ocean island setting. The xenolith suite comprises ultra-refractory spinel harzburgites recording 20-40% partial melting and fertile spinel lherzolites, documenting a strongly heterogeneous lithospheric mantle section extending to >100 km depth.

Metasomatism is preserved by reaction coronae surrounding relict orthopyroxene and consisting of clinopyroxene, olivine, spinel, interstitial phonolitic-trachytic glass, carbonate phases, and CO_2-rich fluids. Silicate-carbonate microveins and fluid-rich melt inclusions further record infiltration of alkali-rich silicate-carbonate melts enriched in Cl, S, F, N, and P. Geothermobarometry indicates that primary harzburgites equilibrated within the spinel-garnet transition and aragonite stability fields (which is found inside inclusions) around 950-1060°C, whereas metasomatic assemblages formed at 1140-1200°C throughout the lithospheric section.

Glass compositions and metasomatic assemblages indicate interaction between depleted peridotites and silicate-carbonate melts compositionally comparable to experimental melts derived from carbonated sediments with a subordinate eclogitic component. Clinopyroxene trace-element systematics and textural relationships record multiple stages of metasomatic refertilisation affecting the deep lithosphere. Metasomatic reactions remained incomplete in the most depleted harzburgites, preserving strong mineral-scale heterogeneities and reaction textures associated with orthopyroxene dissolution and wehrlitisation.

These observations indicate that the deep oceanic lithospheric mantle beneath Cape Verde evolved through infiltration of carbonate-bearing melts capable of transferring recycled crustal components into depleted mantle domains. The Sal xenoliths, therefore, provide direct evidence that the deep oceanic lithosphere is a chemically reactive reservoir undergoing progressive metasomatic modification, rather than a compositionally static mantle section.

Volatile variability and ancient dehydration of recycled lithologies revealed by B-H systematics in MORB components

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Keywords: boron, mantle heterogeneity, MORB.

The compositional variability of mid-ocean ridge basalts (MORB) is commonly interpreted as reflecting melting of a relatively homogeneous depleted mantle source. However, under specific thermal and tectonic conditions, mantle heterogeneity and the volatile history of recycled lithologies can be preserved and expressed in erupted melts. The Eastern Romanche Ridge Transform Intersection (ERRTI), along the Equatorial Mid-Atlantic Ridge, represents a natural laboratory where reduced magmatic supply and limited melt homogenisation allow selective sampling of distinct mantle components (Brunelli et al., 2025).

Here we present new boron concentrations and isotopic compositions ($\delta^{11}B$), integrated with H_2O and $\delta^{18}O$ data, in basaltic glasses from the ERRTI to investigate volatile variability and the imprint of ancient dehydration processes. Boron concentrations (0.39-3.47 ppm) and $\delta^{11}B$ values (-8.52 to -1.28‰) span the global MORB range, yet systematic variations in B/Ce ratios correlate with radiogenic isotope systematics, indicating that the observed variability reflects mantle source heterogeneity. In particular, HIMU-like K-MORB compositions display low B/Ce and H_2O/Ce ratios, consistent with volatile-depleted recycled lithologies that experienced preferential loss of fluid-mobile elements during subduction. Some minor components reach boron enrichments comparable to hotspot-related endmembers, while remaining compositionally distinct from them (Michailow et al., in press).

The coupled behaviour of boron and water highlights that volatile depletion is an intrinsic property of specific mantle lithologies and reflects ancient dehydration processes rather than shallow alteration. Oxygen isotope compositions ($\delta^{18}O \approx 5.5$‰) confirm the freshness of the analysed glasses (Michailow et al., in press).

These results demonstrate that MORB variability records both the heterogeneous distribution of mantle lithologies and their volatile history. At the ERRTI, limited melt production allows these components to be expressed as distinct melts, providing new constraints on volatile recycling and on the long-term evolution of recycled lithologies in the convecting mantle.

Brunelli D. et al. (2025) - Large melt diversity at a mid-ocean ridge thermal low. Sci. Adv., 11, eadv4654, https://doi.org/10.1126/sciadv.adv4654.

Michailow M.M. et al. (in press) - Deconvolving the depleted mantle: boron systematics from MORB glasses at a ridge-transform intersection. Earth Planet. Sc. Lett.

Diffusion melting, intraplate petit-volcanism, and the asthenosphere low-velocity zone

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Keywords: asthenosphere melting, LVZ, intraplate volcanism.

It has long been supposed that Earth's asthenosphere contains small amounts of seismically visible melt; how and why this melt persists has remained a similarly long-supposed mystery. Here we show how this observation is a simple consequence of the preferential diffusion of hydrogen ('water') from a harder-to-melt peridotite lithology forming ~80% of the mantle into an easier-to-melt pyroxenite lithology that exists as ~m-10 km blobs within the peridotitic matrix. In particular, once decompression melting starts in easier-to-melt blobs, water and latent heat consumption in these melting heterogeneities will induce inward migration of both heat and water from surrounding peridotites. This diffusive transport of water and heat will induce further 'diffusion melting', creating extensive slowly melting heterogeneities within the asthenosphere that explain both the pervasive existence of the asthenospheric low-velocity zone and the persistent existence of low-degree melting beneath intraplate oceanic lithosphere.

Pyroxenites, due to their higher Al content, will have higher trace water contents when in diffusive equilibrium with neighboring peridotite. Their higher water contents, in turn, tend to lower their solidi, and favor their partial melting over nearby peridotites sharing similar p-T conditions. In addition, the latent heat consumed during early pyroxenite melting will locally cool this mantle, thus favoring the inward diffusion of both heat (~10^{-6} m^2/s) and hydrogen from surrounding peridotites.

Here we explore 1-D and 2-D numerical models of flow and melting in upwelling mantle that include the possibility of both heat and hydrogen diffusion between nearby peridotite and pyroxenite lithologies, assuming experimentally measured hydrogen diffusivities of ~10^{-7} - 10^{-8} m^2/s. As H^2 (D) diffuses more slowly than H^1(H), observable diffusive fractionation of D/H is also predicted to occur.

Laterally moving regions of asthenosphere containing long-lived partially melting pyroxenitic blebs and blobs are predicted to continue to partially melt for ~10 s of Ma due to inward water diffusion even as small-degree melts form and escape from this partially molten bilithologic asthenosphere. This provides a simple geodynamic mechanism for why Earth's suboceanic asthenosphere appears to persistently contain small amounts of partial melt at depths shallower than ~150 km, with this mechanism also leading to the formation and escape of small degree melts far from plumes, ridges, or subduction zones. We present and discuss numerical experiments that illustrate these effects.

Drilling the petit-spot basalts off the Japan Trench subduction zone through IODP³ Expedition 502

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Keywords: petit-spot basalts, lithosphere-asthenosphere boundary, subduction-zone seismicity.

Petit-spot magmas (SiO_2 = 39-53 wt.%, Mg# = 39-72) off the Japan Trench are highly alkaline (K_2O = 1-6 wt.%), CO_2-rich (5-10 wt.%) melts formed at the lithosphere-asthenosphere boundary. These melts are squeezed upward through fracture zones formed during the flexural banding of the downgoing oceanic Pacific Plate prior to subduction (Hirano & Machida, 2022). This process resulted in the intrusion of igneous bodies and the formation of small-volume volcanoes on the subducting plate. Such intrusions and small-scale volcanoes altered the physical and chemical properties of the sediment layer and, eventually, played a critical role in the 2011 Mw 9 Tohoku earthquake off the coast of Japan (e.g., Akizawa et al., 2022).

The International Ocean Drilling Programme (IODP³) Expedition 502 (Exp. 502) was designed to investigate the impact of petit-spot submarine magmatism on subduction-zone seismicity and the global geochemical cycle (Yamaguchi et al., 2026). The IODP³ Exp. 502 took place from October 30 to November 24, 2025, on the drilling vessel *Chikyu.* The expedition successfully drilled at an almost complete, continuous section of pelagic sediments and fresh petit-spot basalts in the NW Pacific off the Japan Trench. Specifically, the drilled section consists of siliceous mud with intercalated ash layers from 0 to ~62 mbsf, followed by ~45 m of glassy to cryptocrystalline basalts containing olivine and very minor clinopyroxene phenocrysts. Some of these lavas host rare mantle xenoliths and olivine xenocrysts.

Collectively, the IODP³ Exp. 502 was an unparalleled success, as it overcame various scientific challenges due to the petit-spot deep-marine setting (>5500 meters below sea level), which limited direct observations and analyses to a small number of samples collected via dredging and submersible dives (Akizawa et al., 2022). Furthermore, because petit-spot submarine basaltic volcanism has been further recognized off the Java, Tonga, Chile, and Mariana trenches (Hirano & Machida, 2022; Yamaguchi et al., 2026), the results obtained through the IODP³ Exp. 502 will provide an unprecedented opportunity to improve our understanding of the impact of petit-spot submarine volcanisms, both throughout the Pacific Plate and at a global scale.

Akizawa N. et al. (2022) - A direct evidence for disturbance of whole sediment layer in the subducting Pacific plate by petit-spot magma-water/sediment interaction. Mar. Geol., 444, 106712, https://doi.org/10.1016/j.margeo.2021.106712.

Hirano N. & Machida S. (2022) - The mantle structure below petit-spot volcanoes. Commun. Earth Environ., 3, 110, https://doi.org/10.1038/s43247-022-00438-1.

Yamaguchi A. et al. (2026) - IODP³ Expedition 502 "Impact of Petit-Spot Magmatism on Subduction Zone Seismicity and Global Geochemical Cycles" Scientific Prospectus. Proceedings of the International Ocean Drilling Programme, 502, 1-11, https://doi.org/10.5194/piodp-502-1-2026.

Combined Fe isotope compositions and Fe^{3+}/Fe_{tot} of magnesiochromite inclusions in diamonds: New insights into the redox state of the lithospheric mantle

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Keywords: diamonds, magnesiochromite, Fe isotopes.

In this study, we investigated a series of magnesiochromite inclusions - $(Mg,Fe^{2+})(Cr,Al,Fe^{3+})_2O_4$ - hosted in lithospheric diamonds from Russia, Botswana and Canada, representative of three distinct cratonic regions. The magnesiochromite inclusions range between from 50 to 500 µm accross and contain high FeO_t, up to 15 wt.%. Given these features, sufficient amounts of Fe were extracted from the inclusions through ion chromatography, and their precise Fe isotopic composition were determined by multi-collector inductively coupled plasma mass spectrometry. In addition, the Fe^{3+}/Fe_{tot} of the inclusions were determined using advanced MössBauer spectroscopy analyses.

The new data are used to investigate the oxygen fugacity (fO_2) of the lithospheric mantle. Although extensive studies on mantle xenoliths have provided important insights into the mantle redox state, data from mineral inclusions in diamonds remain scarce. Such data, however, are particularly valuable as they are representative of the pristine mantle environment where they formed since they are shielded from secondary events, such as metasomatism, by the strong and chemically inert diamond. In particular, the combination of two different geochemical proxies (Fe isotopes and Fe^{3+}/Fe_{tot}) adopted in this study allows to distinguish the effects of mantle redox state, melting and source heterogeneity on fO_2 proxies, thereby providing new insights into the redox state of the lithospheric mantle.

Fluid-assisted deformation and strain partitioning in an exhumed subduction complex: Insights from the Ligurian Units (Southern Tuscany)

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Keywords: structural architecture, fluid-assisted deformation, accretionary wedge.

Accretionary wedges accommodate a large part of plate-margin shortening and record subduction-related tectonic processes. Their internal architecture is highly heterogeneous, composed of lithologies stacked in thrust sheets and shear zones. Deformation occurs under variable pressure-temperature conditions, producing both brittle and ductile structures. Accretionary wedges are also key loci of seismic activity, which is controlled by rheological contrasts and fluid migration. Fluids released by compaction, mineral dehydration, and metamorphic reactions may strongly influence fault mechanics and earthquake nucleation, promoting transitions between aseismic creep to seismic ruptures. Understanding fluid migration is therefore crucial to unravel the mechanical behavior of accretionary wedges.

This study presents preliminary structural data from the Fortulla Member (Santa Fiora Formation, Ligurian Units, southern Tuscany), classically interpreted as an exhumed sector of an ancient accretionary wedge, aimed at characterizing deformation structures and assessing their role in controlling fluid migration. The investigated outcrop consists of three main lithostratigraphic domains: a northern marly domain, a central clay-rich unit with carbonate lithons, and a southern sector consisting of siliciclastic and marly layers.

The deformation observed along the outcrop is interpreted as the result of a continuous shortening process expressed by both ductile and brittle processes. The ductile deformation, here defined as background deformation, is characterized by first- and second-phase folds associated with two foliations (S_1 and S_2) and by a first generation of fibrous veins (VF_1), lenticular in shape, up to more than 5 cm thick, and strongly boudinaged. The brittle deformation, which represents the main focus of this study, is defined by thrusts, mainly localized along S_1 and arranged in imbricate structures systematically verging toward northwest. Deformation is most intense within the clay-rich member, where part of the strain is accommodated along strike-slip faults oriented roughly orthogonal to the thrusts (150°NE 60°). The fault cores of the thrusts consist of strongly foliated phyllosilicate-rich layers and occurrences of striated shear-veins, whereas those of strike-slip faults contain a more complex vein network with tensile, shear, intricate network microveins and sigmoidal veins. A second generation of fibrous veins (VF_2), average 15 mm thick, occurs within restricted outcrop sectors. VF_2 veins are orthogonal to both S_1 and the thrusts, roughly parallel to strike-slip faults, and result strongly deformed adjacent to the thrusts.

Preliminary structural data indicate that brittle deformation related to thrusting was mainly localized within the clay-rich member. In this sector, compressive deformation is partially accommodated along strike-slip faults. As suggested by the complex vein network, including the VF_2, the strike-slip faults represented the main pathways for fluid migration. Moreover, the high density and structural complexity of the vein system observed within the fault cores, greater than that recognized in the thrusts cores, indicate that transient overpressure processes likely developed along these steeper fault zones, potentially triggering seismic events.

Overall, we speculate that thrusts mainly accommodated aseismic deformation, whereas strike-slip structures released stress through coseismic deformation. Future detailed microstructural and isotopic analyses will help to confirm these hypotheses. Moreover, the new structural data may provide a fresh geodinamically perspective on this sector of the Ligurian Domain, traditionally interpreted as an accretionary wedge, suggesting instead a more complex tectonic history, consistent with processes occurring along a subduction channel.

Archean erupted diamonds: A record of thermal and chemical heterogeneity during the formation of the cratonic lithosphere

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Keywords: diamond, craton, isotope.

Archean Erupted Diamonds (AEDs) are diamonds erupted during the Meso- to the Neo-Archean. This age coincides with the main accretionary period of cratons worldwide. Hence, AEDs have the potential to record the thermal and chemical properties of the young cratonic lithosphere. Recognized occurrences of this type of diamond are limited but worldwide distributed, and include Witwatersrand (Kaapvaal Craton), Olondo (Siberian Craton), Tree River (Slave Craton), Wawa, Knee Lake and Ekomiak (Superior Craton) (see Pezzera et al., 2025b for an overview). These diamonds are found in volcaniclastic rocks of calcalkaline affinity, often associated with ultramafic lamprophyre magmatism, or in derived polymictic conglomerates. These diamonds show unusual physical characteristics, having small dimensions, a restricted size range, a wide variety of shapes and nitrogen aggregation levels. These characteristics are better explained by their crystallization under strong undercooling conditions and variable residence temperatures in the mantle. Pressure-temperature constraints from inclusions geothermobarometry indicate their entrapment at lithospheric geothermal conditions cooler than modern. The study of their mineral inclusions revealed a prevalent peridotitic paragenesis, with a minor eclogitic contribution. These observations suggest that these diamonds formed in a thermally and chemically heterogeneous lithosphere, made by the accretion of subducted slabs, as supported by thermal models (Timmerman et al., 2022; Pearson et al., 2026).

In addition to constraining lithospheric mantle formation models, AEDs also have the potential to record the early cycle of their main constituent elements, i.e. C, N and H. The average carbon isotope composition ($\delta^{13}C$) of AEDs varies from -5‰ to -2‰, close to the modern mantle value of ~-5 ±2‰; a few outliers record $\delta^{13}C$ values as high as ~+5‰ and as low as ~-20‰, typical of crustal-recycled carbon often associated with eclogitic diamond parageneses, further suggesting the occurrence of subduction-like processes since the Meso-Archean. After carbon, N is the second most abundant element in diamond. AEDs show a large variability in N content, from below detection up to ~3000 at. ppm. Average N isotope compositions ($\delta^{15}N$) vary between -2 and +3‰, consistently higher than the modern mantle value of -5‰, suggesting a secular change from a ^{15}N-enriched primordial composition. Diamonds from Knee Lake record both the lowest (-47‰) and highest (+32‰) $\delta^{15}N$ values ever found in terrestrial diamonds. This very large range in $\delta^{15}N$ values could be explained through a combination of N source variability and fractionation processes (Pezzera et al., 2025a). Hydrogen is also present in some of these diamonds, sometimes in relatively high concentrations. Gathering H isotope compositions, especially in the ^{15}N-depleted diamonds, could provide crucial information on the origin of water on Earth.

Pearson D.G. et al. (2026) - The thermal evolution of cratonic roots from assembly to maturity: Constraints from Archean diamonds and modeling of peridotite melting. Geosci. Front., 102339, https://doi.org/10.1016/j.gsf.2026.102339.

Pezzera A. et al. (2025a) - Modeling extreme nitrogen isotope variability in Neoarchean diamonds from Knee Lake, Superior Craton. Geochim. Cosmochim. Ac., 415, 181-195, https://doi.org/10.1016/j.gca.2025.12.039.

Pezzera A. et al. (2025b) - Cool transient lithospheric thermal conditions driven by subduction recorded by Neoarchean diamonds from Knee Lake, northwestern Superior Craton. Miner. Petrol., 119, 823-841, https://doi.org/10.1007/s00710-025-00927-z.

Timmerman S. et al. (2022) - Mesoarchean diamonds formed in thickened lithosphere, caused by slab-stacking. Earth Planet. Sc. Lett., 592, 117633, https://doi.org/10.1016/j.epsl.2022.117633.

Deep mantle melting in the Cambrian: Constraints on source and emplacement of the (ultra) basic complex of Milchenkar, Eastern Austroalpine

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Keywords: mantle melting, rifting, crustal contamination.

The Milchenkar (ultra)basic complex (Sulztal Valley, Längenfeld, Austria) is a partially preserved magmatic intrusive suite representing the eastern section of the Northern Eclogite Zone (Central Metabasite Zone) in the Oetztal-Stubai Complex, Eastern Austroalpine domain. With a Cambrian crystallization age (~530 Ma; Miller & Thöni, 1995), this complex results from the intrusion of basic magmas in the peri-Gondwanan continental crust during the Cadomian orogeny (Ediacaran-Ordovician) and preserves key information on differentiation and emplacement of mantle-derived melts in the early Paleozoic.

New field observations, petrological and microchemical analyses allowed the characterization of exceptionally well-preserved olivine gabbro, anorthosite and pegmatoid gabbro occurrences, enveloped in cogenetic gabbroic rocks almost completely metamorphosed at eclogite facies conditions (Piccin, 2026) during the Variscan orogenic cycle. Olivine gabbros are the most primitive products, characterized by cumulus olivine (Fo_{74-82}), subhedral to poikilitic clinopyroxene (Mg_{82-88}) and interstitial plagioclase (An_{60-68}). The igneous assemblages and chemical compositions suggest the crystallization from a tholeiitic magma with a mildly alkaline character, expressed by the negligible role of orthopyroxene in the crystallization processes and the occurrence of nepheline-normative samples, and possibly explained by melting of a rather deep mantle source. Low amphibole contents and the lack of amphibole-dominated products suggest a H_2O-poor parental melt.

Mineral trace element compositions further constrain the nature of the source and the differentiation of magmatic products. Melting of a relatively deep mantle is suggested by a significant MREE-HREE fractionation in clinopyroxene ($Gd_N/Yb_N \sim 1.2$-1.8), whereas high LILEs contents in amphibole and plagioclase are attributed to the contribution of a crustal component. This is in turn not reflected by isotopic ratios of Sr in plagioclase, which are close to DM values ($^{87}Sr/^{86}Sr \sim 0.7030$), while HFSE contents of clinopyroxene and amphibole do not suggest the interplay of subduction-related fluids. Moreover, modeled melts in equilibrium with primitive clinopyroxene show La_N/Yb_N ratios around 2, similarly to E-MORBs.

Thermobarometric estimates constrain the crystallization conditions at a temperature of 1200°C at a minimum depth of 20 km (5 kbar) for the most primitive products, consistently with the emplacement at mid crustal depth in an extensional setting. In the context of the peri-Gondwanan Cadomian domain, the Milchenkar complex could result from mantle melting triggered by lithospheric extension associated with continental rifting, as inferred for the Central European terranes (e.g., Linneman et al., 2008), or with the development of a back-arc setting with a reduced contribution of slab-derived fluids, nonetheless foreshadowing the widespread Cambro-Ordovician cordilleran magmatism in the Oetztal-Stubai Complex.

Linnemann U. et al. (2008) - The Cadomian Orogeny and the opening of the Rheic Ocean: The diacrony of geotectonic processes constrained by LA-ICP-MS U-Pb zircon dating (Ossa-Morena and Saxo-Thuringian Zones, Iberian and Bohemian Massifs). Tectonophysics, 461(1), 21-43, https://doi.org/10.1016/j.tecto.2008.05.002.

Miller C. & Thöni M. (1995) - Origin of Eclogites from the Austroalpine Ötztal Basement (Tirol, Austria): Geochemistry and Sm-Nd vs. Rb-Sr Isotope Systematics. Chem. Geol., 122(1), 199-225, https://doi.org/10.1016/0009-2541(95)00033-I.

Piccin S. (2026) - Evolution of the Eastern Alps from the Paleozoic onward: constraints and insights from the (ultra) basic eclogitic complex of Milchenkar, Ötztal-Stubai Complex (Eastern Alps, Tyrol, Austria). Doctoral dissertation, Università degli Studi di Milano, https://hdl.handle.net/2434/1240481.

Noble gases isotope signature in the source of Polynesian hotspot volcanism: Evidence from fluid inclusions in Society and Cook-Austral Islands xenoliths

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Keywords: French Polynesia Islands, mantle xenoliths, fluid inclusions.

Mafic rocks and ultramafic xenoliths from Ocean Island Basalt (OIB) systems constitute important geological windows into Earth's mantle processes, as they enable to characterize the origin, abundance and isotopic signature of volatile species in deep mantle reservoirs. Polynesian OIB localities (e.g., Society, Samoa and Cook-Austral Islands) are especially suitable for investigating mantle composition since radiogenic isotopes (Sr-Nd-Pb) have revealed the existence of different geochemical reservoirs (EMI-EMII-HIMU). Building on this geochemical framework, the present study uses noble gases and carbon isotopes to further explore the behavior of volatiles and their relationship with mantle heterogeneity. We investigate the noble gas and carbon isotope signatures of fluid inclusions hosted in ultramafic xenoliths from Tahiti, Rarotonga and Aitutaki islands to better constrain the composition of metasomatic fluids that infiltrate and modify the composition of the Polynesian lithospheric mantle. As part of this study, we report new He, Ne and Ar isotopic data from 5 ultramafic xenoliths from Tahiti (Society islands). Preliminary results indicate that Tahitian samples show radiogenic Rc/Ra values ($^{3}He/^{4}He$ ratios corrected for atmospheric contamination) from 5.52 to 6.98, lower than the typical MORB range (8±1). This confirms the variability of He isotopic signature in EM-type mantle sources, which ranges from 5 Ra (Lanzarote, Canary Islands; Sandoval-Velasquez et al., 2022) to 24 Ra (Western Samoa and American Samoa; Workman et al., 2004; Jackson et al., 2016). Moreover, $^{40}Ar/^{36}Ar$ (629.3 to 2857.1), $^{20}Ne/^{22}Ne$ (10.05 to 10.96) and $^{21}Ne/^{22}Ne$ ratios (0.03 to 0.04) indicate the presence of atmospheric-derived component in the local mantle likely recycled by subducted relict materials. To better constrain these observations, future work will focus on the analysis of CO_2 isotopic composition ($\delta^{13}C$) to evaluate the role of recycled crustal materials in the local mantle. Integrating these data within a multi-analytical framework, including petrographic and geochemical characterization (mineral chemistry), will provide insights on the nature and evolution of the Polynesian mantle.

Jackson M.G. et al. (2016) - Peridotite xenoliths from the Polynesian Austral and Samoa hotspots: Implications for the destruction of ancient ^{187}Os and ^{142}Nd isotopic domains and the preservation of Hadean ^{129}Xe in the modern convecting mantle. Geochim. Cosmochim. Acta, 185, 21-43, https://doi.org/10.1016/j.gca.2016.02.011.

Sandoval-Velasquez A. et al. (2022) - The radiogenic nature of the lithospheric mantle beneath Lanzarote (Canary Islands). Abstract Book Congresso SGI-SIMP, https://doi.org/10.3301/ABSGI.2022.02.

Workman R.K. et al. (2004) - Recycled metasomatized lithosphere as the origin of the Enriched Mantle II (EM2) end-member: Evidence from the Samoan Volcanic Chain. Geochem. Geophys. Geosyst., 5(4), Q04008, https://doi.org/10.1029/2003GC000623.

Clumped isotope thermometry of natural basalt carbonation in the Iblean Plateau (Sicily, Italy): Implications for CO_2 storage

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Keywords: mineral carbonation, CO_2 storage, clumped isotope thermometry.

Mineral carbonation transfers CO_2 from the atmosphere and hydrosphere to the lithosphere, regulating Earth's climate and habitability over geological timescales. The same reactions provide a promising pathway for permanent geological storage of anthropogenic CO_2 through engineered mineral carbonation. Here we investigate natural basalt carbonation in the Iblean Plateau (Sicily, Italy), where interaction between CO_2-rich fluids and basaltic rocks drove carbonate precipitation and long-term CO_2 mineralisation as calcite. This system represents a natural analogue for basalt carbonation relevant to geological carbon storage in Italy (Castellari et al., 2026). To reconstruct the physicochemical conditions of carbonation, we combine carbonate clumped isotope thermometry (Δ_{47}) with conventional stable isotopes ($\delta^{13}C$ and $\delta^{18}O$). Δ_{47} provides an independent determination of the carbonate precipitation temperature, whereas $\delta^{13}C$ and $\delta^{18}O$ constrain carbon and fluid sources. Our results constrain the temperature and fluid conditions that promoted natural basalt carbonation, providing a framework relevant to engineered mineral carbonation for CO_2 storage.

Castellari I. et al. (2026) - Multicriteria decision analysis to predict potential sites for carbon capture and mineral storage: a pre-feasibility study in southeastern Sicily (Italy). Int. J. Greenh. Gas Con., 154, 104692, https://doi.org/10.1016/j.ijggc.2026.104692.

Geochemical evolution of diamond silicate inclusions during fluid-rock metasomatism

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Keywords: diamond inclusions, HPHT experiments, thermodynamic modelling.

Mineral and fluid inclusions in mantle diamonds provide otherwise inaccessible insights into mantle metasomatism and the role of fluids in mass transfer within Earth's interior. Rinaldi et al. (2023) used the Deep Earth Water model to quantitatively predict that fluid-rock metasomatism can generate the range of garnet and clinopyroxene compositions observed in diamonds from the subcontinental lithospheric mantle. These simulations involved reactions between silicic, carbonatitic, and peridotitic fluids with common mantle lithologies (peridotites, eclogites, and pyroxenites) at 5 GPa and 1000°C across a range of redox conditions ($\log fO_2$ = -2 to -4 ΔFMQ). The compositions of metasomatic garnet and clinopyroxene were found to depend primarily on the initial fluid-rock geochemistry, with subsequent mineral evolution following predictable reaction pathways.

In this study, we test these thermodynamic predictions through a series of innovative high-pressure, high-temperature subsolidus experiments performed under diamond-forming conditions (5 GPa, 900-1100°C, $\log fO_2$ = FMQ). A three-layer experimental setup with a solid fluid source was designed to simulate fluid migration along a lithological discontinuity, where the fluid acts as a mass-transfer agent between eclogite and peridotite separated by a diamond powder layer. Garnets in the metasomatized eclogite record progressive Mg enrichment during reaction, evolving from grossular-rich eclogitic compositions toward pyrope-rich peridotitic endmembers. Conversely, garnets in the metasomatized peridotite evolve toward more grossular-rich compositions, reflecting progressive Ca enrichment.

Taken together, natural disequilibrium assemblages (e.g., Smart et al., 2012), thermodynamic modelling (Rinaldi et al., 2023), and experimental results (this work) all indicate that the paragenetic groups traditionally used to classify diamonds should not be regarded as unequivocal genetic indicators. Instead, fluid composition appears to impose a stronger control than host-rock geochemistry during diamond-forming metasomatism and may completely overprint the original geochemical signature of minerals subsequently trapped as diamond inclusions.

Rinaldi M. et al. (2023) - The importance of carbon to the formation and composition of silicates during mantle metasomatism, Geochim. Cosmochim. Ac., 356, 105-115, https://doi.org/10.1016/j.gca.2023.06.025.

Smart K.A. et al. (2012) - Eclogite formation beneath the northern Slave craton constrained by diamond inclusions: Oceanic lithosphere origin without a crustal signature. Earth. Planet. Sci. Lett., 319-320, 165-177, https://doi.org/10.1016/j.epsl.2011.12.032.

An improved thermodynamic model for the melting evolution of a peridotite up to 10 GPa

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Keywords: thermodynamic modelling, peridotitic systems, phase equilibrium modelling.

Since the development of petrological phase equilibrium modelling, thermodynamic modelling has become an essential tool for investigating the evolution of a wide range of magmatic settings. Its flexibility in exploring diverse bulk compositions and environmental conditions, while interpolating between limited experimental data, has significantly improved our understanding of mineral-melt relationships, as well as magmatic processes operating under the hot mantle conditions of the Archean, including the genesis of komatiites. However, the scarcity of experimental constraints for anhydrous compositions has limited existing models to pressures below 6 GPa, restricting investigations to the shallow upper mantle and hindering the study of deeper magmatic systems.

This study presents an extended and improved calibration of melt and key anhydrous ultramafic mineral models by incorporating recent high-pressure, high-temperature experimental data for fertile and depleted peridotites within the KNCFMASTOCr system. The updated thermodynamic model extends the applicability of phase equilibrium modelling to depths of approximately 300 km (10 GPa) in the Earth's upper mantle. The new calibration specifically includes: (1) a revised melt model applicable above 6 GPa, (2) a completely recalibrated pyroxene model, (3) new endmembers for high-pressure phases such as majorite, and (4) refined element partitioning among clinopyroxene, orthopyroxene, garnet, and spinel, with particular emphasis on Cr, Ti and K.

The reliability of the updated database is evaluated through comparisons between model-derived pressures, temperatures, and modal abundances and those obtained using conventional geothermobarometry on natural peridotite samples. We further demonstrate how thermodynamic modelling can compensate for the absence of key mineral phases in an assemblage when traditional geothermobarometric approaches are not applicable. For example, in garnet-free peridotites, where conventional barometry cannot be employed, thermodynamic calculations provide an effective alternative for constraining pressure-temperature conditions. These results highlight the potential of thermodynamic modelling as a powerful approach for advancing our understanding of deep Earth magmatic processes.

Serpentinite-sediment records from Elba Island: Insights into mantle heterogeneity in the Alpine-Apenninic system

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Keywords: serpentinite, Alpine Tethys, mantle.

Elba Island (Northern Apennines) preserves a tectonically assembled mantle record within an Alpine-Apenninic orogenic wedge that offers insights into the evolution of the Alpine Tethys. Previous work has highlighted the coexistence of contrasting serpentinite-sediment associations on Elba, reflecting complex tectonic processes during both extension and convergence. We present new petrographic observations combined with mineral-chemical data (clinopyroxene and spinel) from structurally distinct serpentinite bodies exposed across eastern and central Elba. These data are evaluated within an updated structural framework that distinguishes different serpentinite occurrences based on their field relationships, deformation history, and sedimentary associations. The investigated serpentinites display a wide range of mineralogical preservation, deformation styles, and geochemical signatures. Variations include relatively well-preserved mantle assemblages, strongly deformed and recrystallised serpentinites associated with high-strain zones, and highly depleted compositions occurring in ophiolitic settings. These characteristics point to a more complex mantle record than previously recognised. Our results suggest that the Elba serpentinites may not derive from a single uniform mantle source, but instead reflect contributions from different lithospheric domains formed under contrasting tectonic conditions. The integration of new micro-geochemical data with structural and sedimentary constraints provides a refined perspective on how mantle fragments were sampled, modified, and juxtaposed during the opening and closure of the Alpine Tethys, and provides important constraints on geodynamic models of its evolution.

If not now, when? The oceanic mantle as testbed for the next era of IODP

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Keywords: mantle peridotites, oceanic mantle, IODP.

Despite its central role in controlling geodynamic, geochemical, and long-term climatic processes, the oceanic mantle remains one of the most under-sampled and conceptually under-constrained components of the Earth system. While decades of scientific ocean drilling have revolutionized our understanding of the oceanic crust, direct access to mantle sections is still limited to a handful of sites, leaving fundamental questions about mantle heterogeneity, depletion, and alteration largely unresolved. This contribution presents examples on how recent drilling expeditions in mantle sections in the Atlantic and the Tyrrhenian Sea are changing our understanding on the composition of the oceanic mantle, not a passive residue of melt extraction, but a dynamic and evolving reservoir that records a complex interplay of processes, including melt-rock interaction, fluid circulation, and serpentinization. These processes overprint primary depletion signatures and generate chemical and physical heterogeneity that directly impacts lithosphere formation, volatile cycles, and the deep carbon budget. Drilling into mantle sections across different geodynamic settings - mid-ocean ridges, backarc basins, forearcs and ocean-continent transitions - is critical to capture the full spectrum of mantle variability, and must be considered as a primary scientific objective in future international ocean drilling programs.

High-resolution geothermometry and geospeedometry reveal fast cooling of exhumed mantle beneath the Tyrrhenian ocean-continent transition (IODP Exp 402)

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Keywords: IODP, Tyrrhenian ocean-continent transition, geothermometry.

Geothermometry and geospeedometry provide powerful tools for constraining the cooling history, thermal evolution, and exhumation mechanisms of mantle sequences. However, despite their relevance, detailed studies of exhumed mantle sections remain comparatively scarce and have largely focused on fragmented ophiolitic complexes. Consequently, high-resolution investigations capable of tracing continuous depth-dependent variations in temperature and cooling rates within mantle sections are still lacking.

IODP Expedition 402 drilled the ocean-continent transition (OCT) of the Tyrrhenian back-arc basin and successfully recovered well-preserved in situ sections of mantle exhumed during Late Cenozoic extension. In this study, we present the first high-resolution thermal investigation performed on 37 peridotite samples recovered from Hole U1614C, which penetrated approximately 150 m of mantle basement. The investigated samples consist of variably serpentinized, coarse-grained, spinel- and plagioclase-bearing harzburgites and lherzolites (cpx up to 7 vol%), locally preserving porphyroclastic textures.

The peridotites record widespread evidence of melt-rock interaction, highlighted by olivine-forming, pyroxene-dissolving microstructures, locally associated with altered plagioclase relics. The frequent occurrence of phlogopite-bearing veins, sometimes associated with high-Ti pargasite (up to 2.6 wt.%), further suggests metasomatic modification of the mantle prior to and/or during basin formation.

Mineral compositional variations and clinopyroxene geochemistry indicate that these rocks underwent high degrees of melt extraction followed by variable extents of melt-assisted refertilization.

Geothermometric investigations further constrain this polyphase evolution. REE-in-two-pyroxene ($T_{REE\text{-}Y}$) thermometry yields temperatures of 1050-1250°C, recording a stage of high-temperature re-equilibration, likely associated with reactive melt migration within the shallow mantle. Cooling rates derived from $T_{REE\text{-}Y}$ and T_{BKN} geospeedometry indicate relatively rapid equilibration at high temperatures, on the order of 10^{-3}-10^{-2} °C/yr.

By contrast, conventional two-pyroxene thermometers register substantially lower equilibration temperatures ($T_{Ca\text{-}in\text{-}Opx}$ = 930-980°C; T_{BKN} = 825-907°C), consistent with progressive subsolidus re-equilibration during cooling. Notably, fast-diffusing thermometers ($T_{Ol\text{-}Sp}$ and $T_{Ca\text{-}in\text{-}Ol}$) record significantly higher temperatures than those commonly documented in modern and fossil OCTs, corresponding to thermal re-equilibration rates at 10^{-3}-10^{-2} °C/yr based on olivine geospeedometry.

Our new results indicate unusually efficient and persistently rapid cooling of the Tyrrhenian mantle, contrasting with the prolonged and slow thermal re-equilibration histories typically inferred for magma-poor OCT systems.

Mixed H_2O-H_2 fluids in the Earth's interior: Experimental constraints from the iron-wüstite buffer

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Keywords: hydrogen, fluids, experiments.

Molecular hydrogen production and consumption in Earth's interior play a fundamental role in controlling the redox evolution of the mantle, the global H_2O budget, and the occurrence of melting. In particular, H_2O introduced through subduction and participating in serpentinization reactions may contribute to resupplying mantle H_2 reservoirs, counteracting the degassing of primordial hydrogen. In addition to this, H_2 can also be generated by dissociation of H_2O when redox conditions become sufficiently reducing. Significant H_2 abundances, resulting in mixed H_2O-H_2 fluids, are expected under redox conditions approaching the iron-wüstite buffer, which may characterize portions of modern subduction zones, the subcontinental upper mantle, and the upper mantle of the early Earth.

We performed double-capsule piston-cylinder and multi-anvil experiments at 700-900°C and 1-5 GPa to constrain H_2 production by H_2O decomposition under iron-wüstite buffer conditions. Fluid speciation was measured ex situ using a capsule-piercing apparatus coupled to a quadrupole mass spectrometer. A revised data-reduction procedure enabled the determination of detection and quantification limits, as well as instrumental uncertainties, for both H_2 and H_2O. Analyses of quenched fluids show that the molar fraction of H_2 (XH_2) increases with both temperature and pressure, reaching values up to ~0.33 at 800°C and 5 GPa.

Comparison with commonly used thermodynamic models reveals significant discrepancies, both in the predicted XH_2 values and, more importantly, in the pressure dependence of H_2 proportion. Existing models predict decreasing H_2 concentrations with increasing pressure, in contrast to our experimental observations. This mismatch possibly indicates strong non-ideal behavior in H_2-H_2O mixtures and highlights the difficulty of extrapolating thermodynamic properties to GPa pressures, for which experimental constraints remain scarce. Nevertheless, this previously unconstrained thermodynamic behavior can, as a first approximation, be incorporated into equilibrium constants for water dissociation, thereby improving the predictive capability of existing models. Our results further suggest that aqueous fluids in subducting slabs and the upper mantle may become substantially more H_2-rich than previously assumed, providing an additional mechanism for hydrogen replenishment of the mantle.

A fast-quench system for multi-anvil apparatus and its application to melilititic melts

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Keywords: multi-anvil, fast-quench system, melilititic melts.

In experimental petrology, the quench rate of an experiment is a fundamental parameter for preserving high temperature mineral assemblages, blocking diffusive processes, preventing glass crystallization, retaining volatiles, and preserving fluid speciation. In this respect, the use of larger assemblies in both piston cylinder and multi-anvil apparatuses, often required for analytical purposes, imposes relatively slow quench rates because of the large masses involved and their associated high thermal inertia.

We developed a fast-quench system for a Walker-type multi-anvil apparatus, optimized for 25M assemblies, to improve quenching efficiency. The system employes eight tapered tungsten carbide anvils (32 mm edge length and 17 mm truncation edge length) together with two 3D-printed thermoplastic polyurethane sheaths that inject a cold (As a preliminary test, we investigated the possibility of preserving olivine melilitite and olivine nephelinite glasses, whose quenching poses severe experimental challenges because of their ultrabasic, alkali-rich composition and high volatile content. Formed in a within-plate setting under high-pressure conditions (>3-4 GPa), these compositions have low SiO_2 (37-40 wt.%), high MgO (14-17 wt.%), Mg# > 70 and CaO/Al_2O_3 > l, and have a low-pressure assemblage formed by forsteritic olivine, clinopyroxene, nepheline, melilite, perovskite, apatite, Ba-phlogopite, monticellite ±leucite.

Experiments were conducted at ∼1500°C and 3 GPa using both the standard and the fast-quench configurations. The fast-quench experiment achieved a higher cooling rate, (with a peak at ∼440°C/s compared to ∼360°C for the standard setup, and displayed a smoother quench profile, whereas the standard quench showed pronounced oscillatory behavior. Surprisingly, both experiments produced homogeneous glasses; however, the fast-quench experiment was considerably more stable, sustaining a run of ∼20 minutes before power cutoff, whereas the standard configuration suffered rapid assembly degradation after only a few minutes. This well-known issue is commonly mitigated by inserting a ZrO_2 sleeve between the graphite heater and the MgO pressure medium. Nevertheless, because ZrO_2 has a lower thermal conductivity than MgO, its use is expected to significantly reduce the quench rate and potentially compromise glass preservation.

Our fast-quench system, by improving the quenching efficiency and enhancing the assembly stability, therefore opens new experimental opportunities for investigating melts, and potentially fluids, under lower-crustal and upper-mantle pressure-temperature conditions.

Mantle-hosted granites from the Tyrrhenian back-arc basin

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Keywords: mantle-hosted granites, IODP expedition 402, subduction-modified mantle.

Mantle-hosted granites are uncommon in Earth's lithosphere. A well-known finding was documented in the supra-subduction Samail ophiolite from Oman and the United Arab Emirates, in which the granites typically possess a component derived from partial melting of the subducted sedimentary crust. Here we present a petrological and geochemical study of biotite-hornblende granites intruding the mantle section exhumed at the Tyrrhenian back-arc basin, in the Mediterranean Sea, drilled by IODP expedition 402 (Malinverno et al., 2025). Due to the limited amount of available material and the extensive low-temperature alteration, we adopted a microanalytical approach to identify the origin of the melts forming the Tyrrhenian granites. Specifically, major and trace element compositions of plagioclase, alkali feldspar, biotite and hornblende were analyzed by electron microprobe and laser ablation ICP-MS, respectively, and the Sr isotopic signature of plagioclase was detected by laser ablation multicollector ICP-MS. The granite-forming minerals collectively display wide chemical variations, also within a single rock sample, whereas the Sr isotopic ratio of plagioclase remains nearly constant. We speculate that the Tyrrhenian granites crystallized from SiO_2-rich melts variably evolved through fractional crystallization, derived from differentiation of mantle magmas. The overall geochemical signature of the granites may be reconciled with primary magmas generated by a subduction-modified mantle source.

Malinverno A. et al. (2025) - Expedition 402 Preliminary Report: Tyrrhenian Continent-Ocean Transition. International Ocean Discovery Program, https://publications.iodp.org/preliminary_report/402/.

S7.

Earth Telescope: Integrating geosciences across scales for a unified Earth system vision

CONVENERS & CHAIRPERSON

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Nuclear explosions as *Earth Telescopes*: New materials from extreme geologic processes

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Keywords: new materials, atomic explosions, Earth Telescope.

High-energy processes such as planetary impacts generate extreme, transient environments that drive the formation of mineral phases inaccessible under equilibrium conditions. Nuclear detonations represent a unique anthropogenic analogue of these processes, compressing into microseconds physicochemical regimes otherwise distributed across planetary scales. In this sense, they act as *Earth Telescopes*, enabling direct observation of matter formation under extreme conditions.

Here, we report the discovery of previously unknown materials in debris from the Trinity (1945) and Hiroshima (1945) atomic explosions. In Hiroshima Bay sands, a novel multicomponent alloy preserved within a glassy spherule records condensation from a high-temperature metallic vapor followed by ultrafast quenching. In Trinity samples, a new Ca-Cu-Si clathrate occurs alongside a Si-rich icosahedral quasicrystal, indicating that rapid fluctuations in pressure, temperature, and composition can stabilize both periodic and aperiodic structures from related precursor systems.

These materials document nonequilibrium pathways governed by extreme compression, rapid thermal gradients, and metastable kinetics. Their formation conditions closely parallel those inferred for hypervelocity impacts and, potentially, for shock-compressed regions in planetary interiors.

Taken together, these findings demonstrate that nuclear explosions generate a diverse spectrum of novel compounds and provide a unique observational window into extreme geologic processes. As Earth telescopes, such events allow us to probe the limits of phase stability, structural complexity, and emergent order in matter, bridging mineralogy, materials science, and planetary science within an integrated geoscience framework.

A genetic link between gem and fibrous diamonds

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Keywords: diamond, inclusions, diffraction.

Fluid-rich ("fibrous") diamonds provide a unique window into deep Earth processes by preserving high-density fluid (HDF) inclusions, yet their mineral cargo is commonly nanometric and difficult to characterize, limiting constraints on formation conditions. Using single-crystal micro-electron diffraction (MED) coupled with a novel extraction technique, we structurally identified nanometric inclusions from a fibrous diamond from the Kaapvaal Craton (South Africa). These include Sr-rich åkermanite, unusual carbonates, sellaite, and anatase. We report the first full crystal structure refinement of a nanometric inclusion in diamond, achieved on åkermanite. The observed assemblage, supported by FTIR data, indicates crystallization from an alkali-silico-carbonatitic melt linked to recycling of crustal material into the lithospheric mantle. Thermometric constraints suggest formation at ≥1000°C and ~140 km depth (~4.6 GPa). To investigate whether such fluids are related to those forming gem-quality diamonds, we studied a "coated" diamond from the Democratic Republic of Congo (DRC), consisting of a gem-quality core and fibrous rim. In the gem core, we identified isolated fluid droplets compositionally similar to previously reported Si-O-H-bearing fluid films around mineral inclusions (Nimis et al., 2016), but here occurring independently of solids. Notably, the same fluid was observed in the adjacent fibrous rim, alongside coesite inclusions at the core-rim boundary. A recent work on lithospheric diamonds (Rapikov et al., 2026) was able to detect for the first time the trace element signatures of the fluid film (e.g., Ba, Sr, REEs) showing a genetic link with HDFs in fibrous diamonds. Thermobarometric constraints on the DRC diamond indicate the gem core resided at ~1100°C, while the fibrous rim formed at ~5.5 GPa.

Together, these results bridge the gap between fibrous and gem-quality diamond formation, demonstrating that related deep mantle fluids may contribute to both, and highlighting the role of recycled components in diamond genesis.

Nimis M. et al. (2016) - First evidence of hydrous silicic fluid films around solid inclusions in gem-quality diamonds. Lithos, 260, 384-389, https://doi.org/10.1016/j.lithos.2016.05.019.

Rakipov A. et al. (2026) - Fluids in gem-quality and fibrous diamonds are compositionally similar. Commun. Earth Environ., accepted.

Human impacts and geomorphic change in Alpine high-mountain landscapes

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Keywords: human geomorphology, high-mountain landscapes, Central Alps.

High-mountain environments are particularly sensitive to the combined effects of climate change and human pressure. In the Alps, glacier retreat, permafrost degradation, changes in snow-cover duration and more frequent extreme events are reshaping geomorphic processes, sediment availability and landscape connectivity. At the same time, roads, ski areas, reservoirs, tourist facilities, military remains and other infrastructures have modified high-altitude landscapes, leaving traces that may continue to affect present-day dynamics.

This contribution focuses on human-geomorphic interactions in Alpine high-mountain environments through a multi-temporal and multi-source approach. Historical cartography, archival aerial photographs, orthophotos, satellite imagery, UAV surveys, geomorphological field mapping and high-resolution topographic data are combined to reconstruct landscape evolution over the last two centuries. The aim is to identify anthropogenic landforms and assess how they have contributed to controlling, redirecting or enhancing geomorphic processes such as erosion, slope instability, runoff concentration, sediment redistribution and changes in geomorphic connectivity.

Evidence from Alpine high-altitude areas shows that human interventions cannot be interpreted only as local or temporary disturbances. In many cases, they become persistent components of the geomorphic system. Roads and ski infrastructures may alter drainage pathways and favour erosion; reservoirs and water-management systems may affect sediment transfer and valley-floor dynamics; military and tourist structures may influence slope stability and surface processes. These inherited features interact with ongoing climate-driven changes, especially in deglaciating and periglacial settings, producing complex landscape responses.

Interpreting high-mountain landscapes as coupled natural-anthropogenic systems is therefore essential to understand their present dynamics and possible future evolution. Reconstructing the history, spatial extent and geomorphic role of human interventions can support geomorphological mapping, hazard assessment, geoheritage evaluation and the sustainable management of fragile Alpine environments increasingly exposed to both climatic and anthropogenic pressures.

From mineral-scale signals to four billion years of Earth dynamics: Revisiting the zircon Eu anomaly

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Keywords: Earth dynamics, detrital zircon, mineral-scale signals.

Detrital zircon archives provide a unique opportunity to investigate Earth evolution across spatial and temporal scales, linking mineral-scale geochemical signatures to long-term geodynamic processes. Europium anomalies in zircon (Eu/Eu) have traditionally been interpreted as proxies for crustal thickness and, in turn, for tectonic regimes through time. Here we revisit the significance of zircon Eu/Eu by integrating batholith-scale observations with thermodynamic, petrological, and geochemical constraints, alongside global compilations of detrital zircon geochemistry spanning nearly four billion years of Earth history. Our synthesis (Bartoli & Carvalho, 2025) suggests that secular variations in zircon Eu anomalies are more consistently explained by changes in crustal redox state and the progressive recycling of reduced supracrustal material within crustal hot zones, rather than by crustal thickness alone. In particular, the long-term decrease in Eu/Eu from the Neoarchean to the Mesoproterozoic reflects enhanced incorporation of reduced metasedimentary material during crustal reworking, whereas the subsequent increase through the Neoproterozoic-Phanerozoic may record the emergence of colder and more oxidizing subduction systems associated with modern plate tectonics.

This contribution highlights how mineral-scale geochemical signals can be translated into large-scale interpretations of Earth structure and evolution when integrated with multidisciplinary datasets and process-based models. By linking zircon geochemistry with crustal differentiation, redox evolution, and secular geodynamics, this work illustrates the potential of integrating mineralogy, petrology, geochemistry, and tectonics within an Earth Telescope framework connecting deep Earth processes to planetary-scale evolution.

Bartoli O. & Carvalho B.B. (2025) - From single batholith to global detrital zircon archive: Earth dynamics as seen from zircon Eu anomalies. Earth-Science Rev., 268, 105175, https://doi.org/10.1016/j.earscirev.2025.105175.

Big earthquakes: Lessons from the 2023 Türkiye and 2025 Myanmar Mw7.7 supershear ruptures

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Keywords: earthquakes, supershear rupture, strike-slip fault.

Large strike-slip earthquakes along continental transform faults often rupture mature, geometrically complex fault systems where deformation may be either distributed across broad damage zones or progressively focused along principal slip zones. Here, we compare recent $Mw_{max} \geq 7.6$ earthquake sequences along two major transform faults: the East Anatolian Fault, Türkiye, ruptured during the 2023 Kahramanmaraş sequence, and the Sagaing Fault, Myanmar, ruptured during the 2025 Mandalay sequence. Building on previous results from the East Anatolian Fault and extending the analysis to the Sagaing Fault, we investigate whether seismicity, focal mechanisms, and cumulative seismic moment reveal systematic pre-mainshock to aftershock patterns. The comparison suggests that both fault systems behave as highly efficient deformation guides, although with potentially different degrees of spatial focusing and temporal organization. Along the East Anatolian Fault, seismic slip channeling appears closely associated with repeated $Mw \geq 6.8$-7.7 sequences and with the progressive concentration of seismic moment before large ruptures. Along the Sagaing Fault, the 2025 sequence indicates a similarly strong tendency for deformation to be trapped along the main fault trace, supporting the interpretation of the fault as a large-scale deformation funnel across Myanmar. These observations highlight the importance of fault-zone architecture, inherited structural maturity, and earthquake-cycle processes in controlling where and how large strike-slip ruptures nucleate and propagate. More broadly, the Türkiye-Myanmar comparison provides a framework for assessing seismic slip localization, rupture preparation, and possible implications for supershear rupture dynamics along mature transform faults.

Minerals as a vocabulary of Earth Sciences

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Keywords: mineralogy, mineral diversity, Earth Sciences.

Minerals are fundamental constituents of Earth and other planetary bodies, but their significance in Earth sciences extends beyond their material presence. They are natural archives of physical, chemical and biogeochemical processes: their structures and compositions record the conditions under which geological systems form and evolve. The rise in mineral species, from ca. 200 in the 19th century to >6,200 today, reflects stronger analytical methods and the exploration of Earth and extraterrestrial environments.

Mineral diversity also mirrors planetary evolution. From planetary differentiation to water-rock interaction and photosynthesis-driven oxygenation, geological history has generated new mineral species and increasing crystal-chemical complexity (Hazen et al., 2008). This diversity requires a rigorous mineralogical vocabulary. Even the "simple" olivine series, for example, illustrates why nomenclature cannot merely reflect natural compositional variability. Olivine compositions vary continuously between Mg-rich and Fe-rich terms, with no natural discontinuity separating one mineral species from another. The names forsterite and fayalite require abstraction from empirical to endmember compositions, Mg_2SiO_4 and Fe_2SiO_4, with the boundary where Mg and Fe have equal dominance. Mineral names thus translate continuous chemical variability into standardized crystal-chemical reference entities.

The central role of mineralogy is evident when mineral identification changes our understanding of geological processes. The recognition of coesite in rocks of the Dora-Maira Massif showed that continental crust can be subducted to mantle depths and later exhumed, opening the field of UHP metamorphism (Chopin, 1984). Likewise, ringwoodite have transformed views of mantle and planetary interiors. The recent discovery of xiexiandeite, an UHP SiO_2 polymorph, challenges models of mineral stability under deep-Earth conditions (Gu et al., 2025). Rare Tl-bearing sulfosalts such as boscardinite show how tiny minerals reveal hidden geochemical anomalies and environmental concerns (Biagioni, 2025).

Mineralogy should not be regarded as an ancillary or merely descriptive discipline. Its importance rests on two complementary dimensions. The intrinsic dimension concerns minerals as natural solids: atomic structure, bond topology, site occupancies, chemical composition and physical properties. It is the domain in which a mineral substance is measured, and a mineral species is abstracted as a crystal-chemical entity defined by a name, formula and coherent structural topology. The extrinsic dimension concerns what minerals reveal about their geological context: P-T conditions, redox state, fluid activity, element mobility, resources, hazards and planetary evolution. These dimensions are inseparable: without the intrinsic framework, minerals become poorly defined labels; without the extrinsic framework, they lose much of their interpretive significance.

Biagioni C. (2025) - Rare minerals as a key to understand Earth's complexity. Rend. Fis. Acc. Lincei, 36, 151-164, https://doi.org/10.1007/s12210-025-01307-7.

Chopin C. (1984). Coesite and pure pyrope in high-grade blueschists of the Western Alps: a first record and some consequences. Contrib. Mineral. Petr., 86, 107-118, https://doi.org/10.1007/BF00381838.

Gu X. et al. (2025) - Xiexiandeite, IMA 2025-006. CNMNC Newsletter 85, Mineral. Mag., 89, https://doi.org/10.1180/mgm.2025.10100.

Hazen R.M. et al. (2008) - Mineral evolution. Am. Mineral. 93, 1693-1720, https://doi.org/10.2138/am.2008.2955.

Connecting surface and deep Earth dynamics: The CARG 3D initiative

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Keywords: 3D geological modelling, CARG, earth system observatory.

Extensive 3D geological modelling is a fundamental component of multi-scale Earth system observatories, seamlessly connecting the surface and subsurface architecture. In this context, the CARG Programme promotes the systematic production of 3D models across Italy, enriching the traditional language of geological mapping with the third dimension and providing a unified framework for integrating diverse geoscientific disciplines.

The value of this national initiative - aligned with European infrastructures and standards such as EPOS, EGDI, INSPIRE and GeoSciML - lies in the definition of a common data model (Petricca et al., 2025) including lithology, age (of rocks and events), depositional environments, structural elements (including active, seismogenic, and capable faults), and geometrical and physical parameters such as temperature, density, V_p and V_s, where available.

Through the creation of the National 3D geological database, the CARG Programme facilitates a paradigm shift from isolated project-based efforts toward a permanent institutional repository, essential for managing the increasing complexity and multidisciplinarity of geoscientific information.

The CARG vision is to supplement the geological sheet (approx. 600 km^2) with a corresponding 3D model, improving the understanding of the geological structures and their geometric and temporal relationships. These 3D models result from a collaborative effort involving the Geological Survey of Italy (GSI), some regional authorities, CNR, OGS and 21 university departments.

Planned activities, effectively reconciling new detailed field data, borehole stratigraphy and geophysical surveys (seismic, gravity, and magnetics) primarily provided by ENI, will produce over 50 geological 3D models covering most of Italian geological domains. These models represent the modular and interoperable building blocks for a multidisciplinary-constrained national geological 3D model, providing the structural backbone needed to bridge deep Earth processes with surface dynamics as proposed by the Earth Telescope initiative.

This framework will serve as a fundamental input both for the scientific community and a broad range of stakeholders, supporting applications in georesources, natural hazards, engineering and urban planning.

To support this effort, open-source tools have been specifically designed to facilitate formal compliance with the national database structure (Petricca, 2025) and enable the accuracy of modeled features to be rigorously evaluated (Petricca 2026).

Finally, the GSI, through the Geo-IT3D viewer (https://geo-it3d.isprambiente.it), fully adheres to FAIR principles providing access to Italian 3D geological models, including those developed beyond the CARG Programme, based on semantically controlled terms, while offering standard metadata and download services.

Petricca P. (2025) - check-GeoIT3D-model, GeoIT3D Model Validator - A set of routines for verifying the consistency, formatting, and content of file packages to ensure compliance with the requirements of 3D geological models for uploading and visualization on the GeoIT3D web viewer of ISPRA - Servizio Geologico d'Italia - CARG project, https://github.com/BaterHub/check-GeoIT3D-model.

Petricca P. et al. (2025) - Linee guida Struttura Banca Dati Nazionale dei Modelli Geologici 3D. https://doi.org/10.15161/oar.it/vyn6s-4ra91.

Petricca P. (2026) - GeoSurface_Accuracy, A toolset for evaluating the accuracy of geological surface models based on spatial autocorrelation metrics, designed to support quality assessment and model validation in 3D geological modeling workflows. https://github.com/BaterHub/GeoSurface_Accuracy.

Controls of Dauphiné twin boundaries on deformation mechanisms in quartz: Insights from EBSD, AFM, and full-field numerical simulations

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Keywords: Dauphiné twin boundaries, coincident site lattice, Atomic Force Microscopy.

Understanding how atomic-scale crystallographic features influence macroscopic deformation remains a key challenge. In quartz-rich rocks, Dauphiné twin boundaries (DTBs) represent a special class of coincident site lattice (CSL) boundaries (McLaren, 1986) that imparts certain special properties to the material and stabilizes the microstructure by reducing the overall grain boundary surface energy (Shimada et al., 2002). Based on this, the present study explores the CSL relationships of DTBs and how they can control strain accommodation and deformation mechanisms. Atomic Force Microscopy (AFM) imaging of chemically polished thin-section surfaces reveals a marked contrast in boundary morphology: RHAGBs develop nanometric grooves due to preferential material removal, whereas DTBs remain topographically coherent, consistent with their lower interfacial energy and higher structural compactness (Dey et al., 2024). At RHAGB-DTB junctions, "bridge-like" nanoscale features indicate local reorganization of boundary geometry, consistent with CSL-controlled stabilization. Interestingly, misorientation across adjacent quartz grains between consecutive RHAGB-DTB intersections indicates that the RHAGB segments are modified by DTBs into low-energy twin boundaries, thereby reducing the overall surface energy of the aggregate. Additionally, the presence of DTBs is postulated to cause strain partitioning, resulting from stiffness differences between the positive and negative rhomb faces of quartz. This effect is evident in the CPO patterns: only the recrystallized grains exhibit activation of rhomb slip systems, while the relict grains do not. Now, to assess the effects of DTBs on the deformation mechanisms and critically resolved shear stress (CRSS) of slip systems, numerical simulations were performed in the full-field ELLE-EVPFFT package - marking its first application to quartz deformation studies. Simulations were conducted under varying CRSS ratios for basal, rhomb, and prism[c] slip systems. Post-processing in the MTEX toolbox demonstrates that rhomb slip becomes dominant when its CRSS is comparable to or lower than that of basal, especially when prism[c] slip is difficult to activate. The high frequency of DTBs is expected to lower rhomb CRSS due to rhomb-plane rotation within twins. These observations suggest that DTBs act as atomically controlled, low-energy interfaces that influence strain partitioning by modulating slip activity, establishing a direct link between DTBs and deformation mechanisms. Importantly, the nanoscale observations suggest a potential control of DTBs on grain-boundary networks and on fluid percolation in quartz-rich crustal rocks. This has broader implications for permeability evolution, fluid transport, and the mechanical behavior of the continental crust, which are critical for understanding geothermal energy systems, fluid-assisted mineralization, and the sustainable utilization of subsurface resources.

Dey S. et al. (2024) - Nanoscale visualization of high-angle misorientations in quartz-rich rocks using SEM-EBSD and Atomic Force Microscopy. J. Struct. Geol., 183, 105146, https://doi.org/10.1016/j.jsg.2024.105146.

McLaren A.C. (1986) - Some speculations on the nature of high-angle grain boundaries in quartz rocks. Geoph. Monog. Series, 36, 233-245, https://doi.org/10.1029/GM036p0233.

Shimada M. et al. (2002) - Optimization of grain boundary character distribution for intergranular corrosion resistant 304 stainless steel by twin-induced grain boundary engineering. Acta Mater., 50, 2331-2341, https://doi.org/10.1016/S1359-6454(02)00064-2.

Super acceleration from continental to oceanic rifting

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Keywords: continental rifting, oceanic spreading, extension rate acceleration.

Continental rifting and oceanic spreading are end-members of lithospheric extension, yet the transition between them is not a smooth kinematic continuum. Using a representative global dataset of continental rifts, transitional breakup systems and oceanic ridges, we compare extension or spreading rate, surface heat flow, lithospheric thickness and characteristic duration. Continental rifts typically operate at ~0.1-10 mm/yr and may persist for tens to more than one hundred million years, whereas oceanic spreading commonly occurs at ~10-150 mm/yr under a higher heat flow, thinner-lithosphere regime. Transitional systems such as Afar and the Red Sea occupy an intermediate field but already display strong thermal weakening and faster rates. Across the combined dataset, heat flow increases and lithospheric thickness decreases with log-rate moving from continental to oceanic rifting. Regression analysis reveals a non-linear acceleration of extension rates, with an increase of up to one or two orders of magnitude from continental to oceanic domains. This transition reflects a shift from strength-controlled lithospheric rift-resisting to other processes, such as a more effective shearing from below or from above active on the escaping plate. This confirms the asymmetry of rifts and questions the mechanism determining plate tectonics since plates can spread apart without any lateral slab pull. For example, North and South America plates move westerly relative to the mantle, without any attached slab which could drag them, indicating that slab pull is neither necessary nor sufficient to drive the process. We propose that rift acceleration is controlled by progressive lithosphere-asthenosphere decoupling. As the lithosphere thins and ruptures, a continuous lower-viscosity layer in the Low Velocity Zone (LVZ) beneath the western plate with respect to the LVZ of the conjugate plate could explain the faster westerly motion of the plate and the faster spreading rate once the continental lithosphere is spread apart.

Hyperspectral mapping of alteration zones using PRISMA: Kuhpanj case study

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WITHDRAWN

EU-vitis insights: Soil-effect and physiological adaptability of grafted vs. ungrafted *Vitis vinifera* L. in Calabria

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Keywords: EU-vitis, grafting, soil.

In the face of global warming, Mediterranean viticulture urgently requires resilient adaptation strategies. The PRIN2022-funded project EU-vitis evaluates the physiological performance and soil interactions of the 'Magliocco Dolce' grapevine variety in Calabria (Southern Italy), comparing young self-rooted plants with adult grafted vines across different slope positions. The experimental workflow integrated ampelographic observations, molecular analyses, physiological chlorophyll a fluorescence analysis, and pedological investigations to assess spatial variability. The results revealed that grafted grapevines exhibited higher photosynthetic efficiency and a greater Total Performance Index on absorption basis ((PI_{TOT}), than self-rooted plants, which proved more sensitive to diurnal photoinhibition. Notably, grafted vines outperformed self-rooted ones specifically in the downslope sections. Pedological analysis showed significant spatial variability in the grafted vineyard: downslope soil profiles were well-defined and more mature, promoting vigorous plant growth through enhanced nutrient availability and water retention. Conversely, soils in the ungrafted vineyard appeared poorly developed and weakly structured across all slope positions. Consequently, the "soil effect" (the heterogeneity of soil among and within vineyard parcels) represents a crucial factor when comparing grafted and ungrafted systems. However, despite exhibiting lower light energy conservation efficiency than the older, more established grafted plants, the self-rooted vines did not exceed critical failure thresholds, demonstrating a remarkable ability to survive in sandy substrates. Furthermore, the similar performance observed between ungrafted vines and upslope grafted plants indicates that rootstock is not the main determinant of plant vigour in weakly structured soils.

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LIBS quantification of major elements and total carbon in peat soils: Insights into carbon storage and salinity in the Mezzano lowland (Italy)

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Keywords: laser-induced breakdown spectroscopy (LIBS), peat soil, Mezzano lowland.

Laser-induced breakdown spectroscopy (LIBS) is a fast analytical technique, provides real-time elemental analysis (Zhang et al., 2021), and ideal for assessing total soil carbon content. This study investigates elemental and carbon quantification by LIBS in peat soil samples (i.e., surface soil: 0-30 cm, and deep soil: 110-150 cm) from the Mezzano lowland, Italy. LIBS analysis revealed higher Si quantification in deeper soil layers (0-30 cm: 51.6-57.4%; 110-150 cm: 55.8-60.6%), followed by Al (0-30 cm: 15.9-16.7%, and 110-150 cm: 14.7-16.5%), and Ca (0-30 cm: 4.42-8.50%; 110-150 cm: 2.59-6.72%). The other elements such as Fe, Na, Mg, K, Mn, and Ti showed minor compositions across layers. XRF and XRD analyses confirm enrichment of element-specific minerals in deeper horizons, while upper peat-dominated layers are mineral-poor and organic-rich. The quantification of total carbon (TC) by LIBS is achieved with moderate composition, while P and N present low composition across all samples. Mineral phases especially oxides, carbonates, and silicates-exert first-order control on major elements (Si, Al, Fe, Ca, Mg), forming distinct mineral-rich layers in the organic peat matrix. These phases drive systematic correlations between LIBS signals and mineralogy for organic carbon (OC), inorganic carbon (IC), and P partitioning. Recurrent smoldering fires in the Mezzano Lowland reshaped surface (0-10 cm) geochemistry, forming gypsum, anhydrite, and hematite via sulfate transitions (gypsum → anhydrite) during fire burning. Positive correlations among organic, inorganic, and total C reflect well-preserved SOM in peat profiles, with little oxidative loss and ties to carbonate minerals. This makes the LIBS technique ideal for carbon certification. Na rises with depth, pointing to saline groundwater leaching from past marine influence (Macumu et al., 2024). LIBS enables fast, affordable, transparent verification of stock maintenance or gains supporting sustainable farming and EU climate targets.

Macumu P.H. et al. (2024) - Additional sources of salinity and heavy metals from plant residues of peaty horizons in the Po River lowland (Italy). Sci. Total Environ., 957, 177671, https://doi.org/10.1016/j.scitotenv.2024.177671.

Zhang Y. et al. (2021) - Application of laser-induced breakdown spectroscopy (LIBS) in environmental monitoring. Spectrochim. Acta B, 181, 106218, https://doi.org/10.1016/j.sab.2021.106218.

In situ synchrotron XRD investigation of phase stability and structural transitions in kalsilite ($KAlSiO_4$) at high P and T

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Keywords: kalsilite, phase transition, in situ synchrotron X-ray diffraction.

Kalsilite ($KAlSiO_4$) is a diagnostic mineral essential for understanding ultrapotassic magmatism and mantle metasomatism (Lustrino et al., 2020; Innocenzi et al., 2024). Despite its geological significance, the stability limits of its polymorphs under simultaneous high-pressure and high-temperature conditions remain poorly constrained. In this study, we present new in situ angle-dispersive X-ray powder diffraction data collected at the ID06 beamline (ESRF) using a large volume press (LVP).

Two experimental runs were conducted up to approximately 6 GPa and 1000 K. In both experiments, a structural transition was observed from the initial trigonal framework ($P3_1c$) to a high-pressure/high-temperature (HP-HT) phase. This HP-HT phase is characterized by a nepheline-type metric, showing a doubling of the *c*-axis parameter compared to the starting kalsilite. This transition was identified at intermediate P-T conditions (ca. 700 K and 4 GPa), providing the first in situ evidence of such a transformation under combined non-ambient conditions. The post-transition behavior exhibited significant differences between the two runs. In the first run, the transformation proved to be reversible upon cooling; however, the thermal discrepancy between the forward and backward transitions suggests the presence of marked hysteresis. In the second run, the HP-HT polymorph with a nepheline-type cell was metastably preserved down to ambient conditions, indicating an irreversible transformation path possibly depending on the specific P-T trajectory followed.

These results allow for a refinement of the kalsilite phase diagram, providing new constraints for thermodynamic models of metasomatized mantle environments and the characterization of alkali reservoirs in the Earth's interior.

Innocenzi F. et al. (2024) - On the occurrence of kalsilite in melilite-bearing ultrapotassic lavas from the Roman Province (Vulsini Mts., central Italy). Lithos, 482-483, 107704, https://doi.org/10.1016/j.lithos.2024.107704.

Lustrino M. et al. (2020) - Strongly SiO_2-undersaturated, CaO-rich kamafugitic Pleistocene magmatism in Central Italy (San Venanzo volcanic complex) and the role of shallow depth limestone assimilation. Earth Sci. Rev., 208, 103256, https://doi.org/10.1016/j.earscirev.2020.103256.

Nanoscale variations of cation order in columbite-group minerals revealed by 3D electron diffraction

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Keywords: columbite group, cation order, 3D electron diffraction.

Columbite-group minerals (CGMs) are orthorhombic oxides with general formula AB_2O_6 where typically A = Mn^{2+}, Fe^{2+} and B = Nb^{5+}, Ta^{5+}. Depending on the crystallization and thermal history, CGMs may exhibit different degrees of cation order. In the case of complete order, the A and B sites host divalent and pentavalent cations, respectively; conversely, when divalent cations enter the B site and pentavalent ones enter the A site, the degree of order (Q) decreases, eventually leading to a completely disordered end-member where A and B become equivalent. In this latter scenario, the structure retains the same space group as ordered columbite, *Pbcn*, but displays only one site, M, to host the divalent-pentavalent mixed cations. This process results in a shortening of the cell parameter *a*, which becomes one-third (~ 4.8 Å) of the columbite *a* cell parameter (~14.2 Å). Such structure is no longer a columbite-type structure sensu stricto and is instead described as an ixiolite-type structure.

To date, studies on CGMs cation ordering have been performed with X-ray diffraction (Tarantino et al., 2005), Mössbauer spectroscopy (Ausburger et al., 1999) and infrared absorption spectroscopy (Tarantino et al., 2005). In all these works, natural CGMs appear to be highly ordered, with the least ordered crystal having Q = 56.5%.

Here we report the first study on cation ordering using 3D electron diffraction (3DED) on seven crystals of CGMs via transmission electron microscopy (TEM). The crystals originate from the albitized pegmatites of the Vigezzo Valley (Verbania-Cusio-Ossola province, Piedmont, Italy). Our results show that, despite lack of appreciable contrast in TEM and scanning TEM images, the crystals are widely inhomogeneous in terms of Q. By performing dynamical refinement, site occupancies were successfully refined. We compare the degree of order obtained from site occupancy refinement, Q_{dyn}, with that calculated from cell parameters using the Ercit's formula (Ercit, 1986), Q_{par}.

Our work demonstrates that 3DED is capable of providing site occupancies for disordered minerals at a scale unattainable by any other method. Furthermore, CGMs appear to possess an order variability at the nanoscale which has been suggested only once before (Tarantino et al., 2011).

Ausburger M.S. et al. (1999) - Mössbauer Assessment of Cation Disorder in Columbite-Tantalite Minerals. J. Solid State Chem., 143, 219-223, https://doi.org/10.1006/jssc.1998.8090.

Ercit S.T. (1986) - The simpsonite paragenesis. The crystal chemistry and geochemistry of extreme Ta fractionation. PhD thesis, University of Manitoba.

Tarantino S.C. et al. (2005) - Structural properties of $(Mn_{1-x}Fe_x)Nb_2O_6$ columbites from X-ray diffraction and IR spectroscopy. Phys. Chem. Miner., 32, 568-577, https://doi.org/10.1007/S00269-005-0031-4.

Tarantino S.C. et al. (2011) - Rhombic-shaped nanodomains in columbite driven by contrasting cation order. Am. Mineral., 96, 374-382, https://doi.org/10.2138/am.2011.3571.

Fossil pockmark-related carbonate deposits record late Miocene fluid migration within the Majella petroleum system (Central Italy)

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Keywords: methanogenic carbonates, Messinian, petroleum system.

Pockmarks are geomorphological depressions commonly linked to fluid seepage and hydrocarbon migration in modern marine environments, yet their recognition and preservation in the geological record remain poorly documented. Here, we present sedimentological and geochemical evidence for fossil pockmark-related carbonate deposition in the Majella Mountain area, one of the major petroleum systems of Central Italy.

The Colle del Lettuccio carbonate deposits consist of breccias containing reworked lithoclasts derived from the underlying succession, together with microbial boundstones and ooidal grainstones, suggesting localized and short-lived depositional processes controlled by focused fluid discharge. Carbon isotope data show markedly negative $\delta^{13}C$ values, consistent with a thermogenic methane source and supporting a genetic relationship with deep-rooted fluid migration within the petroleum system.

Stratigraphic constraints indicate that these deposits formed within a limited time interval between 5.6 and 5.33 Ma, implying that fluid migration and associated carbonate precipitation occurred over a period shorter than 270 kyr. These findings reveal a previously unrecognized type of fossil pockmark system developed in a carbonate platform setting and provide new insights into the timing, mechanisms, and surface expression of hydrocarbon migration in foreland basin systems. More broadly, this study contributes to improving the identification of fossil fluid-escape structures and highlights their relevance for reconstructing ancient hydrocarbon systems.

Archeogemmology and ancient goldsmithing

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Keywords: archeogemmology, minerals, gems.

Gems and ancient jewels represent particularly complex artefacts due to their intrinsic multi-material nature, combining metals, minerals, glass, and other artificial or composite materials. In recent years, archaeogemmology has emerged as a promising interdisciplinary approach for the study of historical goldsmithing, offering interpretative perspectives that extend beyond traditional gem identification and provenance studies. By integrating gemmological analysis with art-historical, historical, and cultural interpretation, archaeogemmology allows investigation not only of the material nature of gemstones, but also of their symbolic value, technological use, and circulation within historical societies.

Within this framework, the present contribution explores patterns of gemstone selection, reuse, and circulation through a series of case studies focused on Byzantine and medieval sacred jewellery preserved in museums in Central Italy and Vatican City. The research is based on the combined application of non-invasive gemmological observation and portable spectroscopic analyses performed directly on the artefacts, enabling the investigation of mounted gemstones while fully preserving the physical integrity of the objects.

Particular attention is devoted to the use of natural, artificial, and composite gem materials, as well as to the cultural and symbolic significance associated with specific stones in ecclesiastical contexts. The analysed corpus includes more than 1,000 gemstones mounted in objects dating from the 6th to the 16th century CE, providing a broad comparative framework for reconstructing technological practices and material choices across time.

Among the most significant results are new evidence concerning the circulation of both natural and artificial gemstones during the Byzantine and medieval periods (Martiniello et al., 2024; 2025a) ; the symbolic role of gems in reliquaries associated with the reliquaries of the True Cross (Martiniello et al., 2026); the evolution of cutting techniques and surface treatments; the technological and symbolic importance of glass in antiquity; and the unexpected diffusion of composite gemstones from the 13th century onward (Martiniello et al., 2025b).

Overall, the study highlights the potential of archaeogemmology as an interdisciplinary methodological framework capable of connecting mineralogical characterization with broader historical and cultural interpretation, contributing to a more comprehensive understanding of ancient goldsmithing and the social life of gemstones.

Martiniello S. et al. (2024) - The relic and reliquary of St. John the Baptist in Siena (Italy) and their gems. J. Cult. Herit., 67, 443-451, https://doi.org/10.1016/j.culher.2024.04.008.

Martiniello S. et al. (2025a) - The Pace di Siena and its gems. J. Raman Spectrosc., 56, 1254-1278, https://doi.org/10.1002/jrs.70032.

Martiniello S. et al. (2025b) - Composite gems in Medieval era: The art of counterfeiting before the sixteenth century. Eur. Phys. J. Plus, 140, 571, https://doi.org/10.1140/epjp/s13360-025-06505-8.

Martiniello S. et al. (2026) - Jewelled Byzantine and medieval reliquaries of the true cross: Peridots and other gemstones in material and symbolic perspective. J. Raman Spectrosc., 1-30, https://doi.org/10.1002/jrs.70172.

An integrated multi-scale framework for coastal aquifer vulnerability in the Volturno Plain, southern Italy

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Keywords: coastal aquifer vulnerability, multi-scale integration, saltwater intrusion.

Coastal aquifers are increasingly threatened by salinization, but in low-lying and stratigraphically complex coastal plains their vulnerability cannot be explained by sea-level rise, groundwater abstraction or land subsidence alone. The Volturno Plain, southern Italy, represents an emblematic Mediterranean case study where inherited Quaternary stratigraphic architecture, present-day hydrogeological dynamics, subsidence, river-sea interaction and anthropogenic pressure interact across multiple spatial and temporal scales.

Here we propose a multi-scale Earth-system framework to reinterpret coastal aquifer vulnerability by integrating geological, geomorphological, hydrogeological, geophysical, hydrochemical and ecological evidence. The approach builds on a critical synthesis of previous studies and on ongoing activities within the SAL.WE. project, including georeferenced borehole databases, hydrostratigraphic reconstruction, Electrical Resistivity Tomography, CTD profiling, groundwater and surface-water observations, subsidence analysis and coastal-system assessment.

The Volturno case shows that present-day salinization patterns are not uniformly distributed and do not reflect a single advancing saline front. Instead, they emerge from the interaction between inherited depositional elements, such as the MIS 5 marine ingression, the Holocene transgression and the infilling of the Last Glacial Maximum paleovalley, and active drivers including relative sea-level rise, land subsidence, seasonal pumping and low hydraulic gradients. The Quaternary evolution of the plain provides the long-term stratigraphic template controlling aquifer architecture and groundwater pathways (Amorosi et al., 2012), while satellite interferometry has shown that subsidence acts as a major amplifier of coastal vulnerability (Matano et al., 2018). Hydrochemical and isotopic evidence helps distinguish active marine intrusion from residual or fossil salinity (Colombani et al., 2024), whereas geophysical imaging highlights the spatial continuity of low-resistivity bodies and the role of subsurface heterogeneity in controlling saline groundwater pathways (Tarallo et al., 2023).

By making different datasets and disciplinary approaches “speak to each other”, the proposed framework moves beyond sectoral interpretations and supports a system-scale understanding of coastal aquifer vulnerability. The Volturno Plain is therefore presented as a natural laboratory for linking geological inheritance, present-day environmental change and future groundwater-risk assessment. This perspective is transferable to other Mediterranean coastal aquifers affected by stratigraphic heterogeneity, human pressure and climate-driven relative sea-level rise.

Amorosi A. et al. (2012) - Late Quaternary incision and deposition in an active volcanic setting: The Volturno valley fill, southern Italy. Sediment. Geol., 282, 307-320, https://doi.org/10.1016/j.sedgeo.2012.10.003.

Colombani N. et al. (2024) - Unravelling the salinity origins in the coastal aquifer/aquitard system of the Volturno River (Italy). Water Res., 263, 122145, https://doi.org/10.1016/j.watres.2024.122145.

Matano F. et al. (2018) - Subsidence Trends of Volturno River Coastal Plain (Northern Campania, Southern Italy) Inferred by SAR Interferometry Data. Geosciences, 8(1), 8, https://doi.org/10.3390/geosciences8010008.

Tarallo D. et al. (2023) - Geophysical assessment of seawater intrusion: the Volturno Coastal Plain case study. Appl. Water Sci., 13, 234, https://doi.org/10.1007/s13201-023-02033-x.

Seismological experiment in the south Adriatic Sea for imaging the lithosphere-asthenosphere system

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Keywords: geophysics, OBS, broadband seismic stations.

The Mediterranean region offers a unique opportunity to study the driving forces that cause the slow-moving of Africa and Eurasia plates, which create a complex mosaic of lithospheric blocks and orogenic belts. To date, the geological history of these blocks and their boundaries remains poorly constrained and many of these are offshore. In this context, the SAKURA research line within the ROSE (Reinforcement of the Observational Systems of the Earth) infrastructural project of INGV funded by the Italian Ministry of University and Research, was born with the purpose to investigate lithosphere-asthenosphere coupling in the Mediterranean through integrated geophysical observations, offshore monitoring experiments, and advanced geodynamic and petrophysical modeling. We focus here on the seismological experiments, funded by SAKURA, with the aim to produce high-resolution data to obtain a detailed characterization of the asthenosphere and lithosphere at the Adriatic and Tyrrhenian scale. The first step is the implementation of offshore temporary monitoring systems with the installation of broadband Ocean Bottom Seismometers (OBS) and GNSS antennas that complement the existing national and European infrastructures and initiatives (such as AdriaArray). Twenty OBS were deployed in the Southern Adriatic Sea in May 2026 in a 40-45 km grid for one year, thanks to the TRACE project, which provided ship time aboard the CNR research vessel Gaia Blu, carrying out multidisciplinary geophysical investigations in the area (collaboration with ISMAR-CNR, University of Modena and Reggio Emilia, Dalhousie University, University of Zagreb and IPGP). This offshore experiment is integrated with the installation of five temporary broadband seismic stations along the Apulian coast. The instruments will record data for approximately 12 months and are expected to provide high-quality datasets. The network configuration was planned to ensure a homogeneous acquisition coverage, which is essential for detailed structural imaging.

We present the configuration of the new instruments (OBS and onshore seismic stations) installed within the SAKURA project, along with the first acquired data and prospective future applications.

Integrated multi-analytical study of lavender jadeite: Insights into natural and treated materials

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Keywords: lavender jadeite, multi-analytical characterisation, gem treatment identification.

Jadeite is a sodium-aluminium pyroxene with the ideal chemical formula $Na(Al,Fe^{3+})Si_2O_6$ (Hughes, 2022). In gem-quality material, it occurs as a compact aggregate of fibrous to granular crystals and represents one of the principal mineral species encompassed by the commercial term "jade", together with nephrite, omphacite, and kosmochlor. Among its varieties, lavender jadeite has generated increasing gemmological interest, owing to its distinctive lilac to violet hues and relative rarity. Its natural colouration is generally attributed to Mn^{3+} substituting for Al^{3+} within the crystal structure, potentially associated with other contributions (Lu, 2012; Zhao et al., 2026). The high commercial demand and limited availability of gem-quality material have encouraged the widespread use of artificial enhancement treatments, aimed at improving both transparency and colour saturation. In gemmological terminology, untreated materials are classified as Type A, while bleached and subsequently polymer-impregnated materials are classified as Type B, and artificially dyed materials as Type C, including possible combined treatments. The identification of such modifications is essential for the correct classification and commercial evaluation of jadeite, yet it still represents a significant analytical challenge, particularly in more sophisticated cases. This study presents an integrated multi-analytical approach for the compositional, structural, and spectroscopic characterisation of natural and treated lavender jadeite samples from different localities. The investigation combined different techniques able to provide morphological-textural (SEM-EDS, X-ray micro-computed tomography), structural (XRPD), spectroscopic (UV-Vis-NIR and FTIR-DRIFT), and compositional (EMPA-WDS and LA-ICP-MS) data in order to identify diagnostic parameters useful both for the discrimination of artificial treatments and for a better understanding of the chromophore mechanisms in untreated materials. FTIR-DRIFT spectroscopy enabled the detection of organic substances associated with different degrees of anthropogenic alteration, ranging from superficial treatments to pervasive polymer impregnation extending throughout the internal porous network of the material. Particularly significant was the identification of samples subjected to combined treatments, which are often difficult to recognise using only conventional gemmological approaches. The results highlight not only previously unreported aspects related to the enhancement processes of lavender jadeite, but also the need for advanced multi-analytical protocols for the reliable characterisation of particularly complex gem materials.

Hughes R.W. (2022) - Jade - A Gemologist's Guide. Lotus Publishing, Bangkok, 536 pp.

Lu R. (2012) - Color origin of lavender jadeite: An alternative approach. Gems & Gemol., 48(4), 273-283, http://dx.doi.org/10.5741/GEMS.48.4.273.

Zhao M. et al. (2026) - Jadeite from Guatemala: New Observations and Distinctions Among Lavender and Black Jade. Crystals, 16(2), 130, https://doi.org/10.3390/cryst16020130.

Microbially mediated Jurassic Fe-Mn crusts from western Sicily: Genesis and palaeoenvironmental significance

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Keywords: Fe-Mn crusts, Jurassic, palaeoceanography.

Jurassic Fe-Mn crusts associated with hardgrounds represent key archives of condensed sedimentation, seawater chemistry and benthic microbial activity on pelagic carbonate platforms. This study presents an integrated sedimentological, mineralogical and geochemical investigation of Fe-Mn crusts from two Jurassic successions (Rocca Che Parla and Contrada Nadorello) cropping out in western Sicily. These crusts developed on sediment-starved structural swells formed by extensional tectonics related to Pangea rifting and mark the transition from peritidal to condensed pelagic limestone. Microfacies analyses reveal finely laminated fabrics and *Frutexites* arborescent textures, indicating slow, episodic growth at the sediment-water interface in conditions of very low sedimentation rates and mediated by benthic microbial communities. Mineralogical and geochemical data obtained through X-ray diffraction, secondary electron microscopy and X-ray microfluorescence analyses show that the crusts are dominated by Mn- and Fe-oxyhydroxides, with mineralogical differences between the sections: hollandite prevails at Rocca Che Parla, whereas todorokite dominates the laminated crusts at Contrada Nadorello. Trace-element distributions (Ni, Co, Cr) suggest efficient scavenging by Mn-oxyhydroxides and point to early diagenetic redistribution processes. This dataset supports a mixed genetic model involving hydrogenetic precipitation from seawater mediated by benthic microbial communities, early diagenetic transformation of Mn phases, and a dispersed hydrothermal contribution acting as an external metal source rather than direct vent-related precipitation.

Pakistani topaz as a natural laboratory for origin discrimination

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WITHDRAWN

Fluid and element recycling and the timescales of fluid flow in the deep Earth

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Keywords: fluid, timescales, deep Earth.

Earth is the only known planet where plate tectonics and surface water coexist. Although water is only a small fraction of the entire Earth's mass, it exerts a profound influence on geodynamics and global cycling of elements. This coupling is most effective in subduction zones, where burial of seawater-altered oceanic lithosphere into the mantle is accompanied by mineral dehydration reactions and release of aqueous fluids. These fluids trigger mantle metasomatism, arc magmatism and generation of continental crust, while contributing to the long-term return of volatiles to the surface and sustaining planetary habitability.

Deep fluids also affect the tempo of geological processes. Recent studies indicate that fluid release and fluid-rock interaction at depth are not necessarily slow processes lasting millions of years. Instead, they may occur as spatially localized, transient pulses which can unfold in less than one million years, while reaction halos around metamorphic veins indicate that fluid-rock interaction may develop over timescales of weeks to months. These durations approach the ones of seismic cycles and are orders of magnitude faster than plate motions and long-term metamorphic evolutions.

Transformative processes in the deep Earth can therefore couple with short-lived mechanical events and operate on timescales comparable to those of human lives. This emerging view challenges the traditional perception of geological processes as uniformly slow; rather, the deep Earth appears as a dynamic system in which fluid-mediated transformations occur through episodic, rapid events. Recognizing the pulsed nature of deep fluid flow has important implications for models of element recycling, mantle heterogeneity, and the temporal framework of geodynamic processes, as well as for understanding the feedback between the solid Earth and the conditions that sustain life.

The necessary history of Earth and Life that someone may one day ask us to tell

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Keywords: Earth system science, Earth, knowledge.

What story would we be asked to tell if someone, from the cosmos, could ever reach us? If someone, from very far away, pointed their telescope toward Earth, they would see things that - with very high probability - differ from the rest of the cosmos. These intelligent life forms would likely posses knowledge equivalent to our mathematics, physics, and engineering - it would be unlikely that their questions would concern these subjects. And they would know a great deal about the geology of our planet as observable from its surface. What they would not know, however, is how the deep Earth works, and how this unique machine - at least within the Solar System - has allowed Life to emerge and persist for billions of years.

The story they would ask us to tell is that of a planet which - very early in its history - encountered Life, and which Life then claimed as its own, contaminating its depths to the point of controlling its very functioning. It is a story that, to be told, requires the combined effort of every geological discipline and its interactions with the biological world. This is a necessary story: it does not cease, and we are in great need of it. And only we will be able to tell it.

The role of diamond defects in identifying synthetic stones: Statistics and characterization within the D-Z scale

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Keywords: diamond, defects, comprehensive overview.

The experimental analysis of diamond relies on the accurate interpretation of its chemistry and a comprehensive understanding of its complex defect states. While the direct and indirect effects of the crystal's physicochemical and optical properties - dynamic and unique to each specimen - can manifest on a macroscopic scale, a systematic spectroscopic approach has become essential for diagnostic purposes. The analytical distinction between natural and synthetic diamonds is established by modularly reconstructing the indelible history of the crystal's growth process. Ultimately, the ability to conduct such investigations through a comprehensive overview depends on prioritizing analytical complementarity, which remains the only definitive tool for integrated information management.

S8.

Minerals as fundamental components of Earth and planetary bodies

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Crystal chemistry of axinite-(Mn)-tinzenite series minerals from the Val Graveglia Manganese District (Italy), and relations with axinite-group minerals

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Keywords: axinite-group minerals, tinzenite, Mn ore deposits.

Fifteen Mn-rich axinite samples from the Val Graveglia Manganese District (Liguria, Italy) were investigated by electron microprobe and single-crystal X-ray diffraction to define the crystal chemistry of the axinite-(Mn)-tinzenite solid solution. The samples span the full compositional range between the two endmembers (5-83 mol% tinzenite) and are described by the general crystal-chemical formula: $^{X1}Ca_2{}^{X2}(Ca_{2-x}Mn^{2+}{}_x)^{Y}(Mn^{2+}{}_{2-w}Mn^{3+}{}_w)^{Z1}(Al_{2-y}Mn^{3+}{}_y)^{Z2}Al_2{}^{T5}B_2{}^{(T1-4)}Si_8O_{30}(OH_{2-w}O_w)$, where $0 \leq x \leq 2$ apfu, $0 \leq w$ £ ≤ 0.1, and $0 \leq y \leq 0.2$.

Homogeneous compositions are only observed near the end-members, whereas most intermediate samples display strong chemical zoning, with axinite-(Mn)-rich cores and tinzenite-rich rims. This zoning records a progressive Mn enrichment and Ca depletion during late-stage re-equilibration under decreasing temperature conditions. The structural site *X*1 is fully occupied by Ca, whereas *X*2 hosts variable amounts of Ca and Mn^{2+}, which control the evolution from axinite-(Mn) to tinzenite. The *Y* site is dominated by Mn^{2+}, and both *Z*1 and *Z*2 sites are dominated by Al. Minor contents of Mn^{3+} are present, mainly ordered at the *Z*1 site, with Mn^{3+} partially substituting Al and showing the same substitution mechanism and ordering arrangement previously observed for Fe^{3+} in (Fe,Mn)-axinite samples. For all samples the Mn^{3+}/Mn_{tot} ratio averages ~8%, a value that is consistent with sub-oxidizing metamorphic conditions.

The structural analysis of selected samples, compositionally closest to the endmembers, reveals that in axinite-group minerals the cation distribution correlates with the relative size and distortion of the coordination polyhedra, with cations with larger ionic radii preferentially occupying the larger and more distorted octahedra.

Unit-cell parameters *a*, *b*, *c*, and *V* increase linearly from axinite-(Mg) to axinite-(Fe) to axinite-(Mn) due to occupancy of the *Y* site by the larger divalent cations but decrease sharply from axinite-(Mn) to tinzenite, that is for $Mn_{tot} > 2$ apfu, due to incorporation of additional $^{X2}Mn^{2+}$ replacing ^{X2}Ca. The unit-cell contraction, particularly along the **b** axis, reflects coupled cation substitutions involving $^{X2}Mn^{2+}$ and $^{Z1}Mn^{3+}$.

The mineral assemblage observed in the Val Graveglia Manganese District [braunite + axinite-(Mn) or tinzenite + quartz ± rhodonite ± piemontite ± carbonates] were formed under sub-oxidizing conditions, within the prehnite-pumpellyite to lower greenschist facies. These results indicate that axinite-group minerals can record subtle variations in redox state and Ca activity during low-grade metamorphism, providing potential structural proxies for Mn oxidation and fluid-rock interaction in metamorphosed Mn deposits.

Sulfosalts from the hydrothermal veins of the Apuan Alps (Tuscany, Italy): New crystal chemical data

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Keywords: chovanite, izoklakeite, jaskólskiite.

The Apuan Alps (Tuscany, Italy) represent a reference locality for the study of sulfosalts in hydrothermal veins hosted in metamorphic settings. Currently, a total of 75 sulfosalt species have been identified, 27 of them having here their type locality. Several of them occurs as well-crystallized specimens, providing good materials for crystal chemical studies. New data on three acicular lead sulfosalts are here presented, i.e., chovanite, izoklakeite, and jaskólskiite.

Chovanite, ideally $Pb_{28}Sb_{30}S_{72}O$, was previously reported from the Pollone and Monte Arsiccio mines (Biagioni & Moëlo, 2017). By using some specimens collected in the 1990s, chovanite was identified also in the sulfosalt assemblage of the Buca della Vena mine, where several oxysulfosalts were first discovered in the 1990s and 2000s. Chovanite occurs as black thin acicular crystals associated with sphalerite. Its unit-cell parameters are a = 48.317(2), b = 4.1042(2), c = 34.2338(16) Å, β = 105.914(2)°, V = 6528.5(5) Å^3. Owing to the crystal thinness, only very weak reflections doubling the b parameter were observed. Observed structural features (R_1 = 0.0706 for 5718 observed reflections) agree with the ideal formula and with the occurrence of O atoms.

Izoklakeite, ideally $Cu_2Pb_{26}(Bi,Sb)_{20}S_{57}$, was previously known from the cavities of the Seravezza marble quarries (Orlandi et al., 2010), but its crystal structure was not refined. New data have been collected. Its empirical formula is $Cu_{1.82(4)}Ag_{0.83(4)}Hg_{0.12(4)}Pb_{24.26(14)}Bi_{13.66(11)}Sb_{7.16(14)}As_{0.15(7)}S_{52.61(41)}Se_{4.21(16)}$. Its unit-cell parameters are a = 34.205(3), b = 38.104(2), c = 4.0686(3) Å, V = 5302.9(6) Å^3, space group *Pnnm*. The structure has been refined to R_1 = 0.0574 for 6572 observed reflections. A further occurrence of izoklakeite was identified from the Frigido mine, where it occurs in quartz veins along with chalcopyrite. Its empirical formula is $Cu_{1.47(7)}Ag_{0.18(5)}Fe_{0.42(4)}Pb_{25.95(14)}Bi_{12.31(43)}Sb_{7.68(43)}S_{56.37(44)}Se_{0.06(3)}$. Its unit-cell parameters are a = 34.089(5), b = 38.081(6), c = 4.0674(6) Å, V = 5280.1(14) Å^3, space group *Pnnm*. The structure has been refined to R_1 = 0.0738 for 6104 observed reflections and 333 parameters. The structural study of these two occurrences, having a different chemistry, allows to improve the understanding of the crystal chemistry of this kobellite homologue.

Finally, jaskólskiite, ideally $Cu_xPb_{2+x}(Sb,Bi)_{2-x}S_5$, was identified from the Frigido mine, as thick striated crystals in a quartz vein. Its empirical formula is $Cu_{0.18(1)}Pb_{2.16(3)}(Sb_{1.43(2)}Bi_{0.33(1)})_{\Sigma 1.76}S_{4.99(1)}$. Unit-cell parameters are a = 4.0830(9), b = 11.311(3), c = 19.786(5) Å, V = 913.8(4) Å^3, space group *Pmcn*. The refinement converged to R_1 = 0.0713 for 1599 observed reflections.

Biagioni C. & Moëlo (2017) - Lead-antimony sulfosalts from Tuscany (Italy). XIX. Crystal chemistry of chovanite from two new occurrences in the Apuan Alps and its 8 Å crystal structure. Mineral. Mag., 81, 811-831, https://doi.org/10.1180/minmag.2016.080.134.

Orlandi P. et al. (2010) - Lead-antimony sulfosalts from Tuscany (Italy). X. Dadsonite from the Buca della Vena mine and Bi-rich izoklakeite from the Seravezza marble quarries. Period. Miner., 79, 113-121, https://doi.org/10.2451/2010PM0006.

On mineral groups, formally approved by the IMA/CNMNC or not, and on the revision of the pyrochlore supergroup nomenclature

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Keywords: mineral groups, CNMNC, pyrochlore supergroup.

So far the IMA/CNMNC formally approved 4 families, 37 supergroups, and 34 groups, after voting and approval of specific reports.

The hierarchical subdivision can be very helpful for rationalizing and homogenizing nomenclature, and for writing in a similar way the chemical formulae of closely related minerals.

Minerals belonging to officially recognized groups and supergroups represent more than 30% of the >6,200 existing species. If we include mineral belonging to not formally established groups we encompass over 62% of the mineral kingdom. As CNMNC we plan to officially recognize this second batch of mineral groups soon.

Of course mineral groups do not remain fixed forever, firstly because new mineral species are discovered every month, and secondly because the grouping criteria can change over time. For instance, IMA-approved reports for the nomenclature and classification of amphiboles were published in 1978, 1997, 2003, and 2012, and a new one is currently in preparation.

Something similar is happening with pyrochlores, another important group of minerals. The first report (Hogarth, 1977) classified 16 valid species into three sub-units: pyrochlore group (7), microlite group (6), betafite group (3). After a second report (Atencio et al., 2010) the pyrochlore group was elevated to the rank to supergroup (according to Mills et al., 2009) and many minerals were discredited as inadequately described; only seven minerals survived, having four different rootnames. Shortly thereafter seven more mineral were "revived" (Christy & Atencio, 2013). Since then several new minerals of the pyrochlore supergroup were discovered, reaching a total number of 40.

Despite the rather simple general formula ($A_2B_2X_6Y$), the large number of different chemical constituents (including vacancy) that may substitute to each other at the key sites results in some inconsistencies between the mineralogical name and the ideal formula.

The new proposal on the nomenclature and classification of pyrochlores (currently under evaluation by the CNMNC) is based on the site-total-charge approach, aiming at defining unique end-member formulae for all the known species. The names of minerals will assume the form *y-a-rootname*, where *y* and *a* are adjectival modifiers which reflect the dominant constituent at *Y* and *A*; the adjectival modifiers and the rootname are always separated by hyphens. The rootname is dictated by the dominant constituent at *B* (elsmoreite: $B = W$, microlite: $B = Ta$, pyrochlore: $B = Nb$, roméite: $B = Sb$, coulsellite: $B = Mg_{0.75}Al_{0.25}$, ralstonite: $B = Al$, betafite: $B = Ti$, lewisite: $B = Ti_{0.5}Sb_{0.5}$, jixianite: $B = Fe^{3+}_{1.33}W_{0.67}$, "new root name 1" : $B = Ti_{0.5}Nb_{0.5}$, "new root name 2" : $B = Nb_{0.5}W_{0.5}$). The rootname also corresponds to the group name if minerals with the same rootname are at least two.

Atencio D. et al. (2010) - The pyrochlore supergroup of minerals: nomenclature. Can. Mineral., 48, 673-698, https://doi.org/10.3749/canmin.48.3.673.

Christy A.G. & Atencio D. (2013) - Clarification of status of species in the pyrochlore supergroup. Mineral. Mag., 77, 13-20.

Hogarth D.D. (1977) - Classification and nomenclature of the pyrochlore group. Am. Mineral., 62, 403-410.

Mills S.J. et al. (2009) - The standardisation of mineral group hierarchies: application to recent nomenclature proposals. Eur. J. Mineral., 21, 1073-1080, https://doi.org/10.1127/0935-1221/2009/0021-1994.

Alluaudite-type arseniates at Valletta Mine (CN, Italy)

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Keywords: alluaudite type arsenates, Valletta mine, Raman spectroscopy.

The Valletta mine is a small locality mined for iron in the 15th Century and probably hastily abandoned both due the uneconomic mixture of hematite with manganese ores and because it is located at a very high altitude (2536 m above sea level). Yet Valletta mine has gained importance recently since the discovery of new mineral species containing arsenic as a defining chemical element. Valletta mine is the type locality of 4 minerals of the arsenbrackebuschite group (grandaite $Sr_2Al(AsO_4)_2(OH)$, canosioite $Ba_2Fe^{3+}(AsO_4)_2(OH)$, lombardoite $Ba_2Mn^{3+}(AsO_4)_2(OH)$ and aldomarinoite $Sr_2Mn^{3+}(AsO_4)_2(OH)$) and one pyroxenoid (braccoite, $NaMn^{2+}_5[SiAsO_{17}(OH)](OH)$) and it is also the co-type locality of castellaroite, $Mn^{2+}_3(AsO_4)_2 \cdot 4.5H_2O$, piccoliite $NaCaMn^{3+}_2(AsO_4)_2O(OH)$ and rüdlingerite, $Mn^{2+}_2V^{5+}As^{5+}O_7 \cdot 2H_2O$) (Cámara et al., 2022 and references therein).

Arsenates belonging to the alluaudite group have been reported in Valletta mine but never studied systematically. This was the subject of Conforti's M.Sc. thesis (Conforti, 2024). The study of samples provided by mineral collectors of the AMI (Associazione Micromineralogica Italiana) allowed to characterize the compositions and crystal structure by means of single crystal X-ray diffraction, X-ray fluorescence and Raman spectroscopy.

Alluaudite type arsenates in Valletta show a continuous solid solution starting from manganobadalovite $NaNaMn^{2+}(MgFe^{3+})(AsO_4)_3$, toward samples showing compositions richer in Mn^{2+} and Mn^{3+} corresponding to a Mn^{3+}-rich $NaNaMn^{2+}(Mn^{2+}Fe^{3+})(AsO_4)_3$ yet unclassified end member composition. Eventually, samples with $Mn^{3+} > Fe^{3+}$ may be found in the future. Interesting relation among shifts of Raman peaks and composition have been also observed and help for a broad recognition and classification of these phases. As a matter of fact, alluaudite type arsenates are easily confused with arsenbrackebuschite group minerals and, in case of very rich Mn samples, with piccoliite. Access to a fast and non-destructive approach as Raman spectroscopy allows for a preliminary successful identification and classification of these minerals.

Cámara F. et al. (2022) - Piccoliite, $NaCaMn^{3+}_2(AsO_4)_2O(OH)$, a new arsenate from the manganese deposits of Montaldo di Mondovì and Valletta, Piedmont, Italy. Mineral. Mag., 87(2), 204-217, https://doi.org/10.1180/mgm.2022.129.

Conforti V. (2024) - Studio cristallochimico di arseniati tipo-alluaudite provenienti dalla miniera di Valletta, Canosio, Val Maira (Cn). Tesi Magistrale, Università degli Studi di Milano, 104 pp. (in Italian).

When the crystal is too small, but still matters!

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Keywords: electron diffraction, nanometric crystals, crystal structure refinement.

A mineral can be described based on its physical properties and/or its chemical composition. However, as many minerals have the same, or similar, compositions but different crystal structures (i.e., polytypism or polymorphism), it is of the utmost importance to determine the crystallographic properties of the minerals one is studying. Apart from accurate phase identification, this information can reveal aspects of cation or anion ordering; polyhedral coordination, size, distortion; structure topology; defects, etc. In turn, this information can be used in various geological applications including geothermobarometry, mineral equilibria, geospeedometry and so on.

For decades, mineralogists have relied on X-ray diffraction, particularly single crystal techniques, to obtain pertinent and accurate information in a time-efficient manner. When the crystal of interest is too small, or chemically heterogeneous, high brilliance sources (used in laboratories and synchrotron facilities) have allowed crystallographers to analyze samples down to a few microns in size. Minerals grains of interest that are submicrometric in size reduces the possibility to use powder diffraction and Rietveld refinement techniques. However, this requires sufficient and homogeneous material, which is not the case when dealing with mineral inclusions or very rare materials.

The development of higher sensitivity detectors in the last decade has allowed researchers to investigate submicrometric crystals via electron diffraction. Nowadays, single crystal diffraction techniques can be applied to nanometric crystals using transmission electron microscopes or the new electron diffractometers. However, the strong interaction between electrons and matter (i.e., mineral samples) leads to a highly dynamic interaction that makes it difficult to use the established approach for structure refinements developed for X-ray diffraction data. Over the last decade, development of specialized software, capable of managing electron diffraction data, has made structural refinement based on such dynamic data possible (e.g., see Palatinus et al., 2015; Gemmi et al., 2026).

We will show the results obtained by the first electron diffractometer in Italy applied to Earth Science research in the context of the ERC Advanced project MADAM (grant #101199315).

Gemmi M. et al. (2026) - Round robin on structure analysis from 3D electron diffraction data. IUCrJ, 13(2), 198-210, https://doi.org/10.1107/S205225252600045X.

Palatinus L. et al. (2015) - Structure refinement using precession electron diffraction tomography and dynamical diffraction: tests on experimental data. Acta Crystallogr. B, 71(6), 740-751, https://doi.org/10.1107/S2052520615017023.

Cave sediments phosphatisation at Grotte de la Roquette (Gard, France): Micromorphological and minerogeochemical characterisation

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Keywords: phosphatisation, cave mineralogy, Grotte de la Roquette.

This work presents the comprehensive characterisation of the complex secondary mineral assemblages occurring at Grotte de la Roquette(Gard, Occitania, France). The integration of micromorphological, geochemical and mineralogical methods allows to link the phosphatisation event to the ancient presence of bat colonies at the site, as already suggested by Bruxelles et al. (2022) with reference to the widespread biocorrosion morphologies. The vertical distribution along the studied sediment cores of different mineralogical species (namely, taranakite, leucophosphite, variscite, crandallite, montgomeryite, hydroxylapatite), and the demonstrated correlations with major, minor and trace element composition allow to comprehensively reconstruct the multi-stage evolutionary history of the sediments. Their post-depositional alteration, caused by infiltration of guano-derived acidic fluids, is characterised by the coupling of intense clay dissolution and phosphate deposition. Integrating weathering indices with the spatial distribution of K, Ca, Si, P, and Al, reveals that differential mobility and preferential leaching are the main drivers for variations in the relative weight fractions of detrital and authigenic minerals within the stratigraphic sequence.

Bruxelles L. et al. (2022) - Origin of the asymmetry of certain fossil galleries: the major role of biocorrosion as exemplified in the Roquette cave (Gard, France). Karstologia Mémoires, 18th International Congress of Speleology - Savoie Mont Blanc, 4(24), 305-308.

In vitro bioactivity of a calcium silicate-based sealer: SEM-EDX surface characterization at different setting times

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Keywords: SEM-EDX, calcium silicate, hydroxyapatite.

Calcium silicate-based cements provide a useful model system to investigate calcium-driven mineral precipitation processes in aqueous environments. This study evaluates the evolution of mineral phases formed by a premixed bioceramic sealer (EndoSequence BC Sealer) in contact with a synthetic physiological solution (HBSS), with particular focus on nucleation pathways and phase transformations.

Disk-shaped specimens (48 h and 72 h setting time) were immersed for 10 and 28 days and analyzed by SEM-EDX to investigate morphological and compositional evolution (Ca, Si, P, Zr).

At 10 days, the 48 h samples showed well-defined micrometric euhedral crystals with planar faces and sharp edges, morphologically consistent with rhombohedral or pseudo-pyramidal habits, attributable to Ca-rich phases (calcite and/or portlandite) formed during early hydration. These crystals were embedded in a fine microcrystalline matrix. EDX analysis revealed dominant Ca, Si and Zr peaks with Ca/P > 2, indicating a pre-apatitic stage. Brighter microcrystals, attributed to Ca-silicate and Zr-bearing phases (ZrO_2 or Ca-Zr silicates), appeared as discrete particles or partial coatings over Ca-rich crystals, suggesting secondary precipitation processes. The 72 h samples exhibited a more advanced evolution, with early nucleation of fine granular deposits, indicating faster mineralization kinetics.

At 28 days, both groups showed a marked transformation, with development of a continuous mineral layer. Previously formed Ca-rich crystals were partially or completely overgrown by dense micro- to nanoscale spheroidal aggregates distributed both on crystal surfaces and on the surrounding matrix. These aggregates display nanostructured textures consistent with poorly crystalline carbonated hydroxyapatite. EDX data confirm this evolution, with decreasing Si, increasing Ca and P, and Ca/P ratios between 1.5 and 1.8. Residual Zr signals persist within the mineralized layer.

The results indicate a multi-step precipitation pathway involving: (i) formation of Ca-rich phases (calcite/portlandite-like), (ii) development of Ca-Si and Zr-bearing phases forming a microcrystalline matrix and coatings, and (iii) nucleation and growth of Ca-P phases leading to a continuous apatite layer. The observed overgrowth relationships highlight the role of early Ca-rich crystals as transient nucleation substrates. Faster evolution in the 72 h samples suggests that initial reaction kinetics strongly control phase development.

Preliminary insights into Fe oxidation state and coordination geometry in lunar impact glasses

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Keywords: Impact glasses, lunar meteorites, XAS.

Impact glasses and melt veins in lunar meteorites provide crucial insights into the transient high-temperature events and redox conditions characterizing asteroid impact on the Moon's surface. While the bulk mineralogy of these meteorites is well constrained (Korotev, 2005), assessing the exact oxidation state of iron (e.g., Fe^{2+}/Fe^{3+} and the potential presence of nanophase Fe^{0}) within amorphous impact-generated micro-domains remains analytically challenging. It has been demonstrated that the local oxidation state and coordination geometry of Fe can be qualitatively and quantitatively investigated through X-ray Absorption Spectroscopy (Wilke et al., 2001; Giuli et al., 2002). In this study, Fe K-edge XANES (X-ray Absorption Near Edge Structure) spectra were collected at the European Synchrotron Radiation Facility (ESRF) in Grenoble at the ID21 beamline. Selected micro-areas of impact glass spherules and glass veins were analysed within the lunar polymict breccias Bir Ounane 005 and NWA 5744. The general shape of the XANES spectra are consistent with the amorphous nature of the probed glasses, lacking the long-range order typical of the surrounding crystalline matrix, both in the investigated veins and in the spherules. The absorption edge energy position is consistent with the presence of divalent Fe (Fe^{2+}). Analysis of the pre-edge peak is also consistent with Fe being predominantly divalent. These distinct spectral signatures offer a direct window into the redox environment during transient impact melting. Crucially, these initial observations on natural meteoritic samples serve as a fundamental comparative baseline within a broader, ongoing experimental framework focused on the synthesis and advanced characterization of lunar regolith analogues. Data collected for impact glasses in lunar meteorites can greatly help in choosing the best experimental conditions for synthetising glasses of analogous composition to be used in experiments for sintering, growth of bacterial strains, soil cultivability, and oxygen extraction.

Giuli G. et al. (2002) - Iron local structure in tektites and impact glasses by extended X-ray absorption fine structure and high-resolution X-ray absorption near-edge structure spectroscopy. Geochim. Cosmochim. Ac., 66, 4347-4353, https://doi.org/10.1016/S0016-7037(02)01030-X.

Korotev R.L. (2005) - Lunar geochemistry as told by lunar meteorites. Chem. Erde-Geochem., 65, 297-346, https://doi.org/10.1016/j.chemer.2005.07.001.

Wilke M et al. (2001) - Oxidation state and coordination of Fe in minerals: An Fe K-XANES spectroscopic study. Am. Mineral., 86, 714-730, https://doi.org/10.2138/am-2001-5-612.

Synthesis of a new lunar regolith analogue based on the microchemical and mineralogical characterization of lunar meteorites

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Keywords: lunar meteorites, lunar simulants, microchemical and mineralogical characterization.

Lunar soil simulants have been produced since 1971, as the upcoming space missions needed astronauts to be trained in conducting scientific field works on the Moon's surface (Slabic et al., 2024). However, the first lunar soil simulants were not satisfactory in terms of chemistry and mineralogy, as they were focused on having the proper engineering properties (Taylor et al., 2016). Due to the scarcity and limited accessibility of real lunar soils and rocks samples, and as the interest in lunar colonization with In-Situ Resource Utilization (ISRU) is growing, the production of lunar soil simulants has increased over the years (Taylor et al., 2016). The objective of our work is to develop a new tunable lunar regolith simulant providing a reliable analog in terms of both mineralogy and bulk chemical composition that could be used for experiments on element extraction and for sintering experiments aimed at the production of building materials. In order to do this, we plan to synthesize some mineral components, e.g. anorthite, glass, and to find natural terrestrial analogs with suitable composition for other mineral components, e.g. olivine, pyroxene, and add them in adequate amounts. Anorthositic rocks are major constituents of the highland regions of the Moon (Jaumann et al., 2012), so we aim at reproducing the composition of a regolith whose major component is anorthositic. As lunar meteorites give access to unsampled areas of the Moon's surface (Korotev, 2005), we analyzed microchemically and mineralogically feldspathic lunar breccias and use their mineralogical composition and mineral chemistry as a reference. We performed microchemical and mineralogical characterization of some lunar feldspathic breccias, specifically of samples of the meteorites NWA 7948, Bechar 007, Gadamis 004, NWA 15629, and NWA 6687, all feldspathic lunar breccias with low weathering grade, with the exception of NWA 15629 which is classified as mingled and Gadamis 004 which is a ferroan anorthosite. The samples were analysed through FE-SEM at the University of Camerino and the University of Perugia and through FE-EMPA at the University of Firenze. Amorphous phases were identified through Raman spectroscopy at the University of Camerino. Microcrystalline powders of minerals are synthetized using a muffle furnace in air at the University of Camerino. Characterization of the synthetic powders was performed through X-ray Diffraction (XRD) at the University of Camerino. We started with the synthesis in air of anorthitic plagioclase with composition $An_{94.6}Ab_{5.1}Or_{0.3}$. XRD analysis of the synthesis products confirmed the purity and the structure, which is compatible with that of a disordered sodic anorthite. We are now synthetizing glass in air focusing on the composition which resembles that of impact glass, vescicular glass of the agglutinates, and volcanic spherules found on lunar rocks and lunar meteorites. We plan to synthesize glass and possibly Fe-bearing anorthite also close to the IW buffer. We already found natural terrestrial olivines of suitable chemical composition from Praia do Norte, Portugal, ($Fa_{22.4\text{-}25.5}$) and Lanzarote, Spain, ($Fa_{\sim 33}$) and are currently searching for pyroxenes.

Jaumann R. et al. (2012) - Geology, geochemistry, and geophysics of the Moon: Status of current understanding. Planet. Space Sci., 74, 15-41, http://dx.doi.org/10.1016/j.pss.2012.08.019.

Korotev R.L. (2005) - Lunar geochemistry as told by lunar meteorites. Chem. Erde-Geochem., 65, 297-346, https://doi.org/10.1016/j.chemer.2005.07.001.

Slabic A. et al. (2024) - Lunar Regolith Simulant User's Guide Revision A. NASA Technical Reports Server (NTRS).

Taylor L A. et al. (2016) - Evaluations of lunar regolith simulants. Planet. Space Sci., 126, 1-7, http://dx.doi.org/10.1016/j.pss.2016.04.005.

Comprehensive mineralogical and structural characterization of the EH3 enstatite chondrite ALHA77295

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Keywords: meteorite, mineralogy, enstatite chondrites.

Enstatite chondrites (ECs) represent a unique class of meteorites formed under extremely reducing conditions (Hammouda et al., 2022), offering a new perspective on the chemical processes that occurred in oxygen-poor environments of the early Solar System. To further explore these unique formation environments, this study focuses on the detailed characterization of the ALHA77295 (EH3) chondrite as a key representative of such extreme redox conditions.

This work describes a detailed investigation of the mineralogical and structural features of ALHA77295 using a strictly non-destructive multi-analytical approach. The integration of Micro-Computed Tomography (µ-CT), Scanning Electron Microscopy (SEM-EDS), and µ-Raman spectroscopy allowed for the 3D visualization of the internal features, chondrules distribution, and fragment porosity without compromising its physical integrity. The efficacy of non-invasive methodologies for meteorite characterization has been previously established in studies of Al-Haggounia 001 (Manzari et al., 2023) and the Mt. Gariglione micrometeorite (Agrosì et al., 2025).

ALHA77295 was recovered in 1977 from the Allan Hills region in Antarctica. As detailed in the petrographic descriptions provided by the NASA Antarctic Meteorite Curator (NASA Johnson Space Center, 2026), ALHA77295 ($Fs_{1.7}$) was originally classified as EH4 and subsequently reclassified as EH3. Our analysis revealed the presence of well-defined chondrules, typical of petrologic grade 3, embedded in a matrix where cristobalite, a high-temperature silica polymorph, was identified. In addition to kamacite (Fe,Ni) and troilite (FeS), exotic sulfides such as oldhamite (CaS), daubréelite ($FeCr_2S_4$), and niningerite (MgS) were detected, along with schreibersite ($(Fe,Ni)_3P$).

The presence of oldhamite and niningerite testifies to an environment characterized by extremely low oxygen fugacity and high sulfur affinity. These phases not only constrain the reducing conditions of the formation region but could also act as tracers of the peak temperatures and cooling processes experienced by the parent body. Furthermore, investigating this rare extraterrestrial material through non-destructive methodologies enables the reconstruction of its internal fabric while preserving sample integrity. This approach facilitates the integration of mineralogical, chemical, and microstructural data into a comprehensive 3D framework.

Agrosì G. et al. (2025) - Unique (Al, Cu)-alloys discovered in a micrometeorite from Southern Italy. Commun. Earth Environ., 6, 271, 1-10, https://doi.org/10.1038/s43247-025-02245-w.

Manzari P. et al. (2023) - New insights on the porosity and grain features of Al Haggounia 001, an impact-melt meteorite. Lithos, 438-439, 107015, https://doi.org/10.1016/j.lithos.2022.107015.

NASA Johnson Space Center (2026) - Antarctic Meteorite Sample Description: ALH77156. Astromaterials Acquisition and Curation Office. Available at: https://www-curator.jsc.nasa.gov/antmet/samples/petdes.cfm?sample=ALH77156.

Hammouda T. et al. (2022) - The message of oldhamites from enstatite chondrites. Prog. Earth Planet. Sci., 9, 13, https://doi.org/10.1186/s40645-022-00471-w.

A multi-method investigation on the thermodynamic and kinetic constrains of the taranakite-francoanellite dehydration reaction

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Keywords: taranakite, francoanellite, cave minerals.

Field data reported in the literature have presented the hypothesis that dehydration of guano-derived phosphates can be triggered by shifts in environmental conditions. To better understand the thermodynamic and kinetic constrains which regulate such processes, the dehydration reaction which induces taranakite ($K_3Al_5(PO_3OH)_6(PO_4)_2(H_2O)12{\cdot}6H_2O$) to transform into francoanellite ($K_3Al_5(PO_3OH)_6(PO_4)_2(H_2O)_{12}$) by expulsion of interlayer water was subject to a multimethod in situ investigation, consisting of thermodynamic calculations, High Temperature (HT) XRPD, FTIR and micro-Raman spectroscopy on a sample of taranakite from the Pollera Cave (Liguria, Italy). The obtained results allow to confirm that the onset of the dehydration, caused by the breaking of weak hydrogen bonds serving as bridges between the layers and interlayers in the structure of taranakite, is characterised by a temperature of equilibrium of ~ 96°C and an empirical activation energy of ~7.5 kJ/mol. The heat released by organic matter oxidation in bat guano deposits is proposed to be a viable trigger of the transformation, partly explaining the occurrence of francoanellite in natural environments.

Fe and V oxidation state in chromites formed within the fusion crust of ordinary chondrites

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Keywords: chromites, fusion crust, XAS.

Chromites from H, L, and LL ordinary chondrites were studied and data for chromites in the interior of the same meteorites were compared to those found within the fusion crust. Chromites found in the interior are usually anhedral and relatively large in size (several tens of micrometers), opposite to chromites formed within the crust which are consistently smaller (few micrometers in size) and can display anhedral, or subhedral to euhedral habit.

The Mg# and Al# value of the chromites in the interior display typical composition reported for ordinary chondrites with a limited scatter of Al# (ca.0.13±0.025) but a large variation of the Mg# (from 0.05 to 0.30). Chromites within fusion crusts generally exhibit similar Al# values respect those in the bulk but a much larger scatter of Mg# value and, a larger average Mg# (up to 0.65).

Chromites in the fusion crusts are often associated to magnetite dendrites made up by magnetite octahedral crystals 100-400 nanometers wide; occasionally, other spinel group minerals can be found, as magnesiochromites and magnesioferrites. In most of the studied samples, several chromite crystals are mantled by magnetite crystals. Textural data collected so far suggest a crystallisation sequence in the fusion crust, starting with olivine, going over chromite, to magnetite (see Bellesi et al., 2025).

In this study, Fe and V K-edge XANES (X-ray Absorption Near Edge Structure) spectra were collected at the European Synchrotron Radiation Facility (ESRF) in Grenoble at the ID21 beamline. Chromites from the interior of the studied meteorites clearly display the presence of divalent Fe in tetrahedral coordination and divalent V in octahedral coordination. Data from the chromites present in the fusion crust, while displaying the presence of both divalent Fe and V, can also show the minor presence of trivalent Fe and trivalent V. The presence of minor trivalent Fe and V is interpreted as resulting from the mildly oxidising conditions existing during atmospheric passage of the meteoroid (see Pittarello et al., 2019).

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Bellesi M. et al. (2025) - Chromites in ordinary chondrite fusion crusts. Eur. J. Mineral., 37, 617-626, https://doi.org/10.5194/ejm-37-617-2025.

Pittarello L. et al. (2019) - Meteoroid atmospheric entry investigated with plasma flow experiments: Petrography and geochemistry of the recovered material. Icarus, 331, 170-178, https://doi.org/10.1016/j.icarus.2019.04.033.

A-priori bond-strength theory, a rigorous approach to understanding the crystal structures of dialectric minerals and inorganics

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Keywords: a-priori bond-strength, Noether's theorem, Coulomb's law.

This paper will focus on the ~60% of the mineral kingdom that is dielectric, i.e. the valence electrons are bound and the crystals are dominantly insulators at room temperature. I refer to the atoms of these minerals as cations and anions but these terms have no connection with previous model(s) of ionic bonding. Cation and anion conveniently refer to atoms of low and high electronegativity, respectively, reflecting the bipartite nature of their crystal structures.

The electric field in a crystal is a vector field; bond strengths from cations to anions are positive and bond strengths from anions to cations are negative. Coulomb's Law states that *the magnitude of the electrostatic force of attraction or repulsion between two point charges is directly proportional to the product of the magnitudes of charges and inversely proportional to the square of the distance between them.* Electric charge is thus a continuously differentiable function and hence is subject to a conservation law as required by Noether's first theorem, and the global gauge invariance of the electric field results in the conservation of electric charge. Judicious application of Gauss's law requires that the sums of the incident bond-strengths at all ion sites must equal the formal charges at those sites.

One may derive a bond-strength table to describe the topology of the bond strengths and from this one may write a corresponding charge-conservation matrix, although the resulting set of simultaneous equations is usually under-determined and a solution is not possible. The graph of the crystal structure is a bipartite graph and any path through the graph of the structure involves edges between alternating cations and anions. Hence the bond strengths associated with the edges of that path are alternately positive and negative. Noether's first theorem requires that bond-strengths along non-degenerate bond-paths between symmetrically equivalent ions in a structure must sum to zero. These additional bond-strength equations allow solution of the charge-conservation matrix. I designate the calculated values as a-priori bond-strengths as they are dependent only on topological symmetry and their calculation does not involve bond-lengths.

This leads to the a-priori bond-strength rule: *A-priori bond-strengths may be calculated for all bonds in a structure by constructing a bond-strength table that includes all bond-strengths as unknown variables. The corresponding charge-conservation matrix can be solved for all the unknown bond-strengths by Gaussian reduction.* Although the calculation of a-priori bond-strengths is independent of observed bond-lengths, the a-priori bond-lengths correlate strongly with observed bond-lengths. This relation indicates that, unlike the Pauling model, the bond topology of the structure has a major effect on the variation of individual bond-lengths within each coordination polyhedron in a crystal structure.

Study on Sc-bearing tourmalines from the granophyre of Cuasso al Monte (VA), Italy

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Keywords: tourmaline, scandium, crystal-chemistry.

The Permian granophyre sub-volcanic intrusions of Cuasso al Monte (Varese, Southern Alps, Italy) hosts an unusual Sc geochemical anomaly, characterized by the occurrence of accessory Sc-bearing minerals within the miarolitic cavities of a felsic magmatic system (Pezzotta et al., 2005).

This study presents the first detailed crystal-chemical investigation of Sc-enriched tourmaline from this locality. Nine samples were analysed using electron microprobe analysis and single-crystal X-ray diffraction to obtain accurate crystal-chemical data. These are green acicular tourmalines, and they are classified as Fe^{3+}-rich oxy-schorl. They crystallized in a late-magmatic to pneumatolytic-hydrothermal environment enriched in F and feature notable Sc^{3+} concentrations up to 1.24 wt.% Sc_2O_3, significantly higher than typically observed in tourmaline so far. The generally low concentration of Sc in natural tourmalines can be ascribed to petrological constraints rather than crystal-chemical limitations, as the ionic radius and charge of Sc are compatible with the tourmaline structure, similar to elements such as Fe. In studied samples, chemical variations are mainly governed by the substitution mechanism $2Al \leftrightarrow Fe^{3+} + Sc^{3+}$.

Crystal-chemical data and field observations suggest that Sc underwent successive phases of mobilization and fixation within a complex, partially open, and oxidizing system (as evidenced by the presence of Fe^{3+}). Scandium ideally partitioned from primary micas into the pneumatolytic fluid. At higher temperatures (about 500°C), Sc was predominantly transported as stable fluid complexes, strongly limiting the activity of free Sc^{3+} ions. During this stage, the crystallization of oxy-schorl incorporated only the limited available fraction of free Sc^{3+}. As the hydrothermal system cooled to lower temperatures, the destabilization of these Sc-bearing clusters released free Sc ions into the fluid, promoting the late-stage precipitation of specialized Sc minerals (e.g., bazzite, thortveitite).

These results highlight the utility of tourmaline as a tracer for rare-element behavior and temperature-dependent complexation in NYF-type late-Hercynian granitic systems. The Cuasso al Monte occurrence provides new insights into Sc partitioning mechanisms in evolved felsic magmas, contributing to a better understanding of rare-element mobilization in magmatic-hydrothermal environments.

Pezzotta F. et al. (2005) - Scandium silicates from the Baveno and Cuasso al Monte NYF-granites, Southern Alps (Italy): Mineralogy and genetic inferences. Am. Mineral., 90(8-9), 1442-1452, https://doi.org/10.2138/am.2005.1478.

Mineralogical insights on Fe-bearing taramite from Ebrahim-Abad iron ore deposit, Divandarreh (Iran)

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Keywords: Fe-bearing taramite, multimethodic approach, chemical zoning.

Fe-bearing taramite is a rare member of the sodium-calcium subgroup of the amphibole supergroup (general formula AB2C5T8O22W2). A ferro-ferri-taramite was originally discovered in a nepheline syenite from Vali Tarama, Ukraine (Morozewicz, 1925) whereas a ferri-taramite was recently found in the Jakobsberg Mn-Fe deposit, Sweden (Holtstam et al., 2022). In the present study, a Fe-bearing taramite occurring in a skarn from Ebrahim-Abad iron ore deposit (northwest of Divandarreh, Kurdistan Province), Iran, was investigated by combining X-ray diffraction (XRD) on single crystals and powder, Secondary Electron Microscopy (SEM), Mössbauer and vibrational spectroscopy. The mineral occurs as euhedral crystals associated mainly to feldspar, zircon, ilmenite, quartz, calcite and chamosite. SEM observations highlighted chemical zoning of chlorine. The mineral crystallizes in the C2/m space group and exhibits lattice constants a = 9.9522(4) Å, b = 18.2467(7) Å, c = 5.3646(2) Å, β = 105.008(2)° and volume, V = 940.95(6) Å3. The anisotropic structure refinement converged to R = 5.6 %, Rw = 5.16 %; average = 1.684 Å, = 1.640 Å whereas <M1-O>, <M2-O>, <M3-O> and <M3-O> equal 2.192, 2.045, 2.194, 2.501 Å, respectively. Mean atomic numbers (m.a.n.'s) of M1 and M3 sites are ~24.3 and 25.5 e^-; whereas m.a.n.'s ~21.3 e^- and ~19.9 e^- were refined for M3 and M4 sites. Mössbauer and vibrational spectroscopic analyses are underway.

Holtstam D. et al. (2022) - Ferri-taramite, a new member of the amphibole supergroup, from the Jakobsberg Mn-Fe deposit, Värmland, Sweden. Eur. J. Mineral., 34, 451-462, https://doi.org/10.5194/ejm-34-451-2022.

Morozewicz J. (1925) - Über einige Eisenalkali-amphibole. Tscher. Miner. Petrog., 38, 210-222, https://doi.org/10.1007/BF02993932.

How many are out there? Hidden structural complexity in hollandite supergroup minerals

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Keywords: hollandite, short-range order, tunnel oxides.

Hollandite minerals (XY_8O_{16}) are Mn and Ti oxides commonly classified into two subgroups according to the dominant octahedral cation: the Mn-dominant coronadite group and the Ti-dominant priderite group (Biagioni et al., 2013). Their framework consists of double chains of Y-centered, edge-sharing octahedra, which define tunnel-like cavities (X) typically occupied by large monovalent or divalent cations. The ideal symmetry is tetragonal, *I*4/*m,* but a decrease in symmetry to monoclinic *I*2/*m* is often observed.

Hollandite-type materials are widely studied for applications such as nuclear waste disposal and battery materials, requiring a deep understanding of local order to tune their physical properties. However, despite their apparent simplicity, their structure is often challenging to describe, as they may display a range of distortion and disorder features, including symmetry reduction, displacement of tunnel cations, and disorder among the octahedral cations. Such distortions and disorder phenomena are often not reflected in the average structure obtained from conventional X-ray diffraction (XRD) methods or, when present, they remain difficult to quantify. Our recent studies (e.g. Morana et al., 2026) focused on identifying reliable approaches to detect these features, derive accurate structural models, and clarify the underlying crystal-chemical mechanisms. We have thus investigated a set of natural samples with compositions ranging from hollandite to ferrihollandite and cryptomelane, and also mannardite, combining single-crystal XRD, single-crystal X-ray diffuse scattering (DS) and X-ray absorption spectroscopy (XAS).

What we observed is that, regardless of the formal species under which the investigated phases are classified, markedly different local structural features are present. Specifically, XAS results indicate that the local environment around the X cation is influenced by the Fe^{3+} for Mn^{3+} substitution and is significantly more distorted than suggested by the average structure, with no evidence for the presence of a fourfold axis. DS data confirm these observations and additionally reveal a local tendency toward increased periodicities along the tunnel direction, ranging from twofold to fourfold depending on the investigated phase. We found that both the tunnel occupancy and the nature of the tunnel cations give rise to different short-range periodicities and distinct types of interplay between tunnel and framework. This, in turn, appears to influence the degree of channel distortion and may ultimately lead, at the average-structure level, to either monoclinic or tetragonal symmetry.

Our results suggest that local structural complexity may conceal a far broader diversity of hollandite-supergroup minerals than previously assumed. The question therefore arises: how many structurally distinct hollandites may be hidden within the same average structure?

Biagioni C. et al. (2013) - Nomenclature tunings in the hollandite supergroup. Eur. J. Mineral., 25(1), 85-90, https://doi.org/10.1127/0935-1221/2013/0025-2255.

Morana M. et al. (2026) - Framework response to local order in hollandite. Am. Mineral., 111(5), 836-844, https://doi.org/10.2138/am-2025-9916.

Redox-driven coloration in Mn- and Cu-bearing tourmalines

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Keywords: tourmaline, thermally treated, spectroscopic analyses.

The color of minerals is one of the most significant properties in mineralogy, carrying both scientific and aesthetic value. Tourmalines, complex borosilicates with exceptional color variability and high gemological relevance, also represent important petrogenetic indicators. Their coloration commonly reflects the geochemical conditions of the fluids and genetic processes involved in their crystallization (Henry & Dutrow, 1996). Transition metals, such as Mn, Cu, Fe, Ti, V, and Cr in [6]-fold coordination in the tourmaline structure, act as primary chromophores, while impurity defects and structural distortions may further influence color (Pezzotta & Laurs, 2011; Li et al., 2018). Among gem-quality varieties, red rubellite, primarily driven by Mn^{3+}, and neon-blue Paraíba tourmaline, mainly related to Cu^{2+}, represent two case studies of exceptional interest.

The present contribution explores the origin and enhancement of Paraíba colors through heat-treatment experiments on over 30 Cu-bearing tourmalines from Mozambique under both reducing and oxidizing conditions. Also, the mechanisms responsible for rubellite coloration were examined through irradiation and heating experiments on a colorless tourmaline from Elba Island (Italy). Samples were characterized using electron microprobe, optical absorption, Fourier-transform infrared, and electron paramagnetic resonance spectroscopy. The results for Cu-bearing tourmalines provide new insights into the mechanisms responsible for the development of the "Paraíba" color, highlighting the key role of Cu content and the Cu/Mn ratio in controlling color evolution during heat treatment. Furthermore, the investigation of a multicolored specimen from the Mavuco deposit offers a crystal-chemical interpretation of the processes responsible for the chromatic variability exhibited by tourmalines from this Mozambican deposit.

The Elba tourmaline revealed a reversible color transition between colorless and reddish states, controlled by a $Mn^{2+} \leftrightarrow Mn^{3+}$ redox process (Luppi et al., 2026). Irradiation oxidizes Mn^{2+} to Mn^{3+} with charge compensation occurring through electron trapping in newly formed H^0 defects associated with OH groups. While heating at ~500°C restores the colorless state via electron recombination with Mn^{3+}, temperatures above 700°C induce irreversible Mn oxidation coupled with deprotonation, producing reddish color. The identification of this charge-coupled process extends beyond mineralogy and gemology; it provides a framework for understanding how hydrous minerals respond to radiation and thermal fluctuations in geological and planetary environments, where proton-electron interactions influence color development, defect formation, and redox stability.

Henry D.J. & Dutrow B.L. (1996) - Metamorphic tourmaline and its petrologic applications. Rev. Mineral. Geochem., 33, 503-557.

Li M. et al. (2018) - The Chemical States of Color-Induced Cations in Tourmaline Characterized by X-Ray Photoelectron Spectroscopy. J. Spectr., 3964071, https://doi.org/10.1155/2018/3964071.

Luppi R. et al. (2026) - Redox-induced color changes in Mn-bearing elbaite after electron irradiation and thermal treatments. Am. Mineral., https://doi.org/10.2138/am-2025-10085.

Pezzotta F. & Laurs B.M. (2011) - Tourmaline: The Kaleidoscopic Gemstone. Elements, 7(5), 333-338, https://doi.org/10.2113/gselements.7.5.333.

The crystallographic and thermal history of cristobalite inclusions in Libyan Desert Glass

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Keywords: Libyan Desert Glass, cristobalite, electron diffraction.

Libyan Desert Glass (LDG) is a ~29-million-year-old, silica-rich glass found in Western Egypt, whose origin is still debated (Weeks et al., 1984). The two main hypotheses for its formation are: i) hypervelocity collision of a cometary/asteroidal body; ii) radiative heating during an airburst.

Here we report a characterization of LDG cristobalite inclusions using electron backscattered diffraction (EBSD), transmission electron microscopy (TEM), energy-dispersive X-ray spectroscopy (EDS), 3D electron diffraction (3DED) and 4D-STEM tomography.

Backscattered electrons (BSE) images show that the cristobalite inclusions exhibit core and rim regions and possess radial growth features which are not fully resolvable by means of scanning electron microscopy (SEM).

EBSD data were indexed as a-cristobalite for core regions, with several domains being differently orientated. Parent grain reconstruction using the variant graph method implemented in MTEX (Hielsher et al., 2022) led to parent b-cristobalite grains with domains which are misoriented according to different rotations. The dominant one is a 60°-rotation along [111], representing a spinel law twinning in the b-cristobalite parent grains.

The results of TEM analyses on two FIB lamellae confirmed that the core region is indeed consistent with a-cristobalite, with average cell parameters a = 5.009(6), c = 6.997(17) Å. Integration of data from the rim, instead, led to inconclusive results. Furthermore, EDS analyses showed that the rim region is depleted in SiO_2 and enriched in Al_2O_3 and FeO relative to the core.

Our work shows that the a-cristobalite inclusions most probably formed from b-cristobalite, which is stable for temperatures higher than 1470°C. Moreover, TEM analyses revealed the presence of nanocrystalline inclusions with scattered chemical compositions which may yield information about the thermal history of these cristobalite inclusions. These inclusions are currently under investigation using 4D-STEM tomography.

Hielscher R. et al. (2022) - The variant graph approach to improved parent grain reconstruction. Materialia, 22, 101399, https://doi.org/10.1016/j.mtla.2022.101399.

Weeks R.A. et al. (1984) - Libyan Desert Glass: A Review. J. Non-Cryst. Solids, 67, 593-619, https://doi.org/10.1016/0022-3093(84)90177-7.

A natural copper tartrate from the Rio Marina ore deposit (Elba Island, Tuscany, Italy)

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Keywords: organic minerals, tartrate, Elba Island.

The ore deposits and associated skarn bodies of Eastern Elba (Tuscany, Italy) are known for the occurrence of outstanding specimens of hematite, pyrite, and ilvaite. The latter was first described from the Eastern Elba at the beginning of the 19th century; following its description, three other species have their type locality in the iron deposits, i.e., bonattite, minguzzite, and riomarinaite. Among them, minguzzite is an organic mineral whose genesis was related to the interaction between oxalic acid, probably related to biological activity, and iron ores (Garavelli, 1955).

Specimens collected in June 2013 in the Valle Giove stope of the Rio Marina mine, during an authorized professional excavation for scientific purposes, allowed the finding, within a thick hematite + pyrite vein, of chalcopyrite partially transformed into covellite. The study of this assemblage lead to the identification of baryte, wittichenite, gypsum, and small apple-green crystals of an unknown Cu mineral.

Unit-cell parameters, obtained through single-crystal X-ray diffraction, are $a = 11.7875(12)$, $b = 5.0145(5)$, $c = 8.9855(7)$ Å, $V = 531.12(9)$ Å^3; space group is $P2_12_12$ (#18). The solution and refinement of the crystal structure indicated that this phase is the natural analogue of synthetic $Cu(C_4H_4O_6)$ (Liu et al., 2013). The crystal structure of this compound was refined to $R_1 = 0.0610$ for 940 unique reflections with $F > 4\sigma(F)$ and 113 refined parameters and 3 restraints. The crystal structure can be described as formed by two symmetry-independent $(C_4H_4O_6)^{2-}$ groups, connected by Cu^{2+} atoms along both **a** and **b**, forming electroneutral $[Cu(C_4H_4O_6)]^0$ {001} layers. Successive layers are stacked along **c*** through C-H···O and O-H···O bonds. Raman spectroscopy agrees with the spectral features of other known metal tartrates (e.g., Kaneko et al., 1984).

The genesis of this copper tartrate is probably due to the interaction of low-T aqueous solutions containing tartaric acid and Cu-bearing SO_4-rich solutions derived from the alteration of the chalcopyrite-bearing ore assemblage. The source of tartaric acid may be sought in the plants (in particular the vineyards) growing on the soils previously covering the ore bodies of the Valle Giove stope and described by old authors (e.g., Pini, 1777).

Garavelli C.L. (1955) - Un nuovo minerale tra i prodotti secondari del giacimento di Capo Calamita (Isola d'Elba). Atti Accad. Naz. Lin., 18, 392-402.

Kaneko N. et al. (1984) - Infrared and Raman spectra and vibrational assignment of some metal tartrates. Spectr. Acta, 40A, 33-42, https://doi.org/10.1016/0584-8539(84)80026-4.

Liu Y.H. et al. (2013) - Dehydration induced 2D-to-3D crystal-to-crystal network re-assembly and ferromagnetism tuning within two chiral copper(II)-tartrate coordination polymers. Dalton Trans., 42, 16857-16867, https://doi.org/10.1039/C3DT52330F.

Pini E. (1777) - Osservazioni mineralogiche su la miniera di ferro di Rio ed altre parti dell'Isola d'Elba. Giuseppe Marelli, Milano, 110 pp.

Structural, chemical and magnetic properties of pristine and Fe- doped kesterites before and after thermal annealing

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Keywords: kesterite, magnetic properties, EPR.

Here, we foster the combined use of conventional techniques to obtain a comprehensive structural and chemical characterization of kesterites (Cu_2ZnSnS_4, Copper-Zinc-Tin Sulfide, CZTS), a class of light-absorbing materials employed in sustainable thin-film solar cells, and to identify the nature of their paramagnetic centers. Iron-doped (CZFTS) and non-doped nanocrystals were synthesized by hot-injection method and then treated at 450°C. The structural analysis evidenced that while the raw CZTS and CZFTS nanocrystals do not show any secondary phase, a minority phase is present in the annealed samples. The complementary distribution of the metal ions in both CZTS and CZFTS was also assessed. Magnetometry and EPR spectroscopy pointed out the formation of paramagnetic vacancies following the high temperature treatment and the successful doping with Iron. This work highlighted the unique capability of a multipronged approach to detect paramagnetic defects in kesterite nanocrystals, which are otherwise challenging to identify using single techniques.

Minerals as messengers: Decoding geological processes from Earth to Space

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Keywords: strains, stresses, minerals.

The response of minerals under different deformation regimes ranges from elastic to a variety of inelastic processes that are recorded in different ways. Reading the messages of the deformation recorded by minerals can provide crucial insights into geological processes occurring from deep within the Earth to those acting on the surface of planetary bodies.

For example, mineral host-inclusion systems can be used in the framework of elastic geobarometry to determine pressure and temperature conditions attained during subduction or exhumation processes. It is possible to determine the strain acting on the inclusion when still entrapped in its host by measuring changes in the Raman-peak positions with respect to those of a free crystal, by using the phonon-mode Grüneisen tensors (Grüneisen, 1926). The calculated inclusion strains can then be used in an elastic model to calculate the pressure and temperature conditions of entrapment.

A simple case is when an anisotropic crystal is contained within a quasi-isotropic host, such as quartz in garnet. In this scenario, the symmetry of the inclusion mineral is preserved. But a more complex situation arises when the host-inclusion system is fully anisotropic, as a quartz inclusion in a zircon host, because symmetry breaking of the inclusion occurs as P and T change. In particular, I have explored the use of Density Functional Theory simulations to reproduce as closely as possible the conditions that minerals attain in metamorphic processes and combined these results with experimental data. I have applied this approach to different combinations of symmetries and properties of host-inclusion systems in metamorphic rocks (Murri et al., 2018; 2022), to show that the method can provide reliable and accurate results.

However, geological processes are not limited to the Earth's deep interior, but they are also those shaping the surface of planetary bodies, such as impact cratering processes. Even though impact structures on Earth are not preserved forever due to tectonic activity, vegetation and erosion, there are some shock-induced changes occurring in rock-forming minerals that are, unlike host-inclusion systems, inelastic and irreversible and generate unique structural features such as those retained within the Popigai impact diamonds (Siberia, Russia). I studied these unique samples using a multi-methodological approach to show how deviatoric stresses deform the crystallographic structures during catastrophic impact events, and thereby developed a systematic protocol for examining and cataloguing diamond-related materials recovered from impact sites (Murri et al., 2019).

Grüneisen E. (1926) - Zustand des festen Körpers. In: Drucker C. et al. (Eds.), Thermische Eigenschaften der Stoffe. Springer, 1-59, https://doi.org/10.1007/978-3-642-99531-6_1.

Murri M. et al. (2018) - Raman elastic geobarometry for anisotropic mineral inclusions. Am. Mineral., 103.11, 1869-1872, https://doi.org/10.2138/am-2018-6625CCBY.

Murri M. et al. (2019) - Quantifying hexagonal stacking in diamond. Sci. Rep., 9.1, 10334, https://doi.org/10.1038/s41598-019-46556-3.

Murri M. et al. (2022) - The role of symmetry-breaking strains on quartz inclusions in anisotropic hosts: Implications for Raman elastic geobarometry. Lithos, 422, 106716, https://doi.org/10.1016/j.lithos.2022.106716.

Clinopyroxene as a recorder of magma water content and architecture of Alicudi volcano (Aeolian islands)

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Keywords: clinopyroxene, Aeolian Islands, FTIR.

In memory of Angelo Peccerillo.

Alicudi volcano represents the most primitive magmas of the Aeolian Archipelago. Located in the westernmost part of the archipelago, Alicudi was built during 6 eruptive epochs from a single crater and displays a typical stratocone morphology. Major and trace element geochemistry, together with isotopic signatures, indicate that Alicudi preserves the most primitive magmatic compositions of the Aeolian archipelago. Alicudi rocks are basalt to andesite from the calc-alkaline and high-K calc-alkaline series (Lucchi et al., 2013).

We estimated the pre-eruptive magma water content and integrated these data with magma storage conditions derived from geobarometers and previous studies (Nazzareni et al., 1998) to refine the plumbing system model of Alicudi by following the approach of Nazzareni et al. (2020).

Pre-eruptive magma water contents were estimated by FTIR measurements of H concentrations in clinopyroxene (cpx) phenocrysts from lava samples representative of eruptive epochs 1 to 6. Cpxs show highly variable water contents (0-171 ppm H_2O), likely reflecting hydrogen loss during post-crystallization processes. To recover the original hydrogen content, annealing experiments under H_2 gas flux were conducted at 700°C for up to 16 hours. IR spectra were collected after each experiment to estimate the initial water concentrations.

All treated samples display increased OH-band intensities to a maximum corresponding water contents of 215 ± 43 ppm H_2O. From the reconstructed pre-eruptive cpx H_2O contents, we estimated a water concentrations between 1.03 and 2.39 wt.% for the parental magmas.

Pressure estimates obtained using the crystal-liquid geobarometer of Ágreda-López (2024) range from 1 to 7 kbar and from 1000°C to 1160°C, values in good agreement with results from the single-cpx XRD geobarometer (Nazzareni et al., 1998). Estimated storage conditions suggest a progressively shallowing from the oldest to the youngest eruptive products, with a concurrent slightly increase in water content of the parental magmas.

Ágreda-López M. et al. (2024) - Enhancing machine learning thermobarometry for clinopyroxene-bearing magmas. Comput. Geosci., 193, 105707, https://doi.org/10.1016/j.cageo.2024.105707.

Lucchi F. et al. (2013) - Volcanism, calderas and magmas of the Alicudi composite volcano (western Aeolian archipelago). Geo. Soc. Mem., 37, 83-111, https://doi.org/10.1144/M37.15.

Nazzareni S. et al. (1998) - Structural and chemical variations in clinopyroxenes from the island of Alicudi (Aeolian Arc) and their implications for the conditions of crystallization. Eur. J. Mineral., 10, 291-300, http://dx.doi.org/10.1127/ejm/10/2/0291.

Nazzareni S. et al. (2020) - Magma water content of Pico volcano (Azores islands, Portugal): a clinopyroxene perspective. Contrib. Mineral. Petrol., 175, 87, https://doi.org/10.1007/s00410-020-01728-7.

First finding of Ni_2S in the fusion crust of the Cavezzo L5 chondrite

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Keywords: chondrite, meteorite, Ni_2S.

On January 1st at 18:26:53 UT, eight stations of the PRISMA network detected a brilliant fireball, named IT20200101, in the skies of northern Italy. Thanks to the involvement of local people by an effective media campaign, two fragments were recovered, weighing 3.12 g (specimen 1) and 52.19 g (specimen 2), three days after the bolide

was observed. In this contribution we describe the mineralogical composition focusing on the first find of Ni_2S.

The thin sections were borrowed from the Museum of University of Firenze; also few fragments of the crust from speciment 2 were embedded in resin, polished, and examined by FE-SEM and EBSD.

Both optical observations and microchemical analyses of the meteorite interior were consistent with published classification as a L5 ordinary chondrite . The fusion crust display a complex texture of sckeletal and acicular olivine, often with a rim richer in Fe than the core. The small size of most olivine crystal prevented to obtain an accurate composition for most of them. Magnetite dendrites are commonly associated to the olivines. Minor minerals found in the crust include euhedral crhomites, ilmenites, plagioclases in aggregates with chromites (Pl- chr assemblages). Rare pyroxenes in the fusion crust have been found rimming one of the Ni sulphide

grains found.

The fusion crust of specimen 1 is particularly thin and consists mostly micro- and nanocrystals of Olivines $(Mg,Fe,Ni)_2SiO_4$; minor Chromite $(Fe,Mg)(Cr,Al,Ti,V)_2O_4$ is also present. The interstices are disseminated by dendrites of Magnetite nanocrystals. Conversely to the specimen 1, in all the fragments of crust analyzed and in the thin section of specimen 2, the fusion crust is generally thicker and display vescicularity; the stratification of “melted crust”, “outer substrate” and “inner substrate” described in Genge & Grady (1999) can be easily appreciated.

We have found four grains of a nickel sul- fide whose composition is close to Ni_2S. Several of these grains display submicroscopic inclusions of metallic Ni. One of these Ni_2S sulfide grains is surrounded by a corona of microscopic pyroxene crystals with composition close to En70Fe28Wo2. Ni_2S has never been reported before neither in terrestrial nor in chondritic material. Thus, in order to confirm the composition and in order to determine the structure of this phase, we are planning to cut a slice of one of these grains by FIB and to study this phase by Transmission Electron Microscopy to determine if we are actually observing the presence of a new phase or merely a mixture. Preliminary examination by EBSD, allows to ascertain that the Ni_2S grains are not amorphous, and that the diffraction effects can be indexed and are compatible with a cubic unit cell with a 5.2 Å size.

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Genge M.J. & Grady M.M. (1999) - The fusion crust of stony meteorites: Implications for the athmospheric reprocessing of extraterrestrial materials. Meteorit. Planet. Sci., 34(3), 341-356, https://doi.org/10.1111/j.1945-5100.1999.tb01344.x.

Revisiting gadolinite-(Y) from Ytterby, Sweden: Definition of a neotype

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Keywords: gadolinite-(Y), neotype, Rare Earth Elements.

Gadolinite-(Y), $Y_2Fe^{2+}Be_2Si_2O_8O_2$, is among the historically most important minerals due to its role in the discovery of several rare-earth elements (e.g., Wöhler, 1828; Mosander, 1843). The mineral was first recognised in material collected by C.A. Arrhenius in 1787 from the Ytterby granitic (NYF) pegmatite, later investigated by J. Gadolin, whose work led to the identification of a new "earth" (Gadolin, 1794), subsequently named *yttria* or yttrium oxide. In spite of its major historical and scientific significance, no type material had previously been officially designated for the species. Following approval by the International Mineralogical Association's Commission on New Minerals, Nomenclature and Classification, a neotype specimen of gadolinite-(Y) from Ytterby is established here. The selected sample is preserved in the Swedish Museum of Natural History and was most likely collected originally by Arrhenius himself, and is considered representative of gadolinite-(Y) from the Ytterby pegmatite. The neotype specimen was characterised by electron-microprobe analysis, powder X-ray diffraction, Raman spectroscopy, infrared spectroscopy, and Mössbauer spectroscopy. The obtained data are consistent with metamict gadolinite-(Y) and its empirical formula is $(Y_{1.49}Dy_{0.09}Yb_{0.08}Nd_{0.06}Er_{0.06}Sm_{0.05}Gd_{0.03}Ce_{0.03}Ho_{0.02}Pr_{0.01}Tm_{0.01}Lu_{0.01}Tb_{0.01}Ca_{0.01}Th_{0.005})_{\Sigma 1.96}Fe^{2+}_{0.94}Fe^{3+}_{0.06}Mn_{0.01}Be_{2.00}Si_{2.00}P_{0.01}O_{10}$. Unit-cell parameters refined from powder X-ray diffraction data collected on material annealed at 1000°C are a = 4.729(2) Å, b = 7.487(2) Å, c = 9.937(3) Å, β = 90.37(3)°, and V = 351.8(2) Å^3, with Z = 2 (space group $P2_1/c$), which are similar to those given for a well-crystallized gadolinite-(Y) sample containing less Y (space group $P2_1/a$; Miyawaki et al., 1984).

Gadolin J. (1794) - Undersökning af en svart tung stenart ifrån Ytterby stenbrott i Roslagen. Kongl. Vetensk. Acad. Nya Handl., 15, 137-155.

Miyawaki R. et al. (1984) - A refinement of the crystal structure of gadolinite. Am. Mineral., 69, 948-953.

Mosander C.G. (1843) - On the new metals, lanthanium and didymium, which are associated with cerium; and on erbium and terbium, new metals associated with yttria. Phil. Mag., 23, 241-254.

Wöhler F. (1828) - Ueber das Beryllium und Yttrium. Ann. Phys., 89, 577-582.

S9.

Bridging field and laboratory studies to unravel fault-zone structures, mechanics, and fluid circulation

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Giant pseudotachylyte breccias of Valsesia (Ivrea Zone, Western Italian Alps)

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Keywords: pseudotachylyte breccias, earthquake, Ivrea Zone.

Pseudotachylytes are solidified frictional melts generated in silicatic rocks during seismic slip (Sibson, 1975). They typically occur in the rock record as fault and injection veins, with thicknesses between some millimeters to few centimeters. However, meter-scale giant pseudotachylyte breccias (GPBs) are also documented, commonly associated with dry continental lower crustal rocks, exhumed along large-scale tectonic lineaments (e.g., Woodroffe thrust, Australia; Outer Hebrides Fault Zone, Scotland; Insubric Line, Italy). Field, microstructural and mineralogical analyses of the GPBs of Valsesia (Ivrea Zone, Western Italian Alps) were conducted on four outcrops along a ~9 km transect E of the Canavese Line (CL, local segment of the Insubric Line), in order to understand the P-T conditions and mechanisms of formation of GPBs, the type of earthquake to which they are associated and their geodynamic environment.

GPBs have been identified only in the proximity of the CL (<2 km E), with a mean strike subparallel to the trend of the CL. To a further distance, only thin pseudotachylytes faults with a different orientation, have been mapped. GPBs cut cataclasite-bearing faults and show pristine microlitic structures and vesicles. Multiple melt inputs are not observed. GPBs are cut by late-stage greenschist facies faults and veins. Both at the outcrop and microscale, no evidence of ductile deformation syn- or post-formation of GPBs has been identified. GPBs show roughly tabular geometries, with thickness varying sensibly along strike, up to 1.2 m. Angular/elongated clasts separated by thin layers of pseudotachylyte compose the outer GPB domains, and sub-rounded clasts separated by a thicker layer of pseudotachylyte the inner domains. Pseudotachylyte area percentage in GPBs varies between 23-38% and clast-to-melt ratio is significantly higher with respect to th in pseudotachylytes. Numerical modelling suggests that GPBs could be formed in immature faults and gather in a locally tensional domains (i.e., pull-aparts) that are densely fractured due to interaction of two fault tips. The large volume of pseudotachylyte in the GPBs is not produced in-situ but rather results from the accumulation of melt produced on a larger fault surface surrounding the tensional domains. The melt produced per unit fault area is thus relatively small, but it can rapidly migrate (<1 s) along the fault and accumulate in pull-apart zones due to high coseismic fluid pressure gradients, low viscosity and overheating by frictional shear.

In summary, the GPBs of Valsesia were generated during individual seismic events by frictional shear heating and melting, followed by melt accumulation in densely fractured tensional areas. The coseismic ruptures are indicative of relatively large (Mw>6) magnitude earthquakes, hosted by a shallow (~10-15 km depth) and relatively cold (<350°C) preseismic environment, along immature fault structures associated with the activity of the Canavese Line.

Sibson R.H. (1975) - Generation of Pseudotachylyte by Ancient Seismic Faulting. Geophys. J. Int., 43(3), 775-794, https://doi.org/10.1111/j.1365-246X.1975.tb06195.x.

Carbonation styles and petrophysical evolution of serpentinized peridotites at the Tyrrhenian continent-ocean transition: Insights from IODP Expedition 402

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Keywords: peridotite carbonation, petrophysical properties, Tyrrhenian basin.

Exhumed mantle rocks become sites of intense fluid-rock interaction, promoting hydration and carbonation of peridotite. The IODP Expedition 402 has revealed the exhumation of a hybridized mantle lithosphere in the Tyrrhenian active back-arc basin (Sanfilippo et al., 2025), redefining stages preceding the well-known steady-state sea floor spreading.

To investigate both mineralogical and petrophysical changes related to carbonation in serpentinized ultramafic rocks, we apply a multidisciplinary approach combining optical microscopy, SEM, cathodoluminescence and laboratory rock physics measurements. We analysed several unique dunite, harzburgite and lherzolite samples with varying degrees of carbonation, collected in-situ at the continent-ocean transition during IODP Expedition 402.

Samples from site U1616 show distinctive pseudomorphism of olivine by calcite, promoting local areas of high porosity. In these zones, olivine seems to be completely replaced and subsequently leached/dissolved, ending up leaving a void. At site U1616, we noticed diffuse carbonation which spreads via a nano-scale branched network of carbonate veins, resulting in a highly porous system. In contrast, our findings from site U1614 describe a lower carbonation framework, where reactions develop and remain bound by mm-scale calcite veins.

Our results provide new insights into the Ca-metasomatism of the mantle lithosphere in evolving settings like the continent-ocean transition, with implications for chemical and petrophysical properties relevant to geological CO_2 storage strategies.

Sanfilippo A. et al. (2025) - Heterogeneous Earth's mantle drilled at an embryonic ocean. Nat. Commun., 16, 2016, https://doi.org/10.1038/s41467-025-57121-0.

Phyllosilicate microlayers and injections along the Mattinata fault: Implications for weakening processes in carbonate-hosted faults

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Keywords: strike-slip fault, injection vein, phyllosilicate.

Micrometer-thick phyllosilicate films localized along fault slip surfaces can substantially reduce friction, although their occurrence is unexpected in clay-poor carbonate platform rocks. We investigate how a major carbonate-hosted, seismogenic strike-slip fault can develop mechanically weak slip interfaces and experience dynamic weakening despite the overall strength of its carbonate host rock. We combine structural mapping and drone-based virtual outcrop analysis with microstructural, mineralogical, and geochemical analyses, including optical microscopy, SEM/FESEM-EDS, EPMA, and XRD, along the Mattinata Fault (Gargano Promontory, southern Italy). We identify illite- and kaolinite-rich microlayers, locally up to ~15 μm thick, developed along selected slip surfaces. These layers occur together with ultracataclasites and phyllosilicate-bearing injection veins that branch from the slip surfaces into otherwise nearly pure calcite host rocks. The observed microtextures, vein geometries, and mineral assemblages suggest that clay minerals were externally sourced and emplaced during transient episodes of fluid pressurization associated with coseismic slip, pointing to episodic open-system conditions within the fault zone. Since high-velocity friction experiments demonstrate that even very small amounts of phyllosilicates, when organized into thin films, can promote dynamic weakening, our results provide field evidence for rapid fault weakening in carbonate-hosted foreland settings. More broadly, our observations suggest that carbonate-hosted seismogenic faults may locally develop cryptic clay-rich slip interfaces through transient fluid-assisted processes, with potential implications for fault weakening and rupture propagation in clay-poor carbonate fault zones.

Microscale controls on efficient early strain localisation in carbonate rocks

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Keywords: early strain localisation, microfracture propagation, carbonate rocks.

Strain localisation is a key predisposing factor for frictional instability and earthquake nucleation. Experimental studies demonstrate that increasing localisation promotes unstable slip behaviour (Marone & Kilgore, 1993) and high localisation is also associated with natural earthquake occurrence (e.g., pseudotachylyte and fault mirrors). However, localisation stems from mechanisms that are inherently different depending on the investigated scale. Earthquake nucleation first occurs at the grain-scale, where the number and hierarchy of factors controlling strain localisation remains poorly constrained. In this study, we use field investigation, laboratory experiments, and microstructural analysis to understand the emergence of instability and localisation in carbonate rocks.

Carbonate rocks represent interesting materials in this context because of their presence in several seismogenic terrains (sedimentary sequences) and their non-trivial mechanical behaviour. Indeed, pure calcite microgranular powder obtained by crushing and sieving Carrara marble exhibits stable behaviour, whereas bare rock surfaces of limestone promote instability (Carpenter et al., 2014). This is related to the fact rock surfaces impose preferred pathways for strain localisation at the onset of slip, thus promoting unstable sliding. Curiously, pure calcite nanogranular gouges (1-2 orders of magnitude smaller than the microgranular powder) also promote unstable behaviour. We then infer that the similarity between bare rock surfaces and nanogouge might be, again, related to a matter of efficient localisation of strain. If so, then even in nominally homogeneous materials, geometric and fabric-related factors alone may exert a primary control on carbonate stability.

Comparative microstructural observations on field-derived natural samples of Carrara marble (large-grained carbonate) and Maiolica micrites (fine-grained carbonate) reveal evident differences in the geometry and arrangement of microfractures, suggesting different deformation dynamics for the two cases. Microfracture propagation appears controlled by the twinning activity, grain-boundary geometry, cleavage orientation, and porosity distribution. At the same time, field-scale observations in the origin terrains reveal differences in the modality of faulting. Carrara marbles host sharp and highly localised faults, while micrites develop distributed fracture networks.

The ultimate objective of this work is to establish a scale-dependent framework for the interpretation and quantification of factors that control strain localisation in carbonate rocks, aiming also at assessing their relevance across scales when bridging laboratory and field observations.

Carpenter B.M. et al. (2014) - Frictional heterogeneities on carbonate-bearing normal faults: Insights from the Monte Maggio Fault, Italy. J. Geophys. Res.-Sol. Ea., 119(12), 9062-9076, https://doi.org/10.1002/2014JB011337.

Marone C. & Kilgore B. (1993) - Scaling of the critical slip distance for seismic faulting with shear strain in fault zones. Nature, 362(6421), 618-621, https://doi.org/10.1038/362618a0.

Permeability anisotropy in fault gouges: From clay-rich to granular systems

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Keywords: permeability, faults, rock deformation experiments.

Fluid injection activities associated with CO_2 storage and wastewater disposal are not only linked to induced seismicity hazards, but they also pose a critical challenge related to fluid leakage along faults bounding the trap, or within the overlying top seal. In this context, understanding permeability and its anisotropy in fault gouges is essential in predicting fluid migration pathways and assessing fluid leakage hazard.

In this study, we developed rock deformation experiments to investigate permeability anisotropy in monomineralic, bi-phase and three-phase synthetic fault gouges composed of quartz, calcite and illite. This selection was made because these are among the most abundant mineral phases in fault-bounded reservoirs, where clay smearing within sedimentary rocks can develop different rock fabrics that may strongly influence permeability. The experiments were performed in a double direct shear configuration under a constant effective normal stress (σ'_n) of 20 MPa and a hydrostatic pore fluid pressure conditions. We characterized permeability, both perpendicular ($k_\perp$) and parallel ($k_\parallel$) to the fault plane to evaluate the role of mineralogy and the associated fabric development in the evolution of permeability and its anisotropy.

Our results show that permeability decreases from granular ($k_\perp \approx 10^{-16}$ m^2; $k_\parallel \approx 10^{-15}$ m^2) to illite-rich gouges ($k_\perp \approx 10^{-18}$ m^2; $k_\parallel \approx 10^{-16}$ m^2). Across all compositions, permeability is anisotropic with the anisotropy that systematically increaseas with clay content and, to a lesser extent, with shear strain. Illite-rich mixtures show differences of up to two orders of magnitude between $k_\perp$ and $k_\parallel$, indicating that clay-rich fault gouges may strongly promote directional fluid flow during shear.

These findings have direct implications for subsurface fluid injection scenarios, suggesting that deformation-driven anisotropy may promote preferential flow pathways and potentially enhance leakage risks along faults.

Laboratory earthquakes under hydrothermal conditions in volcanic rocks from Campi Flegrei, Italy

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Keywords: friction, hydrothermal, earthquakes.

In recent decades, the Campi Flegrei volcanic caldera (Italy) has experienced significant ground uplift, ranging from decimetres to meters per year, accompanied by persistent shallow seismicity with magnitudes up to Md 4.6 (Danesi et al., 2024; Patanè et al., 2025). Despite being one of the most intensively studied and monitored volcanic systems worldwide, the mechanical behaviour of its fault networks under hydrothermal conditions, and their role in controlling the seismic cycle, remain poorly constrained.

This study investigates the frictional properties of simulated faults composed of Neapolitan Yellow Tuff, a largely widespread lithology in the shallow seismogenic volume of Campi Flegrei, together with core samples from depths of 500 m, 2.223 m, 2.515 m, and 2.862 m, spanning phyllic to thermometamorphic alteration facies. Experiments were conducted using a rotary shear apparatus (RoSA) coupled with a hydrothermal pressure vessel (HYDROS), under conditions of temperature up to 400°C, effective normal stress from 10 to 40 MPa, and pore fluid pressure up to 30 MPa. These experiments reproduce in situ conditions derived from deep core measurements and enable investigation of fault behaviour under multiphase fluid conditions, including liquid, vapour, and supercritical water.

Our results show that all tested lithologies exhibit predominantly seismic slip behaviour. Stress drop magnitude is strongly controlled by both effective normal stress and physical state of the fluid. Higher effective normal stress leads to larger stress drops, whereas vapour-dominated conditions generally result in smaller stress drops. Notably, large stress drops are observed both in experiments reproducing (1) shallow depth conditions (These findings provide new insights into the mechanical behaviour of faults in hydrothermal volcanic systems and offer a potential physical framework to interpret the ongoing seismicity and ground deformation observed at Campi Flegrei.

Danesi S. et al. (2024) - Evolution in unrest processes at Campi Flegrei caldera as inferred from local seismicity. Earth Planet. Sci. Lett., 626, 118530, https://doi.org/10.1016/j.epsl.2023.118530.

Patanè D. et al. (2025) - Campi Flegrei Caldera During 2020-2024. GeoHazards, 6, 19, https://doi.org/10.3390/geohazards6020019.

What is the contribution (if any) of off-fault damage to the earthquake energy budget?

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Keywords: fault, earthquake, damage zone.

Many ruptures initiate in strong crystalline basement and propagate into mechanically heterogeneous upper-crustal layers. Faults in these settings develop complex architectures that depend on lithology and deformation mechanisms. In particular, upper-crustal faults commonly consist of a main fault core surrounded by a broader damage zone of distributed fracturing.

This architecture exerts strong control on energy dissipation and radiation. The slip zone in the fault core weakens efficiently during fast coseismic slip, reducing frictional dissipation, promoting slip acceleration, and facilitating rupture propagation. However, the extent to which off-fault damage contributes to energy dissipation in the overall earthquake energy budget remains uncertain.

Here, we investigate the role of off-fault damage on slip modes and rupture propagation using dynamic triaxial rupture tests on bimaterial samples (Westerly granite, shale and Carrara marble) at a confining pressure of 50 MPa and room humidity. Fault zones are initially generated within the samples and instrumented with strain gauges and piezoelectric sensors to capture dynamic strain and acoustic emissions (1 Hz to MHz).

Our results show that the brittle-ductile transition (5 MPa -1), smaller stress drop (1.5 MPa), slip (-1), and longer rise time (up to 5 s).

Microstructural observations show that widespread off-fault damage, accommodated by distributed fracturing, developed in the surrounding of the main propagating fault in the ductile regime. Little (Carrara marble) to no (Westerly granite) damage developed in the samples that failed in the brittle regime.

We interpret these results as evidence that increasing off-fault damage enhances energy dissipation, raising the critical nucleation length and suppressing unstable rupture propagation. Consequently, we conclude that damage processes play a key role in modulating seismic radiation and fracture energy in heterogeneous crustal faults.

Time-dependent evolution of fracture permeability in carbonates under reactive flow

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Keywords: fracture permeability, fluid-rock interaction, carbonate rocks.

The hydraulic behaviour of fractured rocks in the subsurface evolves over time as a result of coupled mechanical deformation and fluid-rock chemical interactions. In carbonate rocks, where fluid-rock reactivity is pronounced under shallow crustal conditions, dissolution-precipitation processes can rapidly modify fracture apertures, fluid pathways and sealing efficiency. Constraining the rates and mechanisms of fracture permeability evolution under reactive flow is therefore critical for understanding fault-zone processes, including healing and restrengthening across post- to inter-seismic timescales, as well as for subsurface applications such as geothermal energy, CO_2 storage and mineral carbonation.

We present flow-through experiments on fractured carbonate samples using a recently developed percolation cell designed to reproduce long-term fluid-rock interactions under hydrostatic conditions (up to 100 MPa confining/pore pressure and 250°C). The setup enables circulation of aqueous solutions with controlled chemistry, continuous permeability monitoring and periodic fluid sampling. Mechano-chemical processes are tracked by X-ray computed microtomography (micro-CT) and secondary electron microscopy (SEM) on pre- and post-percolation samples. Experiments were conducted on Solnhofen micritic and coarser-grained bioclastic limestones containing single through-going mated fractures generated by Brazilian-type splitting tests.

In a first series, deionized water was circulated through pre-fractured Solnhofen limestone (20 MPa confining, 5 MPa pore pressure) for durations of 5-60 days. Permeability decreased non-linearly, with an initial drop of up to one order of magnitude (from ~10^{-17} to 10^{-18} m^2), followed by stabilization at ~2-3 × 10^{-19} m^2. Micro-CT volumetric images revealed fracture closure and loss of secondary pathways, ICP-MS fluid analyses indicate net dissolution (increasing Ca^{2+} and Mg^{2+}) and SEM showed localized carbonate precipitation, suggesting asperity dissolution coupled with local mass redistribution. Longer-term tests highlighted intermittent upstream flow increases after ~30 days, consistent with dissolution-driven flowpath reorganization.

In a second series, bioclastic limestone samples at 100°C and 20 MPa confining pressure were percolated for 7-30 days with an H_2O-$CaCO_3$-CO_2 solution (5 MPa pore pressure and 25°C) to promote calcite precipitation during fluid heating. Permeability remained initially stable, then dropped abruptly by ~1.5 orders of magnitude within hours of reactive fluid injection, followed by asymptotic decline. Post-test microstructures reveal calcite precipitation along fracture walls and constrictions, indicating rapid reactive sealing.

These contrasting behaviours highlight the roles of diffusive versus advective reactive transport in controlling permeability evolution in fractured carbonates, and will be discussed in the context of microstructural and geochemical observations from exhumed natural fault zones.

The role of fluid chemistry in fault frictional healing under hydrothermal conditions in the continental crust

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Keywords: fluid-rock interaction, fault frictional healing, fluid chemistry.

The fault's ability to regain strength over time between seismic events, known as fault frictional healing ($\Delta\mu$ or variation of "static" friction coefficient μ), is a key factor in the seismic cycle. It is because of this frictional healing that elastic energy is restored in the surrounding rocks after an earthquake, enabling the next seismic cycle. It is widely accepted that $\Delta\mu$ increases linearly over time and is influenced by the specific rock type or mineralogy of the fault. However, most existing research on frictional healing has been conducted under conditions that do not accurately replicate the environment at seismogenic depths. In these deeper systems, deformation - whether caused by natural processes or human activities - often occurs in the presence of hot and pressurized hydrothermal fluids. These fluids and the variability in their chemical composition significantly impact the strength and frictional properties of faults by promoting dissolution or precipitation processes.

In this study, we present findings from an innovative experimental setup that includes a rotary shear apparatus and a specialized hydrothermal vessel. Combining these systems allows us to simulate loading conditions and large slip displacements typical of natural faults, along with environmental parameters representative of seismogenic depths, such as hot and pressurized fluids, with variable ionic and neutral species compositions. The experimental design also enables post-experimental fluid sampling, suitable for geochemical analyses.

Investigated samples include non-altered granodiorite and feldspars (albite, K-feldspar, and labradorite), the most common minerals in the crust. Results from experiments lasting up to a week with liquid deionized water (fluid temperature T = 300°C) show that, in the non-altered granodiorite, $\Delta\mu$ does not increase over time as typically expected; instead, it decreases. However, initial fluid chemistry and the hold time play a fundamental role in the frictional healing response, showing a dramatic change for both the non-altered granodiorite and the feldspars in the presence of fluids with a different initial chemistry for holds longer than a certain threshold.

Fluid-rock interaction and the dependence of $\Delta\mu$ on the fluid chemistry, and on how these fluids change with time, can have significant implications for the recurrence intervals of earthquakes and magnitude and the seismic cycle. For instance, a decrease in $\Delta\mu$ would result in increasing recurrence intervals and decreasing earthquake magnitude.

Co-seismic selective rock pulverization in the footwall of a Miocene low-angle normal fault

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Keywords: extension, earthquake, off-fault damage.

Large-magnitude earthquakes capable of rupturing to the surface have rarely occurred along detachment faults or low-angle normal faults (LANFs), leaving their seismic potential and related co-seismic damage poorly constrained. Here we document the presence of pulverized rocks formed during final slip stages of the Miocene Waterman Hills detachment (Mojave extensional belt, California).

The Waterman Hills detachment accommodated ~40-50 km of top-to-NE extension and juxtaposes syn-extensional Miocene volcanic and sedimentary sequences onto syn-extensional granodiorites intruded into amphibolite-facies meta-sedimentary and meta-igneous rocks. Early bivergent doming of the metamorphic core complex initiated at amphibolite-facies conditions and localized into NE-dipping mylonites in the greenschist facies, coevally with intrusion and stretching of the granodioritic pluton at ~7-10 km depths. Progressive strain localization led to greenschist-facies mylonitic and ultramylonitic horizons that were overprinted by brittle faulting. The latter includes: (i) gently-dipping (≤ 30°) anastomosing foliated cataclasites and breccias cemented by chlorite + quartz + epidote ± calcite ± albite, crosscut by (ii) pseudotachylytes and tourmaline-cemented ultracataclasites and fault surfaces, crosscut by (iii) steeply-dipping (> 60°) calcite-hematite-cemented faults and veins. The tourmaline- and calcite-cemented faults crosscut both the footwall and hanging wall rocks, pinning the current juxtaposition during final stages of the detachment slip.

Patchy meter-thick lenses of pulverized siliceous rocks are found in the uppermost ~11 m of the footwall damage zone and show very little evidence of post-pulverization displacement. Pulverization occurred at the latest, shallowest stage of detachment faulting, only in the stiffest, fine-grained siliceous footwall lithologies, consistent with the inference that co-seismic tensile stress perturbation due to propagating seismic ruptures caused rock pulverization. The pulverized rocks recorded repeated events of extensional fracturing and healing.

We interpret these pulverized rocks to have recorded the cumulative effects of multiple moderate-large earthquakes propagating to depths ≤ 2 km, in agreement with experimental constraints on dynamic rock pulverization. Our discovery represents the first documentation of dynamic off-fault damage in the footwall of a LANF and demonstrates that shallow portions of LANFs can locally experience co-seismic stress conditions sufficient to induce pulverization, despite their unfavorable orientation for slip.

The effects of ramp and flat geometry on stress states and fluid pathway variations along a regional scale décollement: Examples from the Sestola-Vidiciatico Unit in the Northern Apennines

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Keywords: faults, fluid flow, stress state.

The Sestola-Vidiciatico Unit (SVU) in the Northern Apennines was active as a plate boundary shear zone (200-400 m thick) between the Ligurian prism and the underthrust Adria microplate during the early-middle Miocene. The SVU is composed of kilometre-scale slices of marls, shales and sandstones offscraped from the Ligurian prism and its sedimentary cover and was thrust along a basal décollement onto younger Adria foredeep turbidites. The basal contact of the SVU is folded and crosscut by subsequent reverse and normal faults and displays both flat and ramp geometries with the turbidites in the footwall. We conducted structural, microstructural, thermometric and geochemical analyses on two outcrops of the décollement, in the Vidiciatico and Gova localities, the first displaying flat geometry and the other displaying ramp geometry. In both outcrops the deformation style progresses from soft-sediment deformation to brittle faulting associated with shear and extensional calcite veins during progressive burial. In Vidiciatico, shear veins with NE sense of transport along the décollement are mutually crosscutting with fault parallel and fault perpendicular extensional veins, suggesting stress switching between compression and extension. In Gova, the main décollement is lined by calcite shear veins with NE sense of transport and minor veinlets opening the foliation. The footwall is crosscut by multistage strike slip faults with calcite filled veins and breccias, whose activity was contemporaneous with thrusting as suggested by the similar shortening direction and crosscutting relationships. Early-stage calcite cements derive from interstitial fluids in equilibrium with the wall rock sediments and with a weak marine geochemical signature and equilibration with the wall rock sediments. The last stage of calcite precipitation in both cases resulted from the ingression in the system of an exotic fluid producing a positive Eu anomaly. In Vidiciatico the Eu positive anomaly is stronger in the shear veins along the décollement, suggesting that it was the main pathway for fluid ingression, while in Gova the Eu positive anomaly is stronger in the subvertical strike-slip faults in the footwall. The comparison of the two outcrops suggests that: (i) the décollement flat was active at low differential stress, allowing complete stress drop, stress switching from compressive to extensional and fluid flow along the detachment; (ii) the décollement ramp was active at higher differential stress, under compressive or strike slip stress states, and with fluids flowing preferentially within the strike slip faults in the footwall.

Fault gouges record episodic fluid circulation in the Mykonos detachment (Greece)

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Keywords: stable isotope analysis, X-ray diffraction, K-Ar dating.

Extensional detachments play a key role in crustal thinning and core complex exhumation, acting as major channels for crustal fluid flow. Although their structural evolution is commonly well investigated, the long-term evolution of fluids, recorded by fault rocks during progressive fluid/rock interaction remains poorly understood. Building upon the established time-constrained structural framework of the Mykonos Detachment, which documents fault activity and progressive strain localization between ~13.5 and 6.5 Ma (Zuccari et al., 2024), we investigate the origin and temporal evolution of paleo-fluid circulation within the detachment system. We present new hydrogen isotope (δD) data from multiple fault gouges collected along the brittle detachment, and analysed across different grain-size fractions ranging from 6-10 μm to < 0.1 μm.

Coarse fractions are dominated by detrital minerals (e.g., quartz, K-feldspar, muscovite-2M1), whereas finer fractions show a progressive enrichment in synkinematic mixed layer illite-smectite. Samples spanning ~6-10 Ma exhibit remarkably homogeneous δD values among fractions. Conversely, older gouges (~12-13 Ma) and those characterized by a high abundance of authigenic phases in the 0.4-2, 0.1.0.4, and

In these isotopically variable mixtures, the coarse and fine fractions seem in equilibrium with the same fluid, and reflect the progressive transition from detrital-dominated mineral assemblages in the coarser fractions to synkinematic phases in the finer fractions. These preliminary results suggest circulating fluids were meteoric in origin; nevertheless, old samples - specifically those characterized by exceptionally high contents of synkinematic illite-smectite - may record a more complex, polyphase fluid history, characterized by very negative δD values. Our findings suggest that different grain-size fractions in fault gouges may preserve evidence of multiple events of fluid/rock interaction events, allowing reconstruction of the fluid regime during the evolution of the Mykonos Detachment.

Zuccari C. et al. (2024) - How brittle detachments form and evolve through space and time. Earth Planet. Sci. Lett., 648, 119108, https://doi.org/10.1016/j.epsl.2024.119108.

Tracing fault-controlled methane-rich fluid flow by carbonate concretion pattern developed in high porosity sandstone (Crotone Basin, Italy)

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Keywords: structural diagenesis, carbonate concretions, fluid flow pathways.

Fluid-rock interactions play a key role in modifying the petrophysical, mechanical and geochemical properties of sedimentary rocks, impacting the exploitation of strategic fossil resources, preservation and management of aquifers, and underground storage of anthropogenic CO_2 and H_2. Within high-porosity rocks, paleo-fluid flow can be constrained by the combined structural-geochemical study of diagenetic concretions, providing insights on the flow pattern and fluid composition.

We studied the selective cementation of fluvio-deltaic, Pliocene age, sandstone to conglomeratic bodies exposed in the Crotone forearc Basin, South Italy. The analyzed stratigraphic formation was deposited in a shallow marine setting, is ~200 m thick, and unconformably overlies the Paleozoic Sila Massif metamorphic basement along the NW margin of the basin. The host sandstone preserves most of the original primary porosity. Sandstone beds show a gentle tilting towards SE, with mild brittle deformation in the form of deformation bands and low-displacement faults. The selective cementation produced diagenetic concretions of different shapes and sizes. Concretions span from tabular-lens shaped with lateral extension up to 200-300 m, elongate blade-shaped from 10 cm up to 10-50 m-long, and asymmetric drop-shaped and nodular-spherical bodies. The elongation direction of concretions parallels the SE dip of the bedding, while in the vicinity of deformation bands and faults elongate concretions are parallel to their dip. Pervasive calcite precipitation caused dramatic porosity loss from 27-32% down to 2-3%, with an increase in sandstone cohesion and stiffness leading to the development of 2-3 sets of joints abutting at the concretion-host rock boundary. Cementation reduced permeability down to 3-4 orders of magnitude compared to the host rock. Cold cathodoluminescence revealed the ubiquitous presence of bright yellow, granular to poikilitic calcite cement in all concretions. Stable isotope geochemistry of calcite cement suggests two fluid sources acting in cementation. The first source is made of mixed marine-meteoric fluids with contributions from soil percolation, while the second is given by methane-rich fluids in a shallow marine setting. The shift from meteoric to marine fluids is related to transgressive sea level rise and propagation of basin-boundary faults occurring during and after sandstone deposition. The source of methane can be traced in the evaporitic (gypsum and anhydrite) formation underneath the studied sandstone sequence, providing large volume of biogenic methane. Methane enriched fluids migrated vertically following major basin-boundary faults, mixed with meteoric to marine fluids and generated bed-parallel fluid flow imparted by the regional hydraulic and topographic gradient permeating the high porosity sandstone.

Peering through glass: The dynamics and heat dissipation of laboratory earthquakes

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Keywords: earthquake, deformation, friction.

Rock deformation experiments play a key role in our understanding of earthquake physics and friction constitutive laws. These laws commonly describe the response of analogue laboratory faults as a simple and homogeneous system, without accounting for the spatial-temporal evolution of structures in the sample. However, increasing experimental evidence suggests that slip instability is closely tied to heterogeneity, complex rheologies, and inhomogeneous boundary conditions. To address this, we designed a transparent setup to observe real-time deformation, track the spatial-temporal evolution of shear fabric, and document unstable slip in experimental faults. Our video documentation of experiments performed with clay gouges reveals that the progressive development of fault fabrics results in heterogeneous but not random stress redistribution. We show that stress and structural heterogeneities play a key role in the nucleation, propagation, and arrest of slip instabilities. Furthermore, experiments performed on fine calcite and quartz powders reveal for the first time the spatio-temporal distribution of shear heating during fast slip. This novel information has the potential to improve our quantitative understanding of the energy budget of the earthquake cycle.

Faulty assumptions: Bridging structural, mechanical and numerical perspectives on fault leakage in CO_2 storage

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Keywords: fault damage zone, fracture network connectivity, CO_2 geological storage.

Geological carbon storage hinges on the ability of caprocks to retain CO_2 over engineering and geological timescales, yet faulted caprocks introduce a recurring paradox: faults can simultaneously act as barriers to across-fault flow and as conduits for along-fault migration. The behaviour that ultimately governs containment risk is not captured by single transmissibility multipliers or by average fault-rock properties such as Shale Gouge Ratio. It is governed by the topology of the fault-fracture network, and specifically by whether subsidiary fractures within the damage zone form a connected, percolating pathway across the seal. Where such pathways exist, even small connected sectors of an otherwise sealing fault can dominate leakage; where they do not, faults can be remarkably effective seals over geological timescales.

Drawing on this framework, we propose an integrated workflow combining outcrop fracture characterisation, laboratory stress-permeability measurements and hydromechanical numerical modelling. The methodology is applied to the Agardhfjellet Formation shale at Konusdalen West (Svalbard, Norway), a regional outcrop analogue to the caprock of the Longyearbyen CO_2 Laboratory and to North Sea and Barents Sea storage targets. Fracture networks within the damage zone of a normal fault were digitised from a high-resolution UAV-derived orthomosaic and analysed statistically with FracPaQ. Stress-dependent fracture permeability was constrained experimentally and incorporated into hydromechanical simulations in the MRST/PorePy framework, allowing upscaled permeability tensors to be derived as a function of horizontal and vertical effective stresses.

Two areas within the same damage zone yield markedly different behaviours. One sits above the percolation threshold, with a network dominated by long vertical joints that intersect fault-related conjugate fractures; the other lies below threshold and is characterised by shorter, low-angle fault-related fractures. Upscaled fracture-network permeabilities differ by approximately two orders of magnitude, and analytical estimates based on geometry alone (Suzuki et al., 1998; Sævik & Nixon, 2017) diverge most strongly from numerical predictions in the sub-percolating case. Subsequent graph-theory analysis applied to these and other natural fault-damage zones indicates that node-ratio metrics systematically underestimate connectivity in spatially heterogeneous networks, reinforcing the case for spatially explicit assessment of fault-fracture geometry.

These results show that fault-zone permeability is governed less by mapped fault throw than by the geometry, connectivity and stress-orientation of its associated fracture network, with implications that extend beyond CCS to underground hydrogen storage, geothermal exploitation and the seismogenic behaviour of fluid-bearing faults.

Sævik P.N. & Nixon C.W. (2017) - Inclusion of topological measurements into analytic estimates of effective permeability in fractured media. Water Resour. Res., 53 (11), 9424-9443, https://doi.org/10.1002/2017WR020943.

Suzuki K. et al. (1998) - Permeability changes in granite with crack growth during immersion in hot water. Int. J. Rock Mech. Min., 35 (7), 907-921, https://doi.org/10.1016/S0148-9062(98)00016-3.

Strain hardening as a mechanism for slip arrest in phyllosilicate-rich rocks

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Keywords: phyllosilicates, slow slip events, arrest.

The processes governing the nucleation and arrest of a rupture during slow slips remain speculative. At seismogenic depths (We performed hydrothermal friction experiments at the temperatures and pressures relevant to the seismogenic zone to understand the mechanism(s) behind slip nucleation and arrest. We tested simulated gouges of phyllite (Rio Marina Fm.) and meta-sandstone (Verrucano Fm.) from a natural shear zone exposed in Elba Island (Italy). Experiments were mostly performed at a shearing velocity of 10 µm/s over a wide range of effective normal stresses (20 to 150 MPa), high temperature (350°C) and high slips (displacements up to 40 mm) using two hydrothermal rotary shear machines hosted in Padova University (Italy) and Utrecht University (Netherlands).

Experimental results show that the phyllite sheared at low effective normal stresses (20-50 MPa), show $\mu \sim 0.3$ and a slip weakening behavior. With increasing normal stress (up to 150 MPa) we observe $\mu = 0.35$ that increase up to 0.8 with a slip hardening trend. Conversely, experiments on the meta-sandstone show generally $\mu = 0.6$-0.7 even at small slips at all normal stress conditions.

Frictional weakness is due to the phyllosilicates' ability to develop efficient foliations that accommodate the deformation. An interconnected through-going phyllosilicate network can develop at low effective normal stresses (up to 60 MPa), leading to the observed low friction and slip weakening evolution within the phyllite gouges. At high normal stress, a through-going weak phyllosilicate network cannot develop because of the grinding of phyllosilicates and their expulsion from high stress asperities. The observed slip hardening and high friction trend results from comminution of quartz grains that we also correlate with the occurrence of ultracataclasites in the microstructures. The experimental results on the meta-sandstone confirm this hypothesis, showing a friction and a microstructure similar to the "hardened" phyllite gouges. EDS maps of chemical elements in the phyllite gouge sheared under high normal stress confirm the absence of an interconnected network of phyllosilicates. In natural shear zones, at seismogenic depth, we may observe slip nucleation in weak phyllosilicate rich rocks ($\mu \sim 0.3$). However, the fault patch may quickly strengthen if the propagating slip is fast enough to disrupt the foliation, which would decelerate slip. Our study provides a new mechanism by which slow slip events may nucleate and spontaneously arrest, potentially halting the growth of rupture into regular earthquakes.

Nanoindentation of naturally carbonatized basalts: Mechanical heterogeneity across alteration regimes and carbonate occurrences

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Keywords: CCS, basalt, nanoindentation.

Basalts from the Palaeocene-Eocene North Atlantic Igneous Province (NAIP) have recently been recognized as potential CO_2 storage units (Rosenqvist et al., 2024). Furthermore, the Permian Oslo Rift, located along the southwestern margin of the Baltic Shield in southern Norway (Neumann et al., 2025), represents a natural laboratory to investigate natural carbonatization in basalts and its relevance for long-term CO_2 storage. Experimental studies on laboratory-altered basalts commonly identify carbonate minerals as mechanically weak phases (e.g., Pan et al., 2026), yet the impact of natural carbonatization on basalt petrophysical and mechanical properties remains poorly constrained.

In this study we analyse naturally carbonatized basalt samples from the NAIP (Skoll High, IODP Expedition 396) and the Oslo-Skagerrak Rift (Bærum). These areas record complementary thermal regimes of alteration: NAIP basalts host clay-dominated assemblages indicative of low-temperature (≤ 100°C) carbonate precipitation, whereas Oslo Rift basalts contain chlorite and epidote, reflecting higher-temperature conditions (c. 250°C). By comparing the micromechanical properties of these samples, we assess how carbonatization affects basalt strength and deformation behaviour under different alteration conditions.

Polished thin sections were prepared for imaging and microanalysis to characterize mineralogy, microstructures, and carbonate occurrences, including matrix replacement, veins, and vesicle infillings, as well as associated fluid pathways. Nanoindentation experiments were performed to measure Young's modulus (E), hardness (H), and fracture toughness. High-Speed Nanoindentation Mapping (HSNM) enabled spatially resolved measurements across large heterogeneous areas, producing high-resolution maps of H and E (Rossi et al., 2023).

Nanoindentation results show distinct mechanical responses among mineral phases. Calcite displays consistent properties across all samples, with mean H of 3.3 - 3.9 GPa and E of 66 - 74 GPa. The basalt matrix exhibits greater variability, with mean H of 3.2 - 5.2 GPa and E of 56 - 74 GPa, reflecting groundmass heterogeneity, while clay minerals show markedly lower values, with mean H of c. 0.6 GPa and E of 17.5 - 19.3 GPa. Basalt matrix E values fall within published ranges for basalts and will be compared with bulk elastic properties derived from Vp-Vs data to validate nanoindentation results. Additionally, the similarity between calcite and basalt E suggests that carbonatization does not necessarily reduce elastic stiffness. Evaluating nano- to micro-scale mechanical heterogeneity provides insight into how carbonatization and alteration products affect the structural stiffness of the basalt reservoirs, potentially weakening or strengthening the rock's resistance to fracturing with implications for the generation of new or reactivated fluid pathways during CO_2-rich fluid injection.

Neumann E. et al. (2025) - Geodynamic evolution of the first basaltic volcanism (B1) in the Oslo Rift (Southeast Norway). Lithos, 512-513, 108133, https://doi.org/10.1016/j.lithos.2025.108133.

Pan Y. et al. (2026) - Research on the Characterization of CO_2 Mineralization Rate and Its Impact on the Physical and Mechanical Properties of Basalt. J. Geophys. Res. Solid Earth., 131(1), e2025JB032957, https://doi.org/10.1029/2025JB032957.

Rosenqvist M.P. et al. (2024) - The architecture of basalts reservoir in the North Atlantic Igneous Province with implications for basalt carbon sequestration. Geol. Soc., London, Sp. Publ., 547, 389-413, https://doi.org/10.1144/SP547-2023-9.

Rossi E. et al. (2023) - High-speed nanoindentation mapping: A review of recent advances and applications. Curr. Opin. Solid State Mater. Sci., 27(5), 101107, https://doi.org/10.1016/j.cossms.2023.101107.

Controls of fault mechanics on mineral precipitation in gold-bearing fault-veins, Indiana Deposit, Northern Chile

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Keywords: mineral precipitation, fault slip, fluid flow.

Many epithermal ore deposits form in fault-veins that channel large volumes of fluid flow synkinematic with fault slip. A key genetic process is the interplay among fluid flow, fault activation, and mineral precipitation; however, significant questions remain regarding the mechanics of fault slip under high fluid-flux conditions and its impact on mineralisation. A fundamental question is whether pressure drops during seismic rupture are the dominant trigger for mineral precipitation, or mineralisation occurs during longer-lived, aseismic creep and sealing cycles. A deeper understanding of these processes is essential for predicting ore grade and spatial distribution.

The Cretaceous Indiana deposit, located in the Coastal Cordillera of northern Chile, is a Cu-Au (Mo-Co) fault-vein system composed of several subvertical NW- or ENE-striking fault veins, with lengths ranging from 300 m to 2 km. Artisanal tunnels provide access to multiple structural levels in oxides and sulphides mineralization, offering exceptional three-dimensional exposure. Fault-veins are 1-3 m wide and display complex internal structures. Fault zones of variable thickness occur along the vein margins and mainly record strike-slip motion, expressed as thin (Microstructural analyses document multiple episodes of quartz deposition in the form of subparallel and superposed veins that cross-cut clasts of previous mineralisation events. Some brecciated bands contain spherical clasts surrounded by concentric cement bands, forming cockade-like structures that suggest fluidised conditions in which cement precipitation occurred while clasts were suspended.

The combined evidence at the meso and micro scales indicates the coexistence of long-lived mineralisation processes and cyclic, short-lived deposition events, likely linked to repeated fault activation. Ongoing analyses integrating microstructural observations with mineral chemistry aim to constrain the fault-slip mechanisms responsible for specific mineralisation styles.

Quartz deformation lamellae record high-stress rupture propagation in accreted cherts

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Keywords: rupture propagation, high stress, quartz.

A relevant fraction of seismicity in subduction zones occurs along splay faults and subsidiary structures of the subduction interface that cut across the upper plate accretionary complex. In the Inuyama Sequence (Jurassic Accretionary Complex, central Japan; Kimura & Hori, 1993) out-of-sequence thrusts duplicate a coherent ocean-floor stratigraphy (comprising strong cherts and weak mudstones) at seismogenic conditions (T ~200°C), providing an ideal exhumed example to investigate the lithological control on seismic and aseismic faulting of the upper plate.

Here we focus on a fault core hosted in cherts from the upper portion of a thrust comprising a ~10 m thick deformed zone. The thrust is mainly composed of footwall foliated mudstone that transitions to fractured cherts toward the hanging wall. The 2-cm-thick fault core is made of coarse quartz fragments in an illite-chlorite matrix and is surrounded by a damage zone (~20 cm thick) of foliated clays with rare quartz fragments. It contains a sharp, thin (~50 μm) principal slip zone (PSZ) composed of submicrometric porous and irregular quartz aggregates, potentially representing recrystallized amorphous silica, for example a coseismic silica gel.

Coarse (> mm) quartz grains surrounding the PSZ are fractured. Wider fractures are filled by chlorite, whereas smaller ones are healed by micrometric quartz. The less fractured grains host abundant deformation lamellae (DL): repetitive, sharp, 2-3 μm wide extinction bands affecting the entire grain. Wider (50-100 μm) extinction bands are also found perpendicular to DL. EBSD shows that DL are separated by low-angle boundaries with misorientations of 10^{13} m^{-2}), implying lack of recovery and recrystallization. Locally, DL transition to thin (a few tens of μm) bands of extreme lattice strain, still preserving remnants of the original distribution of DL.

The abundance of dislocations is indicative of deformation at very high differential stress (>> 100 MPa). A piezometric relationship based on DL spacing implies differential stress peaking at 600-800 MPa (Koch & Christie, 1981). Such high differential stresses cannot be sustained on geological time scales. The spatial distribution of DL suggest that high stress was localised in the first few mm around the principal slip zone. Thus, we interpret DL as a record of the stress peak at the tip of a rupture that propagated at seismic velocity. The expected differential stress at 5 mm from the rupture tip is in the range of 0.5-1 GPa for ruptures propagating at $v > 0.6*C_s$ (shear wave velocity) considering energy release rate of 10^5-10^6 J/m^2. Our observations show that fast ruptures can propagate in faults inferred to dominantly creep aseismically by localising in the strongest materials.

Kimura K. & Hori R. (1993) - Offscraping accretion of Jurassic chert-clastic complexes in the Mino-Tamba Belt, central Japan. J. Struct. Geol., 15(2), 145-161, https://doi.org/10.1016/0191-8141(93)90092-O.

Koch P.S. & Christie J.M. (1981) - Spacing of deformation lamellae as a paleopiezometer. EOS Translations American Geophysical Union, 62, 1030.

Time delay neural network reveal pressure-independent fault rupture processes in laboratory acoustic emission

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Keywords: fault nucleation and growth, laboratory rock deformation, seimic attributes.

Fault nucleation and growth are central to earthquake hazard. Here we analyse fault development in Alzo granite under triaxial confining pressures of 5-40 MPa using a time-delay neural network applied to multi-parameter acoustic- emission data. The model integrates waveform attributes (peak delay, scattering) with occurrence metrics (event rates, Gutenberg-Richter b-value, spatial fractal dimension) to track the transition from distributed microcracking to localised faulting. Genetic algorithms optimise the network, which dynamically weights parameters to characterise fault growth. We find three phases consistent across pressures: microcrack nucleation marked by scattering changes; fault growth captured by evolving spatial and magnitude distributions; and coalescence with rapid peak delay increases and b-value change. The model predicts stress-drop timing and size across pressures and failure mechanisms, from axial splitting to shear localisation, linking waveform features to physically interpretable phases of deformation.

Direct observations on the deformation of geologically realistic faults

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Keywords: fault friction, laboratory faults, contact area evolution.

Frictional properties of geomaterials are fundamental for understanding the slip behavior of fault, and expecially the transition between stable, aseismic creep and unstable, seismic slip. These properties are intrinsically related to how fault materials, such as rocks and fault gouges, deform under specific applied boundary conditions. In particular, mineralogy plays a pivotal role in this context, as it dictates the dominant deformation mechanisms and the evolution of the geometrical features of the fault, particularly the frictional contact area and fault fabric.

Previous research has explored the influence of contact area on fault strength and its evolution during the seismic cycle. The pioneering work of Dieterich & Kilgore (1994) utilized transparent analogues (e.g., PMMA) to demonstrate through transmitted light observations that contact area increases during stationary contact and applied normal stress due to asperity-scale plastic flow, thereby controlling peak frictional strength. Subsequent studies have attempted to track contact area evolution in geologically realistic but opaque materials using indirect methods, such as seismic wave attenuation and velocity changes. While these techniques have provided highly valuable insights, they offer only a partial and indirect view of the processes occurring at the slip interface.

In this study, we present results from a preliminary experimental investigation into the evolution of frictional contact area during the deformation of laboratory faults composed of geologically realistic materials such as quartz, calcite, and phyllosilicates. We employ an innovative technique that utilizes high-strength transparent sample assemblies coupled with high-speed, high-resolution imagery. Our approach allows for the first direct, real-time observation of interface deformation and its relationship with stress state evolution of realistic fault materials. Our preliminary results provide new insights on the micro-mechanics controlling frictional properties and fault slip behavior.

Dieterich J.H. & Kilgore B.D. (1994) - Direct observation of frictional contacts: New insights for state-dependent properties. Pure Appl. Geophys., 143(1), 283-302, https://doi.org/10.1007/BF00874332.

S10.

Structural Geology across scales: bridging deformation processes, georesources and geohazard characterization

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Seismotectonic framework and earthquake damage at ancient Hierapolis (SW Turkey): Integrated geological and archaeological constraints supported by multispectral analysis of active faulting in the Pamukkale extensional system

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Keywords: active faulting, archeology, multispectral analysis.

The travertine-covered plateau of Pamukkale, in southwestern Turkey, hosts the ancient city of Hierapolis, a UNESCO World Heritage site located along the active margin of the Denizli Graben. This area is an exceptional natural and archaeological laboratory for investigating the relationships among active tectonics, hydrothermal circulation, travertine deposition and earthquake damage in a slowly deforming extensional province. This contribution presents the results of an integrated study based on surface geological and structural mapping, drone-based multispectral surveys, thermal imaging, and archaeological data collected within the PRIN2022PNRR project (Living on active seismic faults: an archaeological approach. The case-study of Hierapolis of Phrygia) with the collaboration of the Italian Archaeological Mission at Hierapolis. The integration of these datasets allows us to refine the geometry, segmentation and kinematics of the active fault systems affecting the Pamukkale plateau and the urban area of Hierapolis, and to assess their role in controlling landscape evolution, hydrothermal activity and earthquake-related damage. Field data document a network of active normal to oblique-slip faults, mainly striking NW-SE, consistent with a transtensional regime dominated by E-W extension. These structures dissect the travertine plateau, bound sectors of differential uplift and subsidence, and act as pathways for hydrothermal fluids responsible for travertine deposition. Multispectral drone imagery enhances the detection of subtle fault-related lineaments, fracture corridors, lithological contrasts and anomalies, whereas thermal data highlight zones of fluid circulation and structurally controlled hydrothermal discharge. These observations are validated through structural measurements, including fault-slip data, fracture patterns, hydrofractures and syn-tectonic travertine fabrics. Archaeological evidence from excavations and standing monuments, including displaced blocks, ruptured walls, tilted architectural elements is spatially compared with the mapped structural framework. The observed damage distribution suggests a strong control exerted by active and inherited fault zones on the seismic vulnerability of the ancient city. This supports the occurrence of repeated damaging earthquakes, including events of likely Mw > 6, during historical times. The results highlight the importance of combining geological, remote-sensing, thermal and archaeological datasets to reconstruct active fault architecture in complex hydrothermal-travertine systems. In Hierapolis, this approach provides new constraints on the seismotectonic behaviour of the Pamukkale fault system and improves our understanding of the fault network that has generated destructive earthquakes in the Denizli Basin.

The Database of Individual Seismogenic Sources (DISS): A reference database for fault-based earthquake hazard analyses in Italy and Europe

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Keywords: seismogenic sources, earthquake hazard, seismotectonic.

DISS - Database of Individual Seismogenic Sources (DISS Working Group, 2025; https://diss.ingv.it) - is an original tool developed at ING (now INGV) starting in 1997, released to the scientific community in 2000 (v. 1.0) and widely disseminated since 2001 (v. 2.0). Initially conceived as a database devoted to earthquake geology and tectonics in Italy, DISS has continuously evolved through major updates in both contents and structure, reaching the current version 3.3.1 released in 2025.

DISS stores and organizes tectonic, geological, geophysical, and paleoseismological information in a geospatial database to describe the three-dimensional geometry and behavior of the main active and seismogenic faults in Italy and the central Mediterranean region. Based on common magnitude-scaling relations, we consider a threshold of Mw > 5.5 to represent earthquake faults large enough to be reliably identified from geological and geophysical data.

The database focuses on primary faults that accommodate most tectonic deformation (whether rupturing up to the ground surface or not) and generate major earthquakes, thus leaving secondary or ancillary, shallower faults out.

The database architecture includes: (i) Individual Seismogenic Sources (ISS), three-dimensional models of single fault ruptures; (ii) Composite Seismogenic Sources (CSS), simplified three-dimensional representations of a crustal fault or fault system containing an unspecified number of individual potential ruptures; (iii) Debated Sources, faults proposed in the literature but still lacking information to be included in the other categories; and (iv) Subduction Sources, geometrically complex 3D models of subduction systems that form at convergent plate boundaries generating earthquake ruptures of various types.

DISS has also set a benchmark in Europe: the fault typologies developed within DISS, particularly Composite Sources, have been adopted in major international initiatives such as the European Database of Seismogenic Faults (2013) and the European Fault-Source Model (2020). DISS provides a key input for earthquake hazard analyses, which have been widely used in fault-based seismicity rate models over the last decade, such as ESHM13, NEAMTHM18, MPS19, ESHM20, and ISHM. DISS can also be used for other hazard analysis related to secondary environmental effects, such as distributed surface faulting, earthquake-induced landslides. By defining the spatial arrangement, hierarchy, and 3D geometry of seismogenic sources, DISS supports realistic ground-motion and tsunami simulations that, based on geologically constrained fault models, form the backbone of modern earthquake hazard analyses.

DISS Working Group (2025) - Database of Individual Seismogenic Sources (DISS), Version 3.3.1: A compilation of potential sources for earthquakes larger than M 5.5 in Italy and surrounding areas. Istituto Nazionale di Geofisica e Vulcanologia (INGV). https://doi.org/10.13127/diss3.3.1.

Constraining geological interpretation through deep borehole data processing and synthetic seismograms generation: An application to the subsurface geology of northern Umbria (Italy)

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Keywords: log boreholes processing, Altotiberina Fault, LANFs.

The Northern Apennines are characterized by a polyphase tectonic evolution including Upper Miocene thrusting and subsequent Late Pliocene extensional overprinting. In the Umbria region, the Tiber Valley represents an asymmetric graben originated in the hanging wall of the Altotiberina Fault (ATF), an east-dipping low-angle normal fault whose break-away zone causes the exhumation of the Triassic core of M. Malbe. The Tiber graben originated due to the interaction between two extensional fault systems: i) NE-dipping faults (both low- and high- angle) in the Perugia Massifs area, detaching on the ATF (Minelli, 1992; Brozzetti, 1995; Collettini & Barchi, 2002); ii) external SW-dipping high-angle normal faults. Other antithetic normal faults (Umbria Fault System sensu - Barchi, 2002), developed further east, originating the San Sepolcro, Gubbio, and Colfiorito intra-mountain basins.

The normal faults dissecting the Perugia Massifs, are divided into a set of low-angle (30°) faults, which are generally dislocated by a high-angle set (65°). This pattern, recognized at both meso- and macroscale, has been interpreted as a domino-like structure (Brozzetti, 1995), giving rise to two distinct generations of faults, rotated above the ATF.

Two close boreholes (Perugia2 and S. Donato1) cross the ATF, which causes the elision of the entire Meso-Cenozoic carbonate succession. Therefore, the Miocene Marnoso-Arenacea Fm lies directly upon the Triassic evaporites (Anidriti di Burano Fm) and the Permo-Triassic phyllites. Another borehole (M. Civitello1), closer to the Gubbio basin, records the complete stratigraphy from the Triassic anhydrites to the Miocene sediments.

This work implement a customized data-processing workflow with the aim to better constrain the seismic interpretation. The workflow steps can be summarized as follows: i) log data digitization from old paper or raster documents; ii) time-to-depth calibration of available borehole logs, in particular Sonic data, but also Density and Resistivity data; for boreholes not equipped with a sonic log, a synthetic one is necessary to produce it; iii) synthetic seismogram generation through the use of GeoSyn geophysics software module integrated into the Kingdom geological platform. The generated synthetic seismograms are later tied to the nearest seismic profiles.

The resulting outcome of this methodological approach applied for each borehole is the generation of a synthetic seismogram which reproduces the stratigraphic boundaries in terms of seismic signal, linking the well data (in depth) with the seismic profile (in time). To minimize misinterpretation, this work represents the first phase of a new multidisciplinary analysis of the extensional system of the Upper Tiber Valley, aimed at reconstructing its structures in 3D view.

Barchi M.R. (2002) - Lithological and structural controls on the seismogenesis of the Umbria region: observations from seismic reflection profiles. Boll. Soc. Geol. It., 121(1), 855-864, https://hdl.handle.net/11391/110696.

Brozzetti F. (1995) - Stile strutturale della tettonica distensiva nell'Umbria occidentale: l'esempio dei Massicci Mesozoici Perugini. Studi Geol. Camerti, vol. sp. 1995/1, 105- 119, http://hdl.handle.net/11564/109910.

Collettini C. & Barchi M.R. (2002) - A low-angle normal fault in the Umbria region (Central Italy): a mechanical model for the related microseismicity. Tectonophysics, 359(1-2), 97-115, https://doi.org/10.1016/S0040-1951(02)00441-9.

Minelli G. (1992) - Tectonic Evolution of the Perugia Massifs Area, Northern Apennines (Italy). PhD Thesis, 158 pp., Imperial College, London.

Interplay between extensional tectonics and magmatism during crustal thinning: Insights from Elba Island, northern Tyrrhenian Basin

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Keywords: extensional tectonics, Tyrrhenian Sea, transfer zone.

The rapid transition from thick to over-thinned continental crust beneath an orogenic belt is a key process in the evolution of post-collisional extensional systems. This process also characterizes the Neogene evolution of the inner Northern Apennines, where the opening of the Tyrrhenian Basin was accompanied by crustal and lithospheric thinning, with present-day thicknesses of about 20-24 km and 45-50 km, respectively. Elba Island, located in the central part of the northern Tyrrhenian Basin, represents a key area for investigating the relationships among extensional tectonics, transfer faulting and magmatism during crustal thinning. In this study, we integrate field structural data with the interpretation of reflection seismic lines to reconstruct the timing and geometry of extensional structures and their interaction with Neogene magmatic bodies. Superposed extensional events are recognized within a continuous extensional process in which normal and NE-striking transfer faults were active simultaneously. The earliest Aquitanian-Burdigalian event produced extensional structures well documented in Corsica. A second Burdigalian-Tortonian event defined the fault system bounding the Corsica Basin to the west and generated extensional shear zones with mylonitic fabrics, now exposed on Elba Island. Their exhumation was closely associated with Tortonian magmatism, which produced doming of the previously active shear zones during magma emplacement. This magmatic doming represents a crucial mechanism in the tectonic evolution of the area. By deforming and rotating pre-existing extensional shear zones, it led to their progressive inactivation and promoted the development of new fault systems during the late Tortonian-early Messinian. The Monte Capanne Fault provides a clear example of this process, having been domed and rotated during the emplacement and uplift of the Monte Capanne monzogranite. A similar evolution affected the Zuccale Fault during the late Messinian, in relation to the Porto Azzurro monzogranite. Finally, Pliocene-Quaternary faults produced tectonic depressions filled by marine to continental sediments, many of which are widely exposed in Tuscany. The extensional evolution of the Tyrrhenian Basin, Elba Island and Tuscany was accompanied by the activity of NE-striking transfer fault zones, which played a major role in channelling magma and accommodating crustal heterogeneities during stretching. Magmatism was therefore fundamental in softening the crust, enhancing thinning and promoting the development of new, more efficient extensional structures under the same regional stress field. The resulting structural architecture consists of multiple generations of normal faults whose geometry and apparent kinematics were strongly influenced by magmatic emplacement, locally producing rotations that may simulate reverse fault motion.

PDF-Italy 1.0: Probabilistic mapping of distributed faulting in Italy through integration of DISS and ITHACA databases

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Keywords: surface faulting, earthquake hazard, DISS and ITHACA databases.

Surface faulting associated with moderate-to-large (Mw ≥ 5.5) earthquakes is a key expression of active tectonics and a primary source of ground-displacement hazard. While primary faulting reflects slip on seismogenic structures, distributed faulting involves secondary ruptures and diffuse deformation within surrounding fault systems. This process is strongly controlled by fault architecture, kinematics, and strain partitioning, and may extend for kilometers away from the principal fault, posing significant challenges for displacement hazard assessment and land-use planning.

In this context, we present PDF-Italy 1.0, a national-scale assessment of the probability of distributed faulting (PDF) developed within the PNRR MEET Project and released on the Seismofaults platform (https://seismofaults.eu/). The approach integrates the DISS seismogenic source database with the ITHACA database of active and capable faults, combining seismological and geological constraints within a unified framework. This work builds on a previous DPC-funded effort published on the DISS-ITHACA interoperability web page (https://diss.ingv.it/ithdiss/), further advancing the integration of different fault-system data for earthquake hazard applications.

The methodology adopts a tectonic framework in which Composite Seismogenic Sources from DISS represent the main faults responsible for the release of seismic energy and accommodating principal faulting, whereas ITHACA faults are interpreted as elements of the surrounding deformation field potentially involved in distributed faulting. This conceptual model reflects the structural complexity of Italian fault systems, characterized by segmented, interacting, and often non-planar fault networks. Conditional probabilities of distributed faulting are estimated using empirical relationships selected based on fault kinematics and consistent with the Italian tectonic context, with distinct models applied to normal, reverse, and strike-slip regimes (Ferrario & Livio, 2021; Takao et al., 2014).

Probabilities are first computed on a regular grid to capture the spatial variability of distributed deformation at the national scale, highlighting areas where fault interaction and structural complexity enhance the likelihood of off-fault rupturing. The same approach is then applied to ITHACA faults, providing fault-based estimates that explicitly link distributed faulting potential to mapped geological structures. The resulting dataset offers new insights into the role of secondary faulting within active fault systems and provides a tool to bridge seismogenic source models and surface deformation processes. Besides, it emphasizes the importance of integrating geological and seismological datasets to better represent the full spectrum of coseismic deformation. By framing distributed faulting within the architecture of active fault systems, this work contributes to improving the geological basis of probabilistic earthquake hazard assessment in Italy.

Ferrario M.F. & Livio F. (2021) - Conditional probability of distributed surface rupturing during normal-faulting earthquakes. Solid Earth, 12, 1197-1209, https://doi.org/10.5194/se-12-1197-2021.

Takao M. et al. (2014) - Reliability improvement of probabilistic fault displacement hazard analysis. J. Japan Assoc. Earthquake Eng., 14(2), 2_16-2_36, https://doi.org/10.5610/jaee.14.2_16.

Heterogeneous deformation and partial (re-)equilibration of orthogneiss in the Dora-Maira Massif (Western Alps)

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Keywords: mass transfer, microstructure, orthogneiss.

Orthogneisses are widespread in continental crystalline basements (Massonne, 2021) and are often considered less reliable and useful than metabasites and metapelites when reconstructing metamorphic P-T evolutions (Massonne, 2015; 2021). This is primarily due to their frequent tendency to record incomplete metamorphic equilibration, even under high-temperature conditions (e.g., Oberhänsli et al., 1985). In this contribution, we investigate a suite of orthogneiss derived from the same Lower Paleozoic magmatic cycle, cropping out in the central Dora-Maira Massif (Dana et al., 2026), providing a natural laboratory to examine the interplay between deformation, fluid availability, and metamorphic re-equilibration during the deformation of granitic rocks. The studied orthogneiss recorded variable degrees of Alpine deformation and metamorphic re-equilibration, varying from low-strain domains, preserving pre-Alpine features and recording a scarce Alpine metamorphic overprint, to high-strain, mylonitic to ultramylonitic, portions that experienced a complete metamorphic re-equilibration during the Alpine cycle. Microtectonics and geochemical mass transfer analyses are used to reconstruct the microstructural and chemical evolution of the studied orthogneiss from the low-strain towards the high-strain domains. Mineral chemistry and thermodynamic modelling of selected samples are integrated to constrain the Alpine metamorphic evolution of the high-strain domains and assess the control of deformation mechanisms, fluid influx, and rheological heterogeneities in the preservation or obliteration of the pre-Alpine mineral assemblage. Our results show that when low-strain domains in orthogneiss are affected by fluid-deficient conditions, their deformation and metamorphic re-equilibration are limited, and high-pressure (HP) mineral assemblages are usually poorly developed. However, ductile shear zones can act as preferential pathways for fluids during deformation under water-saturated conditions, promoting recrystallization and facilitating metamorphic (re-)equilibration. This process enabled the high-strain domains in orthogneiss to equilibrate under HP eclogitic-facies conditions.

Dana D. et al. (2026) - Heterogeneous deformation and partial (re-) equilibration of high-pressure orthogneiss in the Dora-Maira Massif (Western Alps). Tectonophysics, 930, 231201, https://doi.org/10.1016/j.tecto.2026.231201.

Massonne H.J. (2015) - Derivation of P-T paths from high-pressure metagranites - Examples from the Gran Paradiso Massif, western Alps. Lithos, 226, 265-279, https://doi.org/10.1016/j.lithos.2014.12.024.

Massonne H.J. (2021) - Key patterns of S-type granitic gneiss to define the baric (low-to high-pressure) nature of Phanerozoic basement terranes. Terra Nova, 33(3), 225-239, https://doi.org/10.1111/ter.12510.

Oberhänsli R. et al. (1985) - Geochemistry, geochronology and petrology of Monte Mucrone: an example of Eo-Alpine eclogitization of Permian granitoids in the Sesia-Lanzo Zone, Western Alps, Italy. Chem. Geol., 52(2), 165-184, https://doi.org/10.1016/0168-9622(85)90016-8.

Slip rates analysis of buried thrusts in the Central Adriatic Sea (Italy) since the Pliocene time

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Keywords: buried faults, seismic reflection data, slip rates.

Quantifying the recent tectonic activity of buried faults is a significant challenge for seismotectonic assessment, particularly in offshore settings where high sedimentation rates often outpace tectonic uplift. In the Central Adriatic Sea, Italy, thick Plio-Pleistocene deposits cover the outermost sectors of the Northern and Central Apennines fold-and-thrust belt, hampering the direct detection of active deformation. This study aims to quantify the Plio-Pleistocene tectonic evolution of the region by calculating slip rates and assessing the activity potential of offshore buried thrusts.

The study integrates a vast dataset of regional seismic reflection profiles (both public and confidential) and well logs to reconstruct the subsurface structural framework. Two regional SW-NE trending seismic transects were depth-converted using a multilayer velocity model and restored to their pre-deformational state. To isolate the tectonic signal, a step-by-step restoration process was employed, incorporating a decompaction algorithm to remove non-tectonic deformation caused by sediment porosity reduction under lithostatic load.

Slip amounts were determined for 12 fault systems across five seismostratigraphic horizons (from Zanclean to Middle Pleistocene) using Trishear inverse modelling for fault-propagation folding and the Fault Parallel Flow method for displaced horizons. To account for uncertainties in both stratigraphic ages and the restoration process, slip rates were calculated using a probabilistic approach based on Gaussian and boxcar Probability Density Functions (PDFs).

The results reveal a progressive reduction in regional tectonic activity over time, characterized by an exponential decay in slip rates. A significant kinematic slowdown is observed around 1.5 Ma (Early Pleistocene). Despite this general waning, the study identifies localized evidence of recent thrusting (Middle-Late Pleistocene), particularly in the southern section, where faults appear younger and more active compared to the northern sector. These findings correlate with instrumental seismicity, such as the 2022 Mw 5.5 Pesaro sequence, confirming that these "buried" structures remain seismogenically active despite low long-term deformation rates.

Experimental studies on fluid-rock interaction and the seismic cycle in geothermal systems

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Keywords: seismic cycle, fluid-rock interaction, volcanic calderas.

Geothermal systems are dynamic environments where fluid-rock interactions strongly influence the mechanical, chemical, and hydraulic properties of the crust, ultimately affecting the occurrence and evolution of seismic activity. Here, motivated by the occurrence of shallow seismicity (< 5 km depth) in volcanic calderas (Campi Flegrei, Italy) or associated with the exploitation of geothermal reservoirs (Krafla, Iceland), we will discuss the results (mechanical data, microanalyses of the solid matrix and fluids, etc.) of about 150 experiments performed with new devices which combine rotary shear machines and hydrothermal vessels. These devices are capable of reproducing hydrothermal conditions in the laboratory by imposing aseismic (nm/s) to seismic (m/s) slip rates and slip distances of up to several meters on simulated faults, or by triggering spontaneous laboratory earthquakes in the presence of hot (up to 500°C) and pressurized fluids (up to 70 MPa). We found that fluid-rock interaction, fluid pressure and temperature and fluid physical state (liquid, vapor, or supercritical) can lead to the transition from aseismic creep to earthquake nucleation and control the healing of crustal faults. In particular:

1) the frictional behavior of faults made of basalt gouges from Krafla (Iceland) depends on the physical state of the water (Wu et al., 2026). When the gouges are sheared in the presence of vapor, they exhibit relatively stable aseismic sliding. In contrast, when sheared in liquid water, the gouges exhibit unstable seismic sliding. Our results agree with the *on-site* observations in Krafla (Gluck et al., 2025);

2) the frictional behavior of made of reactive tuffs from Campi Flegrei (Italy) that change their mineral assemblage during the interaction with hydrothermal fluids depends also on temperature. At room temperature, deformation occurs via aseismic slip, whereas higher temperatures promote mineral reactions and rapid fault cementation, leading to unstable seismic sliding. Our results agree with the measured shallow seismicity in Campi Flegrei (Tan et al., 2025).

The experimental and microanalytical approach described above, if supported by geological, seismological, and geophysical studies, could not only contribute in the short to medium term to understanding the physicochemical mechanisms responsible for seismicity in geothermal systems, but also, in the long term, to the development of safer new methods of geothermal exploitation and to understanding seismicity in volcanic calderas, including for civil protection purposes.

Gluck E. et al. (2025) - Seismicity patterns and multi-scale imaging of Krafla, N-E Iceland, with local earthquake tomography. J. Geoph. Res., 130, e2024JB030425, https://doi.org/10.1029/2024JB030425.

Tan X. et al. (2025) - A clearer view of the current phase of unrest at Campi Flegrei caldera. Science, Science, 390, 70-75, https://doi.org/10.1126/science.adw9038.

Wu W.-S. et al. (2026) - The effect of temperature and physical state of water on the frictional properties of chlorite-altered basaltic gouges (Krafla Geothermal Field, Iceland). J. Geoph. Res., 131, e2025JB032343, https://doi.org/10.1029/2025JB032343.

Polymetallic mineralization in a strike-slip fault system: Peloritani Mountains (NE Sicily)

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Keywords: strike-slip faulting, polymetallic mineralization, structural control.

Polymetallic As-Ag-Pb-Cu-Zn mineralization in the Fiumedinisi-Antillo district (Peloritani Mountains, NE Sicily) is controlled by a multiscale network of strike-slip and oblique-slip shear zones affecting the Variscan metamorphic basement and repeatedly reactivated during Alpine and post-Alpine tectonics within the Apennine-Maghrebian orogenic system. This study integrates petro-structural mapping, LiDAR data, and 3D reconstruction of abandoned mine workings to constrain the structural architecture and its role in fluid flow and ore deposition.

Mineralized veins and breccia bodies preferentially localize along NE-SW and NW-SE fault corridors. Structural elements such as Riedel shears, releasing bends, and fault intersections generated dilational domains that acted as high-permeability pathways for hydrothermal fluid ascent. Early pyrite mineralization occurs concordant with foliation in phyllites and shows limited metal enrichment, whereas the main sulphide and sulfosalt assemblages are hosted in fracture systems discordant to foliation, forming vein networks with thicknesses ranging from centimeter to several meters.

These fracture systems, now commonly reactivated as normal faults, locally preserve left-lateral kinematic indicators and are interpreted as part of an antithetic Riedel system associated with dominant NW-SE right-lateral strike-slip faulting. This structural framework reflects the evolution from transpressive nappe stacking (Palaeocene-Miocene) to subsequent Pliocene-Pleistocene extensional reactivation linked to gravitational collapse of the chain.

Ore assemblages dominated by galena, sphalerite, Ag-rich tetrahedrite, chalcopyrite, arsenopyrite, and other Sb- and Ag-bearing sulfosalts occur as open-space fillings, breccia cements, and localized replacements. Textural evidence indicates episodic hydraulic fracturing and rapid sealing, consistent with pressure fluctuations in an active structural regime. Fluid-rock interaction with carbonate-rich and metamorphic lithologies promoted metal precipitation through pH variations, redox reactions, and mixing between deep hydrothermal and shallow basinal fluids.

The long-lived NW-SE structural system likely acted as a major hydrothermal conduit, focusing fluid flow and metal transport. Additionally, Variscan granitoid bodies provided a persistent thermal source, enhancing geothermal gradients, fluid circulation, and metal remobilization during tectonic reactivation.

Overall, the geometry, kinematics, and thermal evolution of the strike-slip fault system exert a first-order control on ore distribution. Major shear zones function as long-lived conduits, whereas secondary extensional structures localize higher-grade mineralization. The Fiumedinisi-Antillo district thus represents a well-constrained example of structurally controlled polymetallic mineralization in a complex orogenic setting, providing insights into mineralizing processes in basement-hosted systems.

New perspectives from the CARG project in the northern Serre Massif (Calabria, southern Italy)

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Keywords: mylonitic shear zone, crystalline basement evolution, geological mapping.

A detailed geological, petrographic, and microstructural investigation was carried out in the Màida area (Northern Serre Massif) with the aim of refining the litho-structural framework of the crystalline basement and reconstructing the tectono-metamorphic evolution of the shear zone separating the main phyllite (footwall) and orhogneiss/paragneiss (hanging wall) tectono-metamorphic units. Field mapping of the sheet 575 Catanzaro, within the CARG Project, is revealing significant discrepancies with respect to the current official geological cartography, particularly concerning unit boundaries and the nature of their contacts. In particular, the latter uniti is subdivided into two lithostratigraphic sub-units informally referring to as the "para- and ortho-derived gneiss unit" hosting the "augen gneiss unit".

The contact between these sub-units, previously interpreted as tectonic, is here re-evaluated as a primary intrusive boundary occurred during late Precambrian - Early Cambrian, subsequently overprinted by Variscan regional metamorphism and ductile deformation. Relict intrusive textures preserved within the metamorphic fabric support this interpretation and highlight the need for updated geological mapping criteria capable of distinguishing metamorphosed intrusive contacts.

Particular attention was devoted to the mylonitic shear zone belonging to the Alpine Curinga-Girifalco Line fault system. A combined petrographic and microstructural observations were performed on several samples collected across the shear zone and from the adjacent undeformed rocks. The results reveal a well-developed tectono-metamorphic gradient associated with top-to-the-northern quadrants kinematics (in present geographic coordinates). In the mylonitic orthogneisses, plagioclase and quartz behavior document a transition from ductile to brittle deformation, with the first deformation mechanism accompanied by crystallization of epidote and phengite, suggesting increasing pressure conditions during deformation. Similarly, the Paleozoic protholiths of the phyllite unit show a mineral assemblage recording a progressive increase in metamorphic conditions toward the hangingwall.

Besides contributing to the ongoing revision and harmonization of geological cartography, this study offers new insights into the architecture, plutonic evolution, and deformation history of crystalline tectonic units in central Calabria, providing new structural and petrological perspectives.

Reading Mercury's tectonic history through geological and structural mapping

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Keywords: Mercury (planet), planetary tectonics, BepiColombo.

The NASA MESSENGER mission revolutionized our understanding of Mercury, revealing a tectonically complex planet shaped by the interaction of global contraction, volcanism, impact basin formation, and long-lived crustal heterogeneities. In parallel with the development of the first global geological mapping effort of Mercury led by a European team, geological and structural mapping became fundamental tools to reconstruct the tectonic evolution of the planet and investigate the role of crustal inheritance in controlling the localization and kinematics of deformation.

Over the last decade, our team carried out structural and geological investigations integrating geological mapping, morphostructural analysis, gravity and topographic datasets, crater-offset measurements, stress inversion techniques, and basin reconstruction approaches. Early work focused on the quantitative characterization of thrust-related tectonic landforms through the analysis of faulted impact craters, providing new constraints on fault geometry, displacement, and oblique-slip kinematics (Galluzzi et al., 2015). Subsequent regional-scale investigations demonstrated that major Mercurian fault systems are not randomly distributed, but instead reflect tectonic patterns controlled by regional stress fields, crustal heterogeneities, and inherited basin-related structures (Galluzzi et al., 2019).

Particular attention has been devoted to the relationship between tectonic systems and ancient impact basins. Structural analyses performed in several quadrangles highlighted concentric and radial tectonic patterns associated with degraded or buried multi-ring basins, suggesting that ancient basin-forming events exerted a long-lasting control on Mercury's structural framework. These inherited structures were later reactivated during global contraction and influenced the development of thrust systems, wrinkle ridges, extensional graben, and volcanic pathways. Recent studies integrating gravity and topographic analyses further indicate that flexural and basin-related processes played a major role in shaping the evolution of large impact basins such as Caloris (Schmidt et al., 2026).

These results support the view of Mercury as a structurally inherited planet, where crustal composition, buried basin architecture, and pre-existing tectonic fabrics influenced the localization, geometry, and evolution of deformation through time. Mercury therefore represents a unique natural laboratory to investigate tectonic inheritance, lithospheric evolution, and deformation processes in a stagnant-lid terrestrial planet.

These investigations now provide an important scientific framework for the ESA-JAXA BepiColombo mission and, in particular, for the SIMBIO-SYS instrument suite (Cremonese et al., 2020), for which dedicated observation strategies are being developed to investigate tectonic targets, crustal boundaries, fault systems, and basin-related deformation at unprecedented spatial and spectral resolution. The synergy between geological mapping, structural analysis, and targeted observations will provide new perspectives for the geological exploration of Mercury and for comparative tectonics of terrestrial planets.

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Cremonese G. et al. (2020) - SIMBIO-SYS: Scientific cameras and spectrometer for the BepiColombo mission. Space Sci. Rev., 216, 75, https://doi.org/10.1007/s11214-020-00704-8.

Galluzzi V. et al. (2015) - Faulted craters as indicators for thrust motions on Mercury. Geol. Soc. Spec. Publ., 401, 313-325, https://doi.org/10.1144/SP401.

Galluzzi V. et al. (2019) - Structural analysis of the Victoria quadrangle fault systems on Mercury: timing, geometries, kinematics, and relationship with the high-Mg region. J. Geophys. Res. Planets, 124, 2543-2562, https://doi.org/10.1029/2019JE005953.

Schmidt G. et al. (2026) - Origin of the bulge topography within Caloris basin, Mercury. J. Geophys. Res. Planets, 131, e2025JE009233, https://doi.org/10.1029/2025JE009233.

High-resolution LiDAR and field structural mapping of the Monte Marsicano Fault (Central Apennines, Italy): Implications for kinematics, activity, and seismic gap characterization

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Keywords: active tectonics, high-resolution topography, seismic gap.

The central Apennines are among the most seismically active regions of the Mediterranean, characterized by post-collisional extensional tectonics and active NNW-SSE striking fault systems as also documented by both historical and instrumental seismicity.

The Upper Sangro Valley fault system in the Abruzzo Region (Central Italy) is a NNW-SSE striking fault system characterized by a significant seismic gap. Unlike nearby, contiguous fault systems, such as those of the Monte Greco-Barrea area (1984 earthquake) and the Fucino basin (1915 earthquake), no historical or instrumental earthquakes have been directly attributed to this system, raising questions about its current activity and seismogenic potential.

The Upper Sangro Valley fault system has been poorly investigated, and previous studies interpreted it as a NW-SE-trending active structure with complex kinematics, including left-lateral strike-slip components along the valley margins and normal faulting within the basin (Galadini & Messina, 1994).

We present a new detailed morphostructural analysis of the Monte Marsicano Fault, integrating original geological and structural field data with high-resolution remote morphotectonic analysis. The latter is based on a newly airborne-acquired LiDAR dataset (20 cm/pixel DTM), characterized by very high point density (~350 pts/m²) at footprint, with exceptional precision and accuracy (~0.02-0.03 m). The removal of vegetation cover and the excellent resolution of the dataset enable the detection of fine-scale geomorphic features not easily recognizable in the field, allowing detailed mapping of fault-related landforms (e.g. fault scarps and minor lineaments), erosional surfaces and continental depositional bodies (e.g. alluvial fans, slope breccias), thus providing a robust basis for detailed quantitative morphometric analyses.

The new morphostructural map documents a complex normal fault system affecting the Plio-Quaternary continental deposits. Field structural data consistently indicate predominant dip-slip kinematics, with only minor localized oblique components controlled by fault geometry.

Geomorphic evidence, including displaced landforms, triggered surface remodeling and offset continental deposits, indicate fault activity at least during the Quaternary, with direct implications for seismic hazard assessment. Although the lack of chronological constraints currently prevents reliable slip-rate estimates, the proposed reconstruction improves the structural characterization of the area and provides a solid basis for future paleoseismological, geochronological, and geophysical investigations aimed at constraining deformation rates across multiple time scales and better assessing the seismic potential of this apparently silent fault system.

Galadini F. & Messina P. (1994) - Stratigrafia dei depositi continentali, tettonica ed evoluzione geologica quaternaria dell'alta valle del Fiume Sangro (Abruzzo meridionale). Ital. J. Geosci., 112(3-4), 877-892.

Kinematic evolution of the Indus Suture (Main Mantle Thrust), northern Pakistan

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Keywords: Main Mantle Thrust, low-temperature thermochronology, exhumation coupling.

The Main Mantle Thrust (MMT) of northern Pakistan marks the Cenozoic suture between the Kohistan Island Arc and the leading edge of the Indian plate, representing one of the most significant tectonic boundaries of the western Himalaya. Following initial India-Kohistan collision at ~50 Ma and peak amphibolite-facies metamorphism of the Indian plate footwall at ~47-39 Ma (650°C, ~1.0 GPa; Soret et al., 2021), the MMT was reactivated as a low-angle, north-dipping normal fault during the Oligocene-Miocene, tectonically exhuming high-grade metamorphic rocks from the leading edge of the Indian plate.

We present new apatite fission track (AFT), zircon (U-Th)/He (ZHe), and apatite (U-Th)/He (AHe) data from the Indian plate in the Swat Valley and from proximal samples of the Kohistan arc. We integrate these with published thermochronological and structural data to better constrain the Cenozoic kinematic evolution of the MMT.

Field structural evidence in the MMT footwall consists of top-to-the-north shear fabrics, shear bands transitioning from semi-ductile to brittle conditions, and cataclastic fault cores. This assemblage documents normal-sense reactivation under greenschist-facies to lower-grade conditions, potentially linked to orogenic wedge dynamics.

New ZHe ages from the Indian plate domes (16-21 Ma) overlap with a ZHe age from the proximal Kohistan arc (~21 Ma), indicating similar cooling ages across the MMT. These consistent ZHe ages at ~20 Ma record the locking of the MMT and the transition to coupled, regional exhumation of the arc and Indian plate as a coherent block. Published ZFT ages in the Indian plate (20-23 Ma) contrast with arc cooling ages (>44 Ma at distances >15 km north of the MMT), confirming active differential exhumation during the fault displacement phase. AHe ages (9-16 Ma) document continued post-coupling exhumation driven by ongoing convergence. Minor differences between the AHe ages could reflect differential dome amplification associated with north-trending folding and/or different erosion patterns along the Swat Valley.

QTQt thermal modeling of the Loe Sar Dome confirms a fast exhumation pulse initiating at ~18-20 Ma and decreasing after ~15 Ma, consistent with the transition from fault-controlled to regionally coupled exhumation. These results provide new constraints on the coupling and decoupling history of a major Himalayan suture zone and on the mechanisms driving large-scale exhumation at the leading edge of a collisional orogen.

Soret M. et al. (2021) - How Himalayan collision stems from subduction. Geology, 49(8), 894-898, https://doi.org/10.1130/G48803.1.

Stress-controlled fault reactivation potential in the Dibrugarh field, Upper Assam foreland basin, NE India

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Keywords: stress, fault reactivation, Upper Assam NE India.

Inherited fault architectures and the present-day tectonic stresses exert a fundamental control on fault reactivation within active foreland basins. In the Dibrugarh field of the Upper Assam foreland basin, NE India, Kumar et al. (2023) documented a complex strike-slip fault architecture within the Tipam Formation (a well-known hydrocarbon bearing sandstone reservoir of the basin) using high-resolution 3D seismic reflection data, including negative flower structures, horsetail splays, transfer faults, segmented fault linkages, and fault interaction zones. These geometries provide an ideal framework for evaluating the mechanical reactivation potential of inherited basin-scale faults under the present-day stress regime.

In this study, focal-mechanism-derived stress tensors are integrated with stress-based fault stability analysis to evaluate the reactivation potential of mapped faults within the Dibrugarh sector (Pietrolungo et al., 2024). The workflow combines slip tendency (Ts), dilation tendency (Td), and fracture susceptibility (Fs), analyses to quantify the mechanical behaviour of pre-existing fault planes. To address stress-model uncertainty and spatial variability, three independent stress scenarios are evaluated: (i) a reconstructed local grid tensor (N = 14N), (ii) an intermediate subset solution (N = 156), and (iii) a regional focal-mechanism-derived stress tensor (N = 361). All calculations were performed at a depth of 2 km (structural level of the Tipam formation) assuming hydrostatic pore pressure, zero cohesion, and a friction coefficient of 0.6 within a unified geo-mechanical framework.

The results reveal strong sensitivity of fault criticality to the scale and spatial distribution of stress inversion. The local and intermediate tensors indicate a predominantly thrust-to-transpressional stress regime, whereas the regional solution suggests a comparatively strike-slip-dominated stress configuration. This contrast highlights pronounced spatial heterogeneity in stress across NE India and underscores the importance of evaluating fault stability within a stress-uncertainty framework rather than relying on a single preferred stress tensor. Faults that remain critically stressed across multiple stress scenarios are interpreted as robust reactivation candidates, whereas faults that exhibit instability only under individual stress tensors are considered stress-model-dependent.

The study provides a first-order geo-mechanical assessment of critically stressed faults within the Dibrugarh field and demonstrates how inherited strike-slip fault architectures interact with the contemporary tectonic stress field. The proposed workflow establishes a transferable framework for uncertainty-aware fault reactivation analysis in structurally complex sedimentary basins and contributes toward improved understanding of tectonic reactivation processes within active foreland systems.

Kumar P.C. et al. (2023) - Geometry and Kinematics of strike-slip faults in the Dibrugarh field of the Upper Assam foreland basin, NE India. Mar. Petrol. Geol., 153, 106291, https://doi.org/10.1016/j.marpetgeo.2023.106291.

Pietrolungo F. et al. (2024) - Comparison of Crustal Stress and Strain Fields in the Himalaya-Tibet Region: Geodynamic Implications. Remote Sens., 16(24), 4765, https://doi.org/10.3390/rs16244765.

Mechanical interactions of geometrically linked cracks and faults: Insights from FEM-based numerical modeling

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Keywords: faults, fractures, Finite Element method.

Fracture development in the upper crust controls strain localization, permeability, and fault evolution in brittle rocks. Although classical fracture mechanics explains many aspects of crack propagation, the mechanisms by which distributed microcracks interact and evolve into system-spanning fractures remain incompletely understood (Griffith, 1924; Pollard & Fletcher, 2005). In particular, the relative contribution of tensile and shear fracturing to macroscopic brittle failure is still debated. In this study, we investigate how the geometry and spatial arrangement of pre-existing microcracks influence fracture development through their elastic stress interactions. We employ two-dimensional Finite Element Method (FEM) simulations to analyze stress and strain perturbations generated by *en echelon* and randomly distributed crack systems under simple shear boundary conditions.

Our models quantify how crack orientation, overlap, and spacing modify the surrounding stress field and produce localized regions of reduced compression and/or elevated tensile stress that may promote fracture propagation. By systematically varying crack geometries, we identify the conditions under which stress concentration regions interact and coalesce, favoring the formation of larger fracture networks. The simulations show that the geometry of pre-existing cracks exerts a primary control on both the orientation and connectivity of emergent fractures. In particular, interacting cracks generate preferential stress trajectories that may evolve into system-spanning structures as natural faults.

The results indicate that macroscopic shear fractures may develop not only through the coalescence of tensile cracks parallel to the maximum compressive stress, as proposed in previous theoretical models (Reches & Lockner, 1994), but also through the interaction of differently oriented pre-existing cracks. Tensile stress concentrations at crack tips commonly organize along directions approximately ±30° to the far-field maximum principal stress, consistent with the orientations predicted by the Mohr-Coulomb criterion and widely observed in laboratory and natural fault systems (Pollard & Fletcher, 2005). *En-echelon* crack geometries further enhance stress localization and promote linkage between neighboring cracks, suggesting that such arrays may represent precursory stages of fault zone development (McBeck et al., 2023).

These findings provide a mechanical framework linking microcrack interactions to the emergence of macroscopic brittle structures and help bridge the gap between classical fracture mechanics and geological observations of fracture and fault networks in the upper crust.

Griffith A.A. (1924) - The theory of rupture. In: Waltman J. (Ed.), Proceedings of the First International Congress for Applied Mechanics Delft, 55-63.

McBeck J. et al. (2023) - Deformation evolves from shear to extensile in rocks due to energy optimization. Communi. Earth Environ., 4(1), 352, https://doi.org/10.1038/s43247-023-01023-w.

Pollard D.D. & Fletcher R.C. (2005) - Fundamentals of structural geology. Cambridge University Press, 514 pp.

Reches Z.E. & Lockner D.A. (1994) - Nucleation and growth of faults in brittle rocks. J. Geophys. Res., 99(B9), 18159-18173, https://doi.org/10.1029/94JB00115.

Tectonics along the plate boundaries in the Tierra del Fuego Island and Southern Patagonia

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Keywords: plate tectonics, Tierra del Fuego, Southern Patagonia.

The Tierra del Fuego region is a complex geological area where the South American, Antarctic, Scotia, and Nazca plates have interacted since the Mesozoic. On the western side, the Antarctic slab plunges eastward with a dip of a few degrees under the South American plate along the Chile Trench. In the outer part of the Andean Cordillera, the Southern Patagonian and Fuegian fold-and-thrust belts, along with the adjacent foreland Austral Basin, are the products of this convergence, which has been active since the Late Cretaceous.

Northward along the Chile Trench, the South Chile Ridge marks the boundary between the oceanic Antarctic and Nazca plates at the Chile Triple Junction. Southward, the convergence between the Antarctic and South American plates becomes progressively oblique toward the southern tip of Tierra del Fuego Island. Here, subduction seems depleted along the Shackleton Fracture Zone, where convergence is transferred into left-lateral strike-slip motion at the boundary with the Scotia Sea.

The eastern region displays continuous outcrops of Meso-Cenozoic rocks belonging to the Fuegian Cordillera. Crustal thickening and horizontal shortening characterize the inner zone, where in- or out-of-sequence thrust sheets drive the rapid exhumation of basement rocks and the shortening of the siliciclastic sedimentary cover of the foredeep basin, forming a NE-verging fold-and-thrust belt. These compressional structures are deformed by transtensional faults resulting from the E-W sinistral wrench tectonics along the Magallanes-Fagnano continental transform system, which has affected the region since the Oligocene, coinciding with the early stages of development of the Western Scotia Sea.

At a regional scale, this transform boundary predominantly displays transtensional structures, featuring fault patterns arranged in a rhomboidal mesh along extensional stepovers. The geometry comprises an interlocking network of extensional fault segments and transcurrent fault strands consistent with wrench-dominated transtension. Moreover, several of these faults crosscut earlier compressional and transcurrent structures.

The present-day geological framework of the region - in terms of seismicity, magmatism, and thermal and basin evolution - can be linked to the progressive northward migration of the Chile Triple Junction. This migration appears to be responsible for the formation of an asthenospheric window that, since the Early Miocene, has modified the configuration and geodynamic evolution of the overriding plates at the southern tip of South America.

Strain softening mechanisms in a regional scale shear zone: The Main Central Thrust Zone in the Mt. Makalu area (Eastern Nepal)

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Keywords: shear zone, Main Central Thrust, Himalaya.

Deformation in mountain belt at middle/deep crustal levels is inherently heterogeneous and largely localized in high-strain zone, i.e. ductile shear zones, with the development of mylonites. One of the largest worldwide shear zones is exposed in the Himalaya, where the Main Central Thrust Zone (MCTZ), a km thick ductile (to brittle) shear zone, tectonically juxtaposes the medium- to high grade metamorphic rocks of the Greater Himalaya Sequence structurally above the low to medium- grade metamorphic rocks of the Lesser Himalaya Sequence (Hodges, 2000). In this contribution, we investigate the processes active during the MCTZ evolution in the Makalu area (Eastern Nepal), where Precambrian orthogneiss, locally known as Num-orthogneiss, are ductile sheared. Structural analysis testifies how a progressive transformation from orthogneiss to micaschist occurs trough a transitional zone.

Quantitative textural evolution, bulk-rock major and trace element chemical changes and mineral phases chemical changes have been characterized studying representative samples from "pristine" orthogneiss, transitional zone and micaschist.

Kinematic indicators developed both at the meso and microscales, such as S-C fabric, rotated porphyroclasts and mica fishes point to a top-to the-south sense of shear. Kinematic indicators are progressively much more developed associated with changes of foliation morphology (from a spaced anastomosing schistosity to continuous) starting from orthogneisses to micaschist.

ICP-MS trace elements data confirm the common protolith origin of the studied rocks. Quantitative modal phase variations have been investigated with image analysis techniques (on BSE-SEM images) pointing to a progressive disappearance of feldspars balanced by increasing of micas. This latter process is assisted by progressive increasing of XMg in white micas and of a transition from biotite to phlogopite.

In summary, microstructural and geochemical analyses led to recognize a non-isochemical process of strain softening related to phase transformation (feldspar replaced by micas) enhanced by fluids infiltration and Mg metasomatism, which progressively favoured deformation localization within the MCTZ.

Hodges K.V. (2000) - Tectonics of Himalaya and southern Tibet from two perspectives. Geol. Soc. Am. Bull., 112, 324-350, https://doi.org/10.1130/0016-7606(2000)112%3C324:TOTHAS%3E2.0.CO;2.

Fracture network analysis of the Capo Bianco laccolith (Elba Island) as an analogue for geothermal reservoirs in igneous rocks

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Keywords: fracture network, Capo Bianco laccolith, geothermal reservoir.

This presentation focuses on the fracture network exposed along the northern coast of Elba Island, near Capo Bianco, where a Tortonian tourmaline-bearing aplite laccolith crops out within flysch-like successions characterized by low to very low permeability. The Capo Bianco intrusion represents an exceptional natural case study, as the laccolith is almost entirely exposed and largely encased within poorly permeable host rocks. This geological configuration provides favourable geological conditions for the development of a fractured reservoir, in which fluid storage and circulation are expected to be primarily controlled by the internal fracture architecture of the igneous body.

The study area can therefore be considered a natural analogue for potential geothermal reservoirs hosted in highly fractured intrusive rocks, comparable to those occurring in the active geothermal systems of Monte Amiata and Larderello. The research combines: (1) petrographic characterization of the Capo Bianco aplite through thin-section analysis; (2) investigation of first-order tectonic structures using photogrammetric modelling and the LIME software; and (3) quantitative assessment of fracture density and connectivity based on 13 scan lines and 3 scan boxes analysed with the MATLAB-based FracPaQ code.

This integrated approach allowed the identification of three main fracture sets, striking NE-SW, NW-SE, and sub-horizontal, consistent with the Miocene-Pliocene tectonic evolution of the northern Tyrrhenian domain. Fracture distribution is highly heterogeneous, with a marked increase in fracture density close to fault zones. Connectivity analysis highlights a high degree of fracture interconnection within the rock mass, suggesting that the fracture network may significantly enhance the capacity of the laccolith to store and channel geothermal fluids. A mean matrix permeability of about 20 μD was measured, supporting the interpretation that fluid circulation is mainly controlled by secondary permeability related to fracturing.

The widespread occurrence of tourmaline crystals with irregular morphologies, together with feldspar phenocrysts affected by pinitization, provides further evidence for hydrothermal fluid circulation within the studied laccolith. This case study offers new insights into the role of fracture networks in controlling the geothermal potential of intrusive bodies and shows how integrated structural, petrographic, and digital fracture-network analyses can support the assessment of igneous-hosted geothermal reservoirs.

Active deformation in the 2001 Mw 7.6 region, Gujarat, NW-India

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Keywords: seismotectonics, earthquake geology, tectonic geomorphology.

The Mw 7.6 2001 Bhuj earthquake stands as a paramount example of a devastating intraplate seismic event, yet the fundamental mechanisms governing its occurrence remain surprisingly poorly understood. Despite being one of the most energetic earthquakes ever recorded instrumentally within an intraplate region, the Bhuj event did not produce the clear, unequivocal surface faulting typically associated with major earthquakes, complicating the direct assessment of the causative fault structure.

To overcome the challenges posed by the lack of clear coseismic surface ruptures, researchers frequently turn to the field of earthquake geology, which employs the analysis of deformed geomorphological markers to reconstruct the long-term history of landscape evolution. In such methodology, the Earth's topography itself is conceptualized as a "tape recorder", diligently preserving the cumulative, long-term imprint of both regional tectonic forces and climatic processes over geological timescales. This approach leverages specific geomorphic features, such as warped marine terraces, offset river channels, and deflected drainage divides, which act as high-resolution, long-term paleo-geodetic indicators. By quantifying the deformation of these features, scientists can not only infer the historical patterns of crustal movement but also gain predictive insights into the future trends of landscape evolution and tectonic activity.

The core objective of this quantitative morphometric analysis is to extract and characterize the cumulated surface deformation due to tectonic processes acting over millennia, and to allow a more robust and accurate parametrization of the causative faults, which is essential for improved seismic hazard assessment.

This current study undertakes a critical re-examination of the seismotectonics of the Bhuj region. It incorporates a pivotal new dataset: the precise documentation of paleo-shorelines discovered within the epicentral area offer a previously unexploited constraint on the long-term vertical deformation of the region. By integrating this new information with paleoseismological information and other geophysical and seismological data, this research aims to build a more comprehensive and refined model of the 2001 Bhuj earthquake seismotectonic framework.

Geostructural Analysis and Integrated Assessment of deformation and mineralisation (GAIA) in gold-endowed shear zones from the Lake Victoria Goldfields in Tanzania

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Keywords: shear zone, gold, metamorphism, fluid-rock interaction.

Gold-endowed shear zones represent transient permeability networks where deformation, fluid flow and mineralisation become dynamically coupled during crustal-scale strain localisation. In these systems, episodic increases in pore-fluid pressure promote brittle deformation, fluid infiltration, sulphide precipitation and progressive rheological weakening, generating evolving feedback between deformation and fluid circulation. However, the mechanisms controlling the spatial and temporal organisation of permeability network within actively deforming Archean shear zones remain poorly constrained, particularly across lithological and rheological interfaces.

The Neoarchean Tanzania Craton (e.g., Kabete et al., 2012; Dirks et al., 2020), and specifically the gold-endowed Gokona deposit within the Musoma-Mara Greenstone Belt (North Mara district), provides an exceptional natural laboratory to investigate the coupling between deformation, transient permeability generation and sulphur-bearing fluid circulation within the Archean lithosphere. The Gokona system preserves a vertically extensive network of mineralised shear zones hosted in volcano-sedimentary rocks metamorphosed under greenschist- to amphibolite-facies conditions.

Mineralisation occurs within structurally controlled vein systems ranging from Mode I extensional veins to hybrid shear veins, recording repeated cycles of brittle deformation hosted within a viscously deformed matrix. In particular, the coexistence of mylonitic fabrics, hybrid veins and repeated fracture-sealing textures.

This project combines structural geology, petrography/petrology, microstructural analysis and vein analysis to reconstruct the evolution of fluid pathways and deformation mechanisms across the shear-zone network. In addition, the Gokona deposit provides an opportunity to investigate how sulphur-bearing fluids interact with evolving rheological heterogeneities to control large-scale gold mineralisation within deforming continental lithosphere.

Dirks P. et al. (2020) - The world-class gold deposits in the Geita greenstone belt, northwestern Tanzania. In: Sillitoe R.H., Goldfarb R.J., Robert F., Simmons S.F. (eds.), Geology of the World's Major Gold Deposits and Provinces, Society of Economic Geologists, https://doi.org/10.5382/SP.23.08.

Kabete J. et al. (2012) - A new tectonic and temporal framework for the Tanzanian Shield: implications for gold metallogeny and undiscovered endowment. Ore Geol. Rev., 48, 88-124, https://doi.org/10.1016/j.oregeorev.2012.02.009.

Syn-extensional Miocene felsic dyke swarm as deep roots of a Super-Hot Geothermal System: A key example from Elba Island (Italy)

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Keywords: geothermal, syn-extensional, Elba Island.

The deep roots of geothermal systems, located proximally to the magmatic heat source and the brittle-ductile (B-D) transition, represent promising targets for geothermal energy exploitation. These are associated with the occurrence of magmatic sources that affect the thermal state of the upper crust, increasing the geothermal gradient. New exploitation targets are then focused on the brittle-ductile transition due to the high temperature of the fluids (up to 350°C) and the possibility of finding fluids in supercritical conditions. The comprehension of these environments its possible from the analysis of analogous, fossil and exhumed geothermal systems, where fluid-rock interaction processes and the control of structures on the flow of geothermal fluids can be studied in detail through the analysis of outcrops.

In this work we show the results of a study in an exhumed geothermal system that developed during the Late Messinian in the context of rocks belonging to a thermometamorphic aureole formed by a magmatic felsic intrusion (Porto Azzurro monzogranite, c. 6.4 Ma), that cause the overheating and circulation of melts and geothermal fluids during the cooling phases, accompanied by the development of normal faults which lead to the thinning of the lithosphere. The study area is the northern Tyrrhenian Sea (Tuscan Archipelago, Elba Island), where Neogene magmatic bodies were exhumed during the extensional tectonics that dismantled the Northern Apennines and allowed the opening of the Tyrrhenian Sea.

A multidisciplinary approach allows us to reconstruct the temporal evolution of magmatic, pneumatolytic and hydrothermal processes that developed during pluton emplacement and cooling.

The main results allow us to document the syn-tectonic formation of leucogranite dyke swarms and subsequently pneumatolytic and hydrothermal fluid circulation, tightly controlled by low- to middle-angle normal faults, revealing a superposed deformational event. The pneumatolytic stage was formed by the circulation of 240-350°C geothermal fluids of relatively high salinity and magmatic origin.

Integrated multi-scale 3D modelling of the northern Abruzzo foreland basin system (Central Apennines, Italy)

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Keywords: Mio-Pliocene foreland basin system, 3D structural modelling, tectono-stratigraphic evolution.

The actual configuration of the Central Apennine Foreland Basin System (FBS) from the Early Miocene to present has been significantly affected by the eastward migration of the compressional front. In particular, the tectono-stratigraphic evolution of the FBS in the Abruzzo Region (Central Italy) is characterized by the onset and development of two adjacent foredeep basins - the Laga and Cellino basins - and by their subsequent overthrusting, with the Laga Succession overriding the Cellino one.

Structural geology is a fundamental tool for deciphering crustal deformations on any scale. In this regard, starting with the integration of field and geophysical data, our primary objective was the realization of a robust and geometrically consistent 3D subsurface geological model, aimed at understanding the mutual relation between surface and subsurface features. Field surveys represented a constraint to the interpretation of geophysical investigations and to the precise location of the main faults. They have also provided detailed surface geological mapping, fault kinematics, and fold geometries.

Geophysical data were used to obtain the trend geometries of structures at depth, the amount of their displacement, and the structural style on the regional scale. This model was validated by available 2D seismic lines from the ViDEPI Project, tied with stratigraphic markers of multiple wells. By reconstructing, through this multidisciplinary approach, the major structural features such as folds and associated thrusts, we defined the spatial distribution and evolution of deformation processes within the upper crust.

The integrated dataset and the resulting 3D model provide a powerful framework for a comprehensive structural characterization of the Abruzzi FBS, crucial to understand its over-time evolution but also to gain insights about the geohazard assessment of the area. In fact, our study can contribute to understanding the structural factors that control fluid migration pathways, thereby providing a basis for future assessments of georesources and possible geothermal exploitation, especially in areas already subject to hydrocarbon investigation, such as the studied one.

Surface expression of slab tearing: Evidence from the Eastern Mediterranean subduction system

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Keywords: Southern Anatolia, late Middle Pleistocene, uplift rate.

Along the southern margin of the Central Anatolian Plateau (CAP), where the Cyprus subduction system is active, we document the world's highest late Middle Pleistocene marine deposits, providing an exceptional record of rapid vertical uplift. New biostratigraphic constraints show that the youngest marine deposits in the Mut Basin (CAP), sedimented between -1, respectively, highlighting fundamental differences in the processes governing vertical movements. By integrating these results with marine-terrace modelling and river-profile inversions, we refine the evolution of the late Quaternary uplift of the CAP southern margin and the IA.

Seismic tomography reveals that the Cyprus slab is segmented into eastern and western domains, separated by the Paphos Transform Fault (Portner et al., 2018; Güvercin et al., 2021). The Mut Basin lies above the eastern Cyprean slab fragment, where our new biostratigraphic and geomorphic constraints indicate two major uplift episodes: (1) a late Messinian, long-wavelength phase generating ~0.8 km of plateau uplift (Schildgen et al., 2012), at rates of ~4 mm yr^{-1}, recently interpreted as due to delamination processes (Öğretmen et al., 2018), and (2) a late Middle Pleistocene uplift pulse exceeding 1.2 km since ~0.40 Ma, with peak rates of ~6.2 mm yr^{-1}, interpreted as expression of slab break-off (Öğretmen et al., 2018). In contrast, the upper plate of the western Cyprus (Antalya) slab, which hosted the development of the Neogene Antalya Basin, shows significantly lower vertical movements. In this region, the P-wave tomography indicates that the subducting slab remains continuous to depth of approximately 600 km (Portner et al., 2018).

In conclusion, deep processes beneath the southern margin of the CAP are dominated by asthenospheric upwelling and crustal rebound following slab break-off. Conversely, uplift in the IA reflects the combined influence of slab retreat and thermal-viscous relaxation of the upper plate. This different vertical movement of the upper plate represents the surface expression following the action of a slab tear fault separating the Cyprus and the Antalya slabs, that is the Paphos Transform Fault.

Güvercin S.E et al. (2021) - New focal mechanisms reveal fragmentation and active subduction of the Antalya slab in the Eastern Mediterranean. Tectonophysics, 805, 228792, https://doi.org/10.1016/j.tecto.2021.228792.

Öğretmen N. et al. (2018) - Evidence for 1.5 km of Uplift of the Central Anatolian Plateau's Southern margin in the last 450 kyr and Implications for its Multiphased Uplift history. Tectonics, 37, 359-390, https://doi.org/10.1002/2017TC004805.

Portner D.E. et al. (2018) - Subduction termination through progressive slab deformation across Eastern Mediterranean subduction zones from updated P-wave tomography beneath Anatolia. Geosphere, 14, 907-925, https://doi.org/10.1130/GES01617.1.

Schildgen T. F. et al. (2012) - Multi-phased uplift of the southern margin of the Central Anatolian plateau, Turkey: A record of tectonic and upper mantle processes. Earth Planet. Sci. Lett., 317-318, 85-95, https://doi.org/10.1016/j.epsl.2011.12.003.

Relationship between deformation and magma emplacement unraveled by microstructural investigation (Asinara Island, Sardinia, Italy)

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Keywords: microstructures, late Variscan magmatism, CARG Project.

Geological mapping of sheet 425 of the Italian National Mapping Project (Asinara Island, NW Sardinia, Italy) made it possible to investigate the relationship between deformation and magma emplacement in this sector of the Variscan belt (Carosi et al., 2024). Five late- to post-collisional Variscan intrusive units have been identified on Asinara Island: i) Pedra Bianca unit; ii) Castellaccio unit; iii) Punta Sabina unit; iv) felsic aplite-pegmatite dyke; v) mafic porphyry dyke.

The Pedra Bianca unit consists of hypidiomorphic, medium- to fine-grained alkali feldspar granite with a decametric laccolith structure. The Castellaccio unit comprises inequigranular monzogranite and granodiorite characterised by large laths of K-feldspar, which often define a magmatic foliation. The Punta Sabina unit consists of sub-hypidiomorphic, medium- to fine-grained monzogranite which is occasionally slightly porphyritic, containing larger K-feldspar grains. The felsic aplite-pegmatite dyke consists of micro-leucogranite and pegmatite with a thickness ranging from decimetric to plurimetric. The mafic porphyry dikes are mainly basaltic andesite with a holocrystalline to hypocrystalline texture.

These magmatic rocks are found within medium- to high-grade micaschist, paragneiss, and migmatitic complexes. A variety of deformation microstructures ranging from submagmatic to low-temperature subsolidus conditions have been identified (Pieruccioni et al., 2025). The main microstructures observed are chessboard patterns in quartz and sub-magmatic fractures in plagioclase, which indicate deformation at high temperatures ($T > 650°C$) in the presence of melt. Solid-state deformations at high temperatures ($T > 450°C$) are characterised by feldspar bulging, myrmekites, quartz grain boundary migration, and subgrain rotation dynamic recrystallisation. Finally, low-temperature sub-solidus microstructures ($T < 450°C$) consist of quartz bulging, mica kinks, and feldspar twinning and bending. Microstructural analysis revealed that the intrusive rocks of Asinara Island, except the mafic porphyry dyke, experienced tectonic stress during the cooling of magmatic bodies, which induced microscale deformation. This provides evidence that they were emplaced under conditions of weak but ongoing deformation during the late stage of Variscan tectonics. These results are like the features highlighted in other sectors of the southern Variscan belt and suggest a complex interplay between transpressional-induced exhumation of the medium/deep crust and magma intrusion.

Carosi R et al. (2024) - Geology of the Asinara Island (Sardinia, Italy). J. Maps, 20(1), 2317136, https://doi.org/10.1080/17445647.2024.2317136.

Pieruccioni et al. (2025) - Microstructural investigation of Variscan late-collisional granitoids (Asinara Island, NW Sardinia, Italy): New insights on the relationship between regional deformation and magma emplacement. Geosciences, 15, 108, https://doi.org/10.3390/geosciences15030108.

Geochronology of Late Variscan magmatism and deformation in the Asinara Island (NW Sardinia, Italy)

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Keywords: microstructural investigations, CARG project, geochronology.

The southern Variscides in the Mediterranean area provide an outstanding example of interaction between tectonics and magmatism. The combination of field, microstructural and minero-chemical data integrated by geochronological analyses can provide the possibility to disentangle the relationship between deformation structures and magma emplacement. In this context widespread late-to-post-orogenic magmatism is present, and a wide geochronological dataset is available. However, limited chronological data are available for northwestern Sardinia. Here, we present the results of a detailed U-Pb zircon geochronological study, combined with field, microstructural observations and mineral chemistry data on the magmatic units that crop out on Asinara Island: the Pedra Bianca alkali feldspar granite; the Castellaccio monzogranite; the Punta Sabina monzogranite; and the felsic dykes (Carosi et al., 2024; Simonetti et al., 2024; this work).

These rocks preserve a sequence of microstructures reflecting dynamic recrystallization during cooling (Pieruccioni et al., 2025). An age of 308.7±2.4 Ma was obtained for the Pedra Bianca alkali feldspar granite, whereas the Castellaccio monzogranite gave an age of 305.9±1.4 Ma. From the Punta Sabina monzogranite, we obtained an age of 309.3±2.6 Ma. Late felsic dykes yielded comparable ages to those obtained for the other units. However, these should be considered mixed ages due to the thin magmatic rim overgrowths. All ages fall within the D2-D3 deformation phases and coincide with the activity of the Posada-Asinara Shear Zone. This provides evidence that the magmatic rocks were emplaced under weak but still active deformation, well explaining the observed sequence of stress-induced microstructures formed during pluton cooling.

The new data revealsa close relationship between late Variscan deformation and magmatism, contributing to a better understanding of the complex crustal architecture and evolution of the Mediterranean Variscides. This work highlights the importance of a comprehensive multidisciplinary approach in a context characterized by active tectonics and magma emplacement.

Carosi R. et al. (2024) - Geology of the Asinara Island (Sardinia, Italy). J. Maps, 20(1), 2317136, https://doi.org/10.1080/17445647.2024.2317136.

Pieruccioni D. et al. (2025) - Microstructural investigation of Variscan late-collisional granitoids (Asinara Island, NW Sardinia, Italy): New insights on the relationship between regional deformation and magma emplacement. Geosciences, 15, 108, https://doi.org/10.3390/geosciences15030108.

Simonetti M. et al. (2024) - A review of criteria, methods, and standards for mapping crystalline terrains: integrating field geology and analytical data. Ital. J. Geosci., 143(3), 426-454, https://doi.org/10.3301/IJG.2024.22.

The art of drawing active faults: Implications for earthquake shaking and surface faulting hazard

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Keywords: active faults, surface faulting, seismic hazard.

The way geologists identify and interpret active faults directly influences how societies assess seismic hazard. Unbeknown to many geologists until recently, fault maps are far more than academic exercises: they inform building regulations, infrastructure design, and even insurance assessments. Yet mapping faults is inherently difficult, as geologists work at the crossroads of structural geology, seismology, geomorphology, and hazard analysis. They often draw conclusions from incomplete and inherently ambiguous observations: either because crucial data are lacking, or because they do not fully understand the available evidence.

What is the main goal of active faulting investigations? A standard AI answer is "*...geomorphic mapping of fault scarps and offset landforms, trenching across fault traces, topographic surveys, and satellite/aerial imagery interpretation...*" (Perplexity, 2026). But this is a gross oversimplification: in many regions worldwide, even the mere confirmation of the tectonic nature of mapped faults is all but objective. In Italy, new regulations passed over the past ten years shed light on a long-ignored issue. Starting in the 1970s, many presumed active faults appeared on Italian geologic maps; fifty years later, some of them have become unsurmountable obstacles for any minimal development or urban planning action. Why is it so?

Identifying active faults in Italy is especially difficult, due to the country's distinctive geological and tectonic evolution and to the "active faulting culture" shaped in universities and in scientific literature. Paradoxically, the main challenge is not the complexity of fault systems, or their poor exposure. Rather, it lies in the interplay between widespread regional uplift in much of peninsular Italy and Sicily, and the nature of bedrock, with Mesozoic assemblages being far more erosion-resistant than their younger and shallower counterparts. These circumstances may cause:

1. exhumation and rejuvenation of buried, inactive faults;
2. selective erosion, which may produce linear features mimicking younger faults;
3. buildup of slope talus above inactive bedrock faults, which may be displaced by strong intervening ground shaking imitating genuine fault offsets; and
4. in uplifting coastal regions, the generation of steep cliffs by returning marine abrasion, often linear enough to be misidentified as true tectonic lineaments.

A chronically weak understanding of both the 3D nature of faulting and the existence of fault hierarchies further compounds the problem. Insight into the spatial/geometric/hierarchical relationships among deeper seismogenic sources and the reactivated surface faults above them remains at a relatively early stage.

We (a) present and discuss field examples of these occurrences, and (b) make a pledge for increasing our ability to single out only faults that are demonstrably relevant to both ground shaking or surface fault displacement hazard, and rightfully discard all others.

Major transverse lineaments in Italy: Hidden sources of large earthquakes?

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Keywords: transverse lineaments, seismic hazard, Apennines fold-and-thrust belt.

Over the past decades, extensive research has refined the understanding of Italy's seismotectonic framework, largely stimulated by the 23 November 1980 Irpinia earthquake (Mw 6.9). Along the Apennine backbone, active normal faulting dominates the present-day tectonic regime and strongly controls landscape evolution, whereas contractional structures formed the core of the orogen and still characterize its external fronts. Within this tectonic architecture, however, a set of regional transverse and oblique structures remains partly concealed and poorly understood in terms of seismogenic significance. These features have alternatively been interpreted as inherited tectonic lineaments and/or transfer zones accommodating differential crustal deformation, in the frame of the geodynamic evolution of the central Mediterranean area.

Italian seismicity is mainly concentrated along the Apennine axis, following its arcuate geometry and reflecting the kinematics of the main regional and subsidiary faults. Nevertheless, several destructive historical and instrumental earthquakes, among the strongest in Italy, fall outside this pattern, being associated with deeper crustal domains or foreland regions. On the basis of their geodynamic setting, focal mechanisms, and structural location, these events can be grouped into four main categories: (1) earthquakes occurring along major inherited and polyphased Mesozoic structures within the Adriatic and Maghrebian forelands (e.g., Di Bucci et al., 2010); (2) earthquakes associated with structures accommodating crustal sectors with different (extensional or compressional) deformation, potentially linked to major northern Apennines transverse lineaments (e.g., Vannoli et al., 2021); and (3) earthquakes related to the rigid lithospheric boundary accommodating differential motion between the advancing southern Apennine front and the retreating or breaking-off Calabrian slab, corresponding to the Subduction-Transform Edge Propagator (STEP) zone (e.g., Maesano et al., 2020); and (4) earthquakes generated at the boundary between areas characterized by differential extensional rates within the Apennine fold-and-thrust belt (e.g., Brogi et al., 2024).

This contribution aims to reassess the role of transverse tectonic structures in the Italian seismotectonic framework and to evaluate their potential as sources of future damaging earthquakes.

Brogi A. et al. (2024) - Reappraising the seismogenic potential of a low-strain rate region: Active faulting in the eastern Siena Basin (southern Tuscany, Italy). Tectonophysics, 886, 230423, https://doi.org/10.1016/j.tecto.2024.230423.

Di Bucci D. et al. (2010) - Tectonic evidence for the ongoing Africa-Eurasia convergence in central Mediterranean foreland areas: A journey among long-lived shear zones, large earthquakes, and elusive fault motions. J. Geophys. Res., 115, B12404, https://doi.org/10.1029/2009JB006480.

Maesano F.E. et al. (2020) - Deformation and Fault Propagation at the Lateral Termination of a Subduction Zone: The Alfeo Fault System in the Calabrian Arc, Southern Italy. Front. Earth Sci., 8, 107, https://doi.org/10.3389/feart.2020.00107.

Vannoli P. et al. (2021) - The seismotectonic significance of geofluids in Italy. Front. Earth Sci., 9, https://doi.org/10.3389/feart.2021.579390.

Transfer structures controlling post-plutonic hydrothermal fluids at Campiglia Marittima (southern Tuscany)

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Keywords: hydrothermal fluids, ore, tectonic structures.

Transverse structures in the Northern Apennines have long been recognized, but their interpretation as transfer zones has gained increasing attention only in recent years. These structures accommodate differential extension domains and serve as preferential pathways for magmas, hydrothermal fluids, and gas rising from deep sources (e.g., Dini et al., 2008; Liotta et al., 2015).

Campiglia Marittima is one of the main magmatic centers of the Tuscan Magmatic Province and is located along a transfer structure connecting the western Elba Island to Larderello. Campiglia Marittima represents an ideal site for investigating an upper-crustal hydrothermal-magmatic system, where Miocene-Pliocene plutonic, subvolcanic and volcanic rocks are associated with different ore types and host lithologies. Past and active quarrying and mining activities provide a unique three-dimensional exposure of the system, which is rarely available at other sites (Vezzoni et al., 2018).

Based on new geological-structural field surveys of the Botro ai Marmi granite pluton and its carbonate cover, we document the structural control exerted by transverse structures on post-plutonic hydrothermal circulation and ore-forming events. Three key occurrences were investigated along the same structural corridor: 1) endoskarn veins and hydrothermal alteration effects on the granite; 2) fractures and veins associated with Fe ore within marble; and 3) hedenbergite(±ilvaite) exoskarn developed in the carbonate cover.

These examples highlight how, at Campiglia Marittima, transverse structures were active during successive hydrothermal events following pluton emplacement, operating both as preferential pathways and structural traps for hydrothermal/metasomatic fluids. The vertical transtensional structures linked sectors affected by differential extension rates, generated by the interaction between regional tectonics and local magma-induced deformation.

The results of this work support that the transfer zones are first-order structural features in magmatic-hydrothermal systems and should therefore be considered in ore and geothermal exploration in the inner Northern Apennines.

Dini A. et al. (2008) - Magma emplacement in a transfer zone: the Miocene mafic Orano dyke swarm of Elba Island, Tuscany, Italy. Geol. Soc. Lond. Spec. Publ., 302, 131-148, https://doi.org/10.1144/sp302.10.

Liotta D. et al. (2015) - Coexistece of low-angle normal and high-angle strike-to oblique-slip faults during Late Miocene mineralization in eastern Elba Island (Italy). Tectonophysics, 660, 17-34, https://doi.org/10.1016/j.tecto.2015.06.025.

Vezzoni S. et al. (2018) - Lateral Extrusion of a Thermally Weakened Pluton Overburden (Campiglia Marittima, Tuscany). Int. J. Earth Sci., 107, 1343-1355, https://doi.org/10.1007/s00531-017-1539-9.

Boron-rich metasomatism and its relationships with uranium-mineralizations in the Central Southern Alps (N Italy)

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Keywords: boron, metasomatism, uranium.

In the Early Permian, the post-Variscan evolution of the present-day Alpine region was characterized by crustal extension combined with intense magmatic activity at different crustal levels, which finally led to the development of intracontinental extensional basins filled with volcanoclastic sediments. In the Central Southern Alps, the opening of these basins was controlled by complex fault system that were active at the same time of plutons intrusion and volcanic activity at the surface. Magmatism was also accompanied by diffuse hydrothermal activity testified by the occurrence of swarms of siderite, fluorite, sulphide-quartz and tourmalinite veins, associated to Sn-W mineralizations in the Val Trompia area. Here the tourmalinites (Type 1) occur in the metamorphic basement hosting minor intrusive bodies, to which they are genetically related. In the western sector of the Central Southern Alps, tourmalinites (Type 2) occur instead along the fault core of Low-Angle Normal Faults developed at the basement-cover contact. Type 2 tourmalinites usually replace former cataclasites, suggesting that B-rich fluids circulated along fault planes at the end or in the late stages of fault activity. Tourmalinites occur in the same structural position of the U ore deposits of the Val Vedello area, that are also localized along the basement cover contact.

Type 1 display a larger crystal size with respect to Type 2, that frequently have a microcrystalline groundmass. The occurrence of relicts of former tourmalinites and layers of different intensity of tourmalinization in Type 2, combined with the zoning of tourmaline crystals in Type 2 tourmalinites, suggest that the hydrothermal event was polyphasic. The composition of both tourmaline types fall into the Schorl-Dravite series, with little variations in terms of Mg and Fe contents. Despite major and trace elements contents and patterns display several differences among veins from different localities, some common features are: high LILE contents, enrichment in L-REE with respect to H-REE and a negative Eu anomaly. The U content is variable, but always higher than the Upper Continental Crust values (UCC, 2.7 ppm), with the highest values displayed by Type 2 veins in the Lago d'Aviasco (close to the Novazza U-deposit) and Vedello area. LA-ICP-MS analyses show that U is mainly contained in tourmaline. The measured $\delta^{11}B$ of both Type 1 and Type 2 tourmalinites ranges from -10‰ to -5‰, with the calculated values for fluids ranging from -11‰ to 1‰. These values are coherent with and hydrothermal origin, linking the B-rich fluids to the Early Permian magmatic activity.

All these lines of evidence suggest that the B-rich metasomatic fluids, originated from intrusive bodies at depth, migrated along the preferential pathways created by the synsedimentary faults and, due to their capability to mobilize U, likely played a fundamental role in the genesis of the outstanding uranium ore deposits of the Central Southern Alps.

Fracture systems in crystalline basement and their role in geothermal energy exploration

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Keywords: fracture analysis, geothermal systems, crystalline basement.

Faults and natural fracture networks strongly influence geothermal reservoir quality by controlling fluid circulation and forming barriers where deformation, sealing or mineralization reduce permeability. Despite their importance for reservoir performance, the distribution of fractures and small-scale faults are rarely determined directly by geophysical surveys or borehole data. Current three-dimensional models of reservoir heterogeneity therefore rely largely on geostatistical interpolation, which extrapolates properties from existing data, after drilling mostly. These methods need dense data and become less reliable away from wells, increasing uncertainty in pre-drilling prediction and resource assessment.

GO-Forward project (Geothermal exploration and Optimization through FORWARD modelling and resource development) addresses these limits through a process-based framework that combines stratigraphic, diagenetic and fracture forward modelling. The project applies Fracture Forward Models (FFM), geomechanical tools that simulate the nucleation, growth, interaction and linkage of fractures and faults, to geothermal reservoir rock types, including crystalline basement rocks. These models are constrained including real data derived by field work in pilot sites, rather than treated as independent stochastic descriptions. This links fracture development to the mechanical and chemical evolution of the reservoir and to its geological setting.

In crystalline rocks the dataset includes pre-existing foliation that can play a role on addressing brittle deformation and fluid flow. To overcome this issue, the study of analogue outcrops is proposed. The workflow is initially based on the classical approach of structural geology, mapping foliation and the main fault zones, in areas where crystalline rocks have been affected by hydrothermal circulation (i.e., hydrothermal mineralization is present). This dataset is then integrated with scan lines and scan box analyses, in key outcrops, to serve as benchmarks for the virtual outcrop analysis, based on drone image acquisition.

We present the preliminary data about the Monte Calamita area (Elba Island) where HT-micaschist is affected by Neogene faults which drove hydrothermal fluids, deriving from the cooling stage of the late Messinian Porto Azzurro pluton. Evaluation of permeability and connectivity among fractures is therefore derived.

The GO-FORWARD project is expected to reduce exploration risk and costs, improve drilling success and support more reliable estimates of geothermal potential, contributing to the wider deployment of geothermal energy in a sustainable energy system.

S11.

Faulting, magmatism and crustal stretching during extension

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Analogue modelling of oblique continental rifts: Investigating the influence of magma in the evolution of rift faults

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Keywords: oblique rifting, modelling, margins.

Oblique continental rifts like the Main Ethiopian Rift (MER) are composed of en-echelon magmatic segments, axial volcano-tectonic systems that accommodate extension during advanced rifting stages. The structure and characteristics of these segments, the relationship between fault and magmatic systems, and how strain is transferred between segments are not yet fully understood.

Building on previous modelling work, we run augmented gravity (centrifuge) physical experiments reproducing rifting conditions in the MER. Specifically, we build lithospheric scale analogue models containing a pre-existing weakness in the lithosphere, oblique to the extension direction and giving rise to oblique rifting. We perform an experimental series to investigate how the deformation switches from the margins to the segments and to analyse how the latter interact and link. In this series, we also investigate how the role of magma bodies in the upper crust may influence the above-mentioned aspects.

We analyse the evolution and characteristics of fault patterns in space and time and investigate how strain is distributed during the evolution of the rift. We use low-viscosity spots to model magma bodies in the upper crust and vary their emplacement in space and time. Our models show the influence of these weak domains on the geometry and evolution of both border and segment faults as extension increases. They demonstrate how magma bodies influence the geometry and orientation of structures, producing complex fault patterns that can explain observations from nature.

New insights on segmentation of fault and magmatic systems in the Main Ethiopian Rift

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Keywords: rifting, segmentation, magma-rich.

Magma-rich continental rifts comprise en-echelon magmatic segments where magmatism and extension are localised, similar to slow and ultra-slow spreading centres. While rift segmentation is clear in mid-ocean ridges, it is less so in continental rifts like the Main Ethiopian Rift (MER). Faulting within the MER initiated at ~11 Ma at the border faults which define the overall NE trend of the MER and are oblique (30°-45°) to the E-W extension direction. However, since ~2 Ma extension has localised to the right-stepping Wonji Fault Belt (magmatic segments), in which small offset faults and alignments of volcanic features strike roughly orthogonal to the extension direction. Despite this general framework, there is a lack of quantitative analysis to understand rift segmentation and its relationship to volcanic systems, and how segments interact. It is unclear how the ratio of magmatic to tectonic processes varies along rift segments.

Using optical satellite imagery and SRTM digital elevation data with a resolution of 1 arc-second, we map fault traces, calderas, and volcanic craters in the central and northern MER at a scale of 1:100.000. We also map scoria cones in the same region using optical imagery at 1:20.000. This data is integrated with existing MER datasets, including previously mapped fault traces, digital elevation models, mafic intrusions derived from gravity data, InSAR-derived locations of magma bodies, and recent dyke intrusions between Fentale and Dofan to define the magmatic segments. We investigate characteristics and scales of MER magmatic segments by analysing fault trace patterns, the distribution of volcanic activity, along-segment displacement variations, and elevation profiles. We define five magmatic segments in the MER and describe systematic variations in fault displacement along-segment, which we interpret to reflect varying contributions of magmatic versus tectonic processes.

Ground displacement detection and monitoring through spaceborne radar techniques

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Keywords: ground displacement, DInSAR, remote sensing.

Spaceborne Synthetic Aperture Radar (SAR) imagery is nowadays widely used due to the large availability of satellite systems and constellations that regularly acquire SAR data over the Earth at different carrier frequencies and spatial resolutions.

By exploiting phase differences between repeated SAR acquisitions, Differential SAR Interferometry (DInSAR) is one of the most diffused SAR-based techniques for measuring Earth surface displacements with centimetric to millimetric accuracy at large spatial scale.

Moreover, when surface displacements exceed the DInSAR detection threshold, for instance during large volcanic eruptions or high magnitude earthquakes, ground motion could still be detected by cross-correlating the amplitude information of SAR images using SAR Pixel-Offset (PO) approaches.

In this context, the Copernicus Sentinel-1 mission is playing a crucial role by providing the remote sensing community with an unprecedented flow of systematically acquired, standardized, and open-access SAR images at global scale, further spreading the use of these data. This aspect not only increased the number of scientific studies investigating natural and anthropogenic phenomena, but also fostered a shift towards the implementation of operational monitoring services operating at both local and global scales.

In this work, we present an overview of the state-of-the-art of DInSAR and PO techniques for detecting the ground displacements induced by various phenomena, such as earthquakes and volcanoes, at different scales.

Furthermore, we show how SAR-based measurements can be generated through automated operational monitoring services and subsequently integrated into civil protection procedures for hazard assessment and risk mitigation.

We also highlight initiatives, primarily the European Plate Observing System (EPOS), that enable the sharing of DInSAR and PO measurements with the scientific community, fostering knowledge exchange and scientific reproducibility.

Finally, we explore the near-future SAR scenario where the availability of the new NISAR (NASA-ISRO, L-Band), and the forthcoming NIMBUS-SAR IRIDE (ASI, X-Band) and Rose-L (Copernicus, L-Band) constellations will significantly improve ground displacement detection capabilities, further enhancing our understanding of the phenomena under study.

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Spatio-temporal graben evolution in a magma-rich rift linkage zone using quantitative geomorphology: Insights from Central Afar, Ethiopia

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Keywords: Central Afar, rift linkage, quantitative geomorphology.

Resolving the growth, interaction and linkage of fault systems is important in understanding the evolution of magma-rich rift systems and the broader processes driving continental break-up. Central Afar provides a rare opportunity to examine fault evolution processes and their interaction with surface processes and magmatic activity, but quantitative observations of long-term fault evolution and linkage, and constraints on fault slip rates remain limited. In this study, we present new geomorphic analysis from 26 river catchments crossing active normal faults in seven major grabens across the Central Afar rift linkage zone. By integrating quantitative geomorphology methods (stream profile metrics and knickpoint retreat timescales) with topography data and swath profiles, we reconstruct the spatial and temporal evolution of individual grabens within the wider Central Afar rift linkage zone. Our results show that rift linkage in Afar has been active for at least 3 Myr, and individual grabens accommodate extension over 0.5-1.0 Myr timescales. Several grabens are active synchronously, but extension has progressively localised towards the centre of the linkage zone. The Dobi Graben is identified as the youngest and most active structure, with fault throw rates of 0.4-0.8 mm/yr. and is therefore the locus of present-day deformation. These findings provide the first quantitative, regional-scale constraints on graben evolution in Central Afar, highlighting the role of en-echelon normal fault systems in accommodating extension and deformation during rift linkage.

Field based structural and geomorphic constraints on normal fault evolution in the Dobi Graben, Ethiopia

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Keywords: Dobi graben, normal faults, fieldwork.

A major challenge in magma-rich rifting is understanding fault evolution and interaction, particularly at the scale of individual fault systems where tectonic activity interacts with surface processes and volcanism. Central Afar, Ethiopia, is a key natural laboratory for investigating active continental rifting and the migration of strain within the structurally complex linkage zone between the Dabbahu-Manda-Harraro and Asal segments of the Red Sea and Gulf of Aden rift systems, respectively. While previous studies based on geodesy, strain-rate analyses and paleomagnetism have outlined the broader tectonic architecture, direct field-based structural and geomorphic constraints on fault evolution remain limited.

In this study, focussing on two river catchments crossing the main bounding fault of the Dobi Graben, Central Afar, we integrate new field measurements of channel geometry (width and slope), bedrock strength (Schmidt Hammer rebound values) and structural indicators of normal faulting, with analysis of geomorphic parameters, stream power estimates and high resolution topography data. Structural observations including scarp dip, dip direction and slickenside lineations confirm active dip-slip normal faulting consistent with the regional extension. Channel geometry analysis shows that the channels narrow and steepen within the fault zone, forming a convex river profile, accompanied by a marked increase in stream power from 5000 W/m^2 to 10000 W/m^2 proximal to the fault. The channels are bedrock bound, incising basalt and ignimbrite units with median Uniaxial Compressive Strength (UCS) values of ~110 MPa. No correlation is observed between UCS and channel geometry indicating that the geomorphic response is bets explained by the active faulting, and that lithology exerts little to no control on regional-scale channel morphology. Finally, comparison between the observed decay in stream power and modelled decay of the uplift rate upstream of the fault reveals a mismatch in decay wavelength, confirming a transient landscape response to ongoing deformation in the Dobi Graben over 1-2 Myr timescales.

Together, these field-derived structural and geomorphic datasets provide new evidence for the growth and evolution of the main Dobi Graben for the first time, as part of the Central Afar rift linkage zone.

From inheritance to magmatism: Multi-scale controls on sedimentary architecture and basin evolution in the Northern Red Sea rift

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Keywords: Northern Red Sea, U-Pb geochronology, seismic interpretation.

The Northern Red Sea (NRS) provides a natural laboratory to investigate how extensional tectonics, magmatism, and salt tectonics interact to shape sedimentary systems across scales, from outcrop observations to seismic imaging. By integrating field data, U-Pb geochronology, and 2D-3D seismic interpretation along the Egyptian margin, this study reconstructs the structural and stratigraphic evolution of a segmented rift system. New U-Pb dating of syn-tectonic calcite from the Hamadat half-graben provides the first direct temporal constraints on brittle deformation in this sector, with ages ranging from ~44 to 23 Ma. Two main deformation stages are identified: (1) Eocene fracturing (~44-39 Ma), attributed to far-field Alpine-Himalayan compression, and (2) Oligocene-earliest Miocene (~29-23 Ma) normal faulting associated with hydrothermal fluid circulation and the onset of crustal extension. Paleostress inversion indicates a coherent extensional regime with a principal tension axis trending ~228°, consistent with near-pure extension. These results highlight the fundamental role of inherited structures in localizing rift-related faulting and controlling early accommodation development.

Syn-rift deformation generated half-graben basins and rotated fault blocks that governed sediment routing and stratigraphic organization. Offshore seismic reflection data reveal a transition from proximal domains, represented by the Hamadat and Duwai half-grabens, to a necking zone dominated by low-angle detachment faults, leading to significant crustal thinning and local exhumation of deep crustal rocks. 2D forward modelling indicates that this domain evolves into a distal margin where the continental crust thins to In distal settings, depositional systems are further modified by late-stage processes. Pleistocene off-axis volcanic edifices developed along extensional faults, indicating episodic magmatic input linked to regional mantle dynamics. In parallel, thick Miocene evaporites underwent halokinesis since the Late Miocene, forming salt walls, diapirs, and associated fault systems that reorganized supra-salt depocentres. Seismic interpretation highlights the interaction between thin- and thick-skinned tectonics, with basement faulting exerting a primary control on salt mobilization.

This multi-scale approach demonstrates that sedimentary architectures in the NRS are governed by the interplay of structural inheritance, early brittle deformation, progressive lithospheric thinning, magmatism, and salt tectonics. Bridging outcrop-scale geochronology with seismic-scale observations provides new insights into extensional margin evolution and the construction of the stratigraphic record, with implications for basin analysis and resource exploration.

On the seismicity in extensional tectonic settings

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Keywords: normal fault seismicity, graviquake, extensional tectonnics.

Earthquakes in extensional tectonic settings exhibit a systematic set of geometric, seismological, and geodetic features that distinguish them from strike-slip and contractional earthquakes, including shorter seismogenic faults, lower maximum magnitudes, higher b-values, prolonged and complex aftershock sequences, lower stress drops, strong near-field vertical ground motion, widespread fluid circulation, and pronounced asymmetry between coseismic subsidence and uplift. We review global observations from seismic catalogs, geodetic measurements, field data, and numerical models to evaluate the extent to which these features can be explained by classical elastic rebound theory. While elastic rebound successfully accounts for first-order seismic radiation, several observations in extensional regimes appear difficult to reconcile within a purely elastic framework when considered jointly. We discuss a complementary perspective, often referred to as the “graviquake” model, in which interseismic tectonic extension prepares the crust through distributed damage and dilatancy, while gravitational loading of the hanging wall systematically biases fault stability and energy partitioning at the coseismic stage. In extensional settings, the maximum principal stress is vertical and coincides with the lithostatic load. As a result, gravitational potential energy represents the dominant source of available energy for fault instability and rupture initiation, while elastic strain energy controls seismic radiation. In this framework, the gravitational potential energy controls fault weakening, rupture initiation, fluid-rock interactions, and inelastic deformation and postseismic evolution. We conclude by outlining observational tests, modeling challenges, and implications for seismic hazard assessment in extensional tectonic environments where graviquakes occur.

Volcanotectonic evolution of the central main Ethiopian Rift

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Keywords: Main Ethiopian Rift, volcanic processes, continental rifts.

The Main Ethiopian Rift (MER) in East Africa is one of the best examples of continental rift where the relations between tectonics and volcanism can be analysed in detail. The rift is characterised by volcanic and tectonic activity related to ongoing divergence between Nubia and Somalian plates, with different sectors of the rift recording different stages of rift evolution. A complex evolution of rift-related volcanism highlighted phases of discontinuous and clustered distribution of volcanic activity and its environmental implications in the Central Main Ethiopian Rift (CMER). Specifically, a large dataset of more than fifty new Ar/Ar dating allowed identifying five phases of intense volcanism alternated with periods of quiescence or reduced volcanic activity in the last 4 Ma. The main aim of the current study is to expand these previous findings and to analyse in more detail the relations between the volcanic activity and the evolution of rifting in this MER sector. To this aim, we integrate detailed field-based volcanological and structural-geological analyses with the results our geochronological survey to characterize the timing and relationships between faulting, volcanic activity and associated topographic variations. The data presented in this work provide new insights into the volcano-tectonic evolution of the CMER in the last 4 Ma by reconstructing the detailed volcanic succession and the areal distribution of the volcanic units with respect to the faults pattern. The phases of intense volcanism recognized are strictly connected to the tectonic evolution of this area, as they are concurrent or followed by periods of major faulting, subsidence and reorganization of the rift topography, supporting a heterogeneous evolution of continental rifting. Rift was largely asymmetric in the CMER with the main boundary fault system located on the western side (Guraghe escarpment). This fault system accommodated major deformation and crustal/lithospheric thinning during initial rifting, but its tectonic activity decreased with time as the volcano-tectonic progressively shifted on the the opposite, Eastern margin (Asela escarpment) during the Late Quaternary. The marked asymmetry in recent volcano-tectonic activity observed in the Guraghe-Asela transect is in line with geophysical studies in the CMER, which suggest complex relations between tectonic structures and magma upraising/emplacement and the resulting architecture of volcanic plumbing systems.

ADD-ON: Afar Dallol Drilling - ONset of sedimentary processes in an active rift basin

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Keywords: Danakil, rift, drilling.

The Afar triangle is a world class natural field lab where the breakup of a continent and the initiation of oceanic seafloor spreading can be observed and studied. The northern part of Afar, the Danakil Depression, especially represents a unique snapshot in space and time when the continent ruptures, and new seafloor and adjacent rifted margins form. However, deep subsurface records are missing in the Danakil basin. Seismostratigraphy suggests the presence of more than 2.2 km of syn-rift sediments in an active rift basin, but deep drillings do not exist. The combination of thick, very young syn-rift sediments and basaltic lava flows in a near sea-level basin, makes the Danakil Depression one of the few modern analogs for studying the development of a classic magma-rich rifted margin. The subsurface has incredible scientific potential with a well-preserved and continuous sedimentary record to unlock the understanding of rift evolution in a tectonically and volcanically active hydrothermal setting paced by global environmental fluctuations and biological processes. Within this framework, this poster details the diverse and inclusive team of international scientists, and local and regional (Afar), and national (Ethiopia) partners who propose to drill to 2.3 km into the Danakil Depression to access those subsurface records and solve globally significant, societally relevant and multidisciplinary questions (Foubert et al., 2024; www.afardalloldrilling.com).

Foubert A. et al. (2024) - Workshop report: Afar Dallol Drilling-ONset of sedimentary processes in an active rift basin (ADD-ON).

The September to November 2024 Fentale dike in the Ethiopian rift

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Keywords: rift, volcano, dike.

Dikes can contribute to rifting, but the space-time behavior and role of magma in young and slowly extending continental rifts is unclear. We use observations and modelling of InSAR and seismicity during the September to November 2024 Fentale intrusion in the Main Ethiopian rift (MER) to understand magma-assisted rifting at slow extension rates (5 mm/yr). From 2021 to mid-2024, the Fentale Volcanic Complex (FVC) uplifted up to 6 cm. From mid-September 2024, upper crustal diking started northwards along the rift, initially with subdued seismicity. From late-September to early November, dike opening increased to ~2m and propagated a total of ~14km north, causing increased seismicity from normal faulting. The dike made ~90% of the total geodetic moment, with the rest from faulting. The character of the event is similar to rifting episodes at mid-ocean ridges and demonstrates that episodic diking can occur in young, slow extending continent rifts but must be more infrequent. This marks the start of a major rifting episode.

Strain migration and plate kinematics in the Afar Rift: Insights from automated fault mapping, geodesy and geological data

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Keywords: rifts, faults, strain.

Continental rifts are dynamic systems where the locus, style (distributed or localized), and driving mechanisms (magmatic or tectonic) of plate divergence shift dramatically through space and time. However, regional-scale studies of continental rift evolution across geological times remain challenging as geophysical methods capture only temporal snapshots, while geological datasets are often spatially fragmented.

In this study we propose a novel approach based on a combination of plate boundary-scale, automatic fault mapping, geodesy and rock dating. We applied it to reconstruct the long-term evolution of tectonic and magmatic deformation in the central and southern sectors of the Afar rift (East Africa) (La Rosa et al., 2025). We used the Fatbox software (Fault Analysis Toolbox, Gayrin et al., 2026) to extract ~4000 faults from Digital Elevation Models across a ~ 70 000 km^2 wide area. We then expanded the software with a new workflow to quantify fault-related deformation, including horizontal extension and the second invariant of strain. Integrating our results with rock dating and decadal geodetic measurements, we reconstructed the rift's deformation history since 4.5 Ma and link it to present-day tectonic and magmatic activity. We find that strain in Central Afar has progressively abandoned its outer margins and concentrated along the rift axis, where magmatic emplacement thermally and mechanically weakens the crust, focusing deformation. A northwest-directed increase in strain rates points to an ongoing migration of rifting in that direction. In Southern Afar, two cross-cutting fault systems record the competing strain regimes imposed by the divergence of the Arabian and Somalian plates from Nubia (Maestrelli et al., 2024).

Our results show the potential of automated and combined geological and geophysical approaches to unravel the spatial and temporal complexity of extensional tectonics, while shedding new light on the evolution of extensional plate boundaries.

Gayrin P. et al. (2026) - Fatbox: the Fault Analysis Toolbox, Solid Earth, 17, 555-572, https://doi.org/10.5194/se-17-555-2026.

La Rosa A. et al. (2025) - Cross-scale strain analysis in the Afar rift (East Africa) from automatic fault mapping and geodesy, Solid Earth, 16, 929-945, https://doi.org/10.5194/se-16-929-2025.

Maestrelli et al. (2024) - Reconciling plate motion and faulting at a rift-rift-rift triple junction, Geology, 1-5, https://doi.org/10.1130/G51909.1.

Fault contribution to plate spreading during and after a dike intrusion at Fentale-Dofen magmatic segment (East Africa)

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Keywords: dikes, faults, remote sensing.

Tectonic extension at continental rifts can be accommodated by episodic dike intrusions and faulting. Dikes occur through pulsing intrusions of magma in the crust lasting days to months and they are sometimes accompanied by normal faulting. Normal faults are known to be important in shaping the rift morphology, to cause seismicity, and to be the preferential permeability pathways for deep gas and fluids. However, how they grow, how much extension they accommodate and what processes they respond to during and after a dike intrusion is less understood. Investigating faults motions and separating the contribution of faulting from magma during and after a dike intrusion can improve our understanding of the long-term processes accommodating the tectonic extension at rifted margins.

Here we address these questions by analyzing the fault deformation, its relationship with magma motions, seismicity and fluids during and after the dike intrusion at Fentale-Dofen (East Africa) of Dec. 2024-Mar. 2025. We used a multi-disciplinary dataset made of frequent optical and InSAR data, field measurements, and compared them with InSAR models and seismicity from literature to analyze the fault growth during the intrusion. We then used InSAR to measure surface deformation after the dike intrusion and modeled it as fault slip.

We show that, during the intrusion, faults grew responding to the lateral migrations of magma in the crust, developing vertical throws up to 2.5 m. Newly formed faults are observed to drive ground-waters toward the surface and to intersected rivers, causing widespread floodings. This suggests the presence of circulating fluids within the fault zones. Seismicity follows the lateral fault propagation but discrepancies between geodetic and seismic moment budgets during dike intrusion suggest that faulting occurs in part aseismically.

Satellite observations after the dike intrusion show resumed inflation and faulting around Fentale, along with time-progressive faulting along the Fentale-Dofen graben. InSAR models suggest faulting is an important process that keeps accommodating extension after diking ends, largely aseismically.

Oblique extension, inherited linkage zones and 3D strain partitioning along the Mid-Tuscany Seismic Zone, Northern Apennines

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Keywords: oblique extension, seismicity, structural inheritance.

Continental rifts rarely start and evolve as continuous fault systems: extension is partitioned among offset basins, inherited structures and decoupled crustal levels. This complexity is amplified in rifting orogens, where extension reactivates older fabrics. The Northern Apennines are a key case, in which active extension overprints a curved thrust belt.

We investigate seismicity across the Mid-Tuscany seismic zone (MTSZ), where instrumental earthquakes cluster along chain-parallel en-echelon extensional basins from the northern Apennine rift tip to Lake Bolsena. The MTSZ developed within a segmented structural framework, bounded by the Mid-Tuscan metamorphic belt and the frontal fold of the Tuscan Nappe. Basins are separated by structural highs, constrained by surface geology, gravity anomalies and bedrock maps, which record different degrees of basin interaction and provide a setting to test how active deformation follows rift fabrics, transfers across linkage zones and is redistributed within the seismogenic crust. We relocate seismicity using INGV phase data and a regional 1-D velocity model. Dense clusters are refined with double-difference using catalogue arrivals and waveform cross-correlation. We compute >500 focal mechanisms for M>2 earthquakes from manual P-wave polarities, with take-off angles and azimuths recalculated from path-specific 1D profiles derived from combined 1D and 3D velocity models. The T-axis catalogue images active extension across Tuscany. It shows that deformation is controlled by the present-day stress field, but locally strongly modulated by older fabrics. Regionally, T-axes rotate clockwise from NE to ENE southward, following the Apennine curvature, while counter-clockwise rotations systematically occur near consecutive basin tips, especially where along-strike lateral steps are largest. A depth-dependent distribution of focal mechanisms is observed, with strike-slip faulting prevailing at deeper levels and dip-slip normal faulting at shallower depths. Along strike, MTSZ exhibits marked spatial variations in rift architecture and deformation style, from the northern to the southern sectors, reflecting different stages and modes of extensional development. Sector 1 represents an incipient, inheritance-controlled rift, where basin interaction is localized along transverse hard-linked structures, producing strong strain partitioning and large T-axis rotations. Sector 2 defines a highly segmented transfer domain, where distributed strike-slip faults redistribute extension laterally and with depth. Sector 3 records the most evolved state, where basin linkage becomes broader and deformation is mainly accommodated by oblique dip-slip faulting with only moderate T-axis rotations.

The MTSZ is an active oblique-extensional system shaped by inherited left-stepping fabrics. Linkage thresholds locally steer extension directions, showing how older fabrics strongly modulate the local stress field.

Geodetic evidence for active transverse faulting in the Northern Apennines extensional domain

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Keywords: transverse faults, interseismic deformation, Northern Apennines.

In slowly deforming continental regions, active faults may remain difficult to identify because tectonic velocities are small, seismicity is sparse, and geomorphic markers commonly record cumulative rather than present-day deformation. This problem is especially relevant in rifting orogens, where active extension overprints inherited contractional architectures and long-lived transverse boundaries may be repeatedly reactivated through time.

We investigate a major transverse morphostructural lineament in the Northern Apennines, long recognized as a first-order intra-belt discontinuity associated with changes in basin architecture, topography, crustal thickness, heat flow and seismicity distribution. Despite its regional significance, its present-day activity, kinematics and seismogenic role have remained debated. Using public ground-motion products derived from satellite InSAR and GNSS, we analyse the present-day horizontal deformation field across this boundary. After reducing the influence of non-tectonic signals, we identify a coherent, low-amplitude velocity gradient consistent with interseismic strain accumulation across a regional-scale segmented transverse fault system. Our elastic interseismic modelling suggests that the system is locked within the brittle upper crust, with locking depths fitting with the local seismogenic thickness inferred from instrumental seismicity. Combining the inferred segment geometry with geodetic slip rates, we estimate a theoretical seismic potential exceeding Mw 6 for all individual segments, with recurrence times on the order of several centuries to millennia. These values are significant for a region where instrumental seismicity is weak and the historical record is incomplete relative to the expected recurrence intervals.

Our results indicate that this transverse lineament is not merely a passive inherited boundary recorded in the landscape, but an active crustal-scale fault system currently accumulating interseismic strain. This has important implications for understanding rift architecture, strain partitioning, and seismic hazard in low-strain continental regions.

Mineral chemistry investigations of the Quaternary alkaline basalts erupted at Dilo-Dukana and Mega volcanic fields (Southern Ethiopian Rift)

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Keywords: anomalous alkaline volcanism, mineral chemistry, olivine zoning.

Continental rifting is characterised by complex interactions between magmatic activity and tectonics with implications for magma ascent and eruption style. The southernmost termination of the Ethiopian Rift in East Africa, depicts a complex tectonic evolution with rapid episodes of rift propagation, abandonment and migration, and anomalous Quaternary volcanic activity spatially and temporally unrelated to rifting, postdating a period of Pliocene rift-related widespread volcanism. The post-tectonic Quaternary volcanism is focused in the Dilo-Dukana and Mega volcanic fields, with volcanic vents on a NE-SW alignment that cut rift-related features, and suggesting emplacement disconnected from the main rift structures, likely exploiting inherited deep lithospheric fabrics (Corti et al., 2019). The two volcanic fields both formed through monogenetic eruptions of alkaline basalts, rich in mantle and crustal xenoliths with composition distinct from the previous Pliocene subalkaline basaltic lavas related to the main rifting phase. Alkaline lavas are dominated by olivines, subordinate orthopyroxene and occasional clinopyroxenes phenocrysts, with minor Fe-Ti oxides. The same phases, excepting for orthopyroxene, also constitute the groundmass alongside feldspars and, in some cases, interstitial feldspathoids. Within the olivine population, four different types can be recognized based on petrographic and compositional features: the two most common types include homogenous, euhedral or skeletal crystals, and directly zoned olivine with jagged rims; secondarily, reversed zoned or complex banding zoning types are also found. Regardless of the zoning pattern, the CaO contents in olivine always increase from core to rim, suggesting either heating due to recharge events or decompression during ascent. Disequilibrium orthopyroxenes phenocrysts, featuring olivine coronas or clinopyroxene armored rims, are ubiquitous and testify peritectic reaction in a silica-saturated melt. Contrarily, clinopyroxenes show complex sector zoning indicating rapid crystallization rates. However, the occurrence of some micro-phenocrysts with resorbed cores and Ti, Al, Fe enriched rims indicates either cooling and/or decompression effect during magma ascent, or an increase in the oxidation conditions.

These new petrological and mineral chemistry data allow to constrain the chemico-physical conditions of the Quaternary alkaline magma as well as the plumbing system architecture, providing evidence of the key role played by kinetic processes during magma crystallization, and suggesting rapid decompression related to direct magma ascent. The occurrence of abundant xenoliths agrees with this hypothesis, testifying to the high “fragmentation capacity” of these magmas. However, the presence of complex zoning in olivines and some clinopyroxenes, along with discordant trace element behavior, suggests the possibility of more complex processes in the feeding system.

Corti G. et al. (2019) - Aborted propagation of the Ethiopian rift caused by linkage with the Kenyan rift. Nat Commun 10, 1309, https://doi.org/10.1038/s41467-019-09335-2.

Dynamics of a large dyke intrusion at Fentale in the Ethiopian rift

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Keywords: InSAR, dyke, Fentale.

Only a few large dykes have been intruded during the era of modern satellite geodesy and as a result the dynamics of how dikes grow over many tens of km's and interact with faults is poorly understood. Here we exploit the exceptional spatial and temporal resolution of InSAR during the December 2024-January 2025 Fentale dyke (Ethiopia) combined with seismicity and numerical models to study the dynamics of a large dyke intrusion. Our results show that a ~40 km long dyke fractured the entire Fentale-Dofen volcanic segment of the Ethiopian Rift from 19 December 2024 to 03 January 2025. The dyke first migrated laterally in just ~15 days but opening continued for a protracted period. Throughout the episode, melt was fed from a single reservoir beneath Fentale at the southern end of the segment. The dyke migration ended with the triggering of two earthquakes, a Mw 5.5 and 5.7 on the 3 and 4 of January, ~20 km beyond the dyke tip. Dyke opening and concomitant deflation at Fentale instead continued until the time of writing this abstract. The volume and seismic character of the Fentale dyke are comparable to other major rifting episodes observed at mature rifts and ridges, like the 2005 Dabbahu dyke, the 2014 Bardabunga dyke, and the ongoing Reykjanes episode. Our results support models of repeated magmatic rifting episodes being the main mode of plate boundary extension even in youthful continental rifts. Our observations are also in agreement with theoretical dyke propagation models in which faulting ahead of the dyke arrests its propagation.

Eruption triggering from connected magma storage at the Erta Ale ridge (East African Rift)

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Keywords: InSAR, East African Rift, Haily Gubbi.

Dyke intrusions and eruptions at nearby volcanoes can influence each other. However, the spatio-temporal connection of the magma storage and the dynamics of these events are rarely observed. We used InSAR, optical data, pixel offset tracking and seismicity to study two eruptions that occurred in the Erta Ale ridge within four months of each other. In November 2025, the Hayli Gubbi volcano erupted explosively sending an ash plume of ~14 km into the atmosphere. The eruption was preceded in July by a dyke intrusion and an eruption neat the Erta Ale lava lake. Dyking lasted 25 days and propagated southward for 36 km along the axis of the Erta Ale ridge, intruding a total of ~0.4 km3 of mafic magma. The dyke also intercepted nearby magma reservoir, including a shallow (1.5 km depth) sill below Hayli Gubbi, causing minor uplift. Interestingly, Hayli Gubbi did not erupt until four months later, in November when InSAR shows that contraction of a source under the Erta Ale caldera occurred simultaneously to contraction at Hayli Gubbi. The July-November events suggests that the magmatic systems of Erta Ale and Haily Gubbi are connected and that along axis dyke intrusions is a mechanism for feeding other magma chambers ultimaltey triggering eruptions. We suggest that mafic magma was injected in Haily Gubbi in July and again in November. Possible magma mixing with the residing melt occurred leading to the Haily Gubbi eruption. This is consistent with separate explosions and two plumes of likely different composition during the eruption.

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The Late-Variscan pyroxene episyenites associated with the Sàrrabus shear zone (SE Sardinia, Italy)

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Keywords: Na-metasomatism, episyenite, late-Variscan shear zones.

The extensional shear zone of Sàrrabus pluton displays peculiar Na-metasomatized rocks (episyenites) hosted in granodiorites and gabbroic rocks. These rocks are scattered along a 15 km-long extensional stepover which represent a possible feeder zone and consist of small, irregular lenses or pipes of hectometric layered episyenitic bodies. Alkali metasomatized rocks show variably albitized plagioclase (54 ÷ 70 vol.%) and anhedral K-feldspar (15 ÷ 20 vol.%), with interstitial aggregates of low-Ti diopside, replaced by amphibole (from Fe-hornblende to hastingsite). As the metasomatism becomes more pervasive, textures become xenomorphic or granoblastic, with low Ti-andraditic garnet coexisting with clinopyroxene close to aegirine-augite. Magnetite and titanite are ubiquitous accessory phases. Rare quartz with mortar textures occurs in veinlets and pegmatitic pockets. Mass balance indicates a general enrichment in Na_2O, Sr and loss of K_2O, Rb, Ba, V and HREE.

U-Pb data from metasomatic titanite yield 279 +15/-22 Ma, which, inside the correlated error, is within the range of the granodiorite and granite emplacement (286 Ma). Episyenites show εNd_{286} in the range of -6.29 ÷ -6.78, overlapping the values observed for host granodiorites (-5.53 ÷ -6.40). The $^{87}Sr/^{86}Sr_{286}$ ratio is in the range of 0.70922 ÷ 0.71140. This confirms alkali metasomatism of a broad granodioritic protolith, caused by rock-interaction with Na-enriched, silica undersaturated fluids. Several calibrations constrain the *P*-*T*-fO_2 conditions of about 2.0 kbars, 450 ÷ 750 °C, and -18.5 ÷ -16.2, respectively. Several stages of metasomatism occurred in the granodioritic intrusion while the latter was still cooling. These stages were controlled by shear faulting and by continuous variations in physicochemical parameters of the fluids, with *T* decreasing from near *solidus* to sub-*solidus* and hydrothermal conditions. Schematically, metasomatic stages may be summarized into: (1) *HT* albitization + primary biotite destabilization + Ca-silicate formation (diopside and andradite); (2) fluid-controlled metasomatic reactions leading to partial consumption of diopside and andradite with segregation of amphibole, titanite and magnetite, and (3) final widespread albitization with hydrothermal amphibole and locally, dark mica and quartz precipitation. Overall, high temperature processes resulted in a singular "sodic fenite" stage, only documented in Iberian massif (La Pedriza pluton) produced under near-solidus temperatures that overlaps those of magmatic stage. Fluids could have been rapidly focused along the syn- plutonic extensional shear zones at shallow crustal levels under prevailing diffusive mechanisms. High temperature textures are then overlapped by lower temperature stages with a general increase in Na, fO_2 and aH_2O in the fluids, with a final and widespread albitization which may be interpreted as a true episyenitization stage.

Cluster analysis reveals increasing plume-like magmatism during progressive rifting in Afar (Ethiopia)

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Keywords: magma genesis evolution, Afar mantle plume, lithosphere metasomatism.

Reconstructing the geochemical variations of magma during rifting is challenging due to the heterogeneous mantle sources of the melt and the variable evolution pathways that magma can potentially follows. Therefore, how and when the magma generation process transitions toward compositions typical of an oceanic ridge (MORB-like composition) is not yet fully understood. The Afar depression is an ideal natural laboratory for studying magma evolution during rift maturation, given that North Afar is approaching continental breakup while older rift products are preserved throughout the region. To investigate magma sources, we applied clustering analyses to a comprehensive geochemical dataset of more than 1000 samples from the Afar rift. The application of different clustering methods (K-means and hierarchical) and correlation analysis between geochemical features (Pearson coefficient) reveal that both trace element and isotope clustering group the North Afar samples, identifying a mantle source containing residual MREE-bearing minerals and an enriched mantle component. These results indicate that North Afar, where the rift is closest to breakup, has a stronger influence of the Afar plume and more extensive partial melting of metasomatized lithosphere relative to the rest of Afar. Our findings demonstrate that geochemical variations during rifting do not always follow a progressive transition toward a MORB-like composition but, instead, plume-like magmatism can intensify until the most advanced stages of rifting (i.e., North Afar), potentially because the mantle plume is channelled toward regions of thinnest lithosphere.

Architecture and deformation processes of a carbonate-hosted fault zone: The Pietrasanta Fault

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Keywords: fault zones, carbonates, Apennines.

This contribution presents the architecture, the microstructures and the deformation processes of fault zones hosted in carbonate units of the inner Northern Apennines. This region is characterized by extensional tectonics since Late Miocene, which has led to the development of normal fault systems bounding Neogene-Quaternary basins and associated with present-day seismicity, characterized by relatively low frequency but occasionally large-magnitude events (Molli et al., 2021).

The Viareggio basin in Northern Tuscany represents one such structure and its onshore part (Versilia and Pisa plain) is separated from the hills of the Apuan Alps by the West Apuan Fault System (WAFS) that comprises the exhumed Pietrasanta Fault, the primary focus of this study.

The Pietrasanta Fault accommodates at least ~400 m of displacement within the non-metamorphic carbonates of the Tuscan nappe and developed at upper crustal conditions. The fault zone is characterized by a remarkably well-developed Principal Slip Surface exhibiting metric- to decametric-scale corrugations. The associated damage zone, approximately at least 250 m wide, consists of domains with variable fracture density intersected and divided by multiple secondary slip surfaces, defining a highly heterogeneous strain distribution, consistent with the widespread splay system of the WAFS.

The results of roughness analysis of the Principal Slip Surface reveal different roughness properties at different analyzed length scales. These data combined with qualitative meso and micro structural observations show how different brittle mechanisms operate across different scales and drive processes such as hangingwall-footwall mass transfer, slip surface growth by fracture interaction and slip surface morphology. Brittle microstructures and reworked cataclasites testify to multiple cycles of rupture and healing of the fault rocks, with important implications for the seismic cycle.

Molli G. et al. (2021) - Active Fault systems in the inner northwest Apennines, Italy: a reappraisal one century after the 1920 Mw ~6.5 Fivizzano earthquake. Geosciences, 11, 139, https://doi.org/10.3390/geosciences11030139.

Local strain reorientation allows the tectonic activation of misaligned lineaments along the Main Ethiopian Rift

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Keywords: Main Ethiopian Rift, strain reorientation, analogue tectonic modelling.

The interaction between the NE-SW striking Main Ethiopian Rift (MER) and the E-W oriented Yerer-Tullu Wellel Volcano-tectonic lineament (YTVL) represents one of the least understood tectonic problems in the East African Rift System (Fig. 1). Despite the numerous studies that have been conducted in the region, the following questions still remain to be answered: did the MER and YTVL evolve simultaneously? Was there a change in plate motion direction to allow a diachronous evolution of the rift and the lineament? How does the E-W oriented YTVL remain active under ca. E-W oriented regional extension? Previous studies propose a two-phase tectonic evolution, involving a change in the direction of plate motion at around 6 Ma causing deformation to focus in the MER. However, this interpretation contradicts plate-tectonic reconstruction data suggesting a constant plate divergence direction since ca. 16 Ma.

We use analogue models to study how deformation may occur along the YTVL (Zwaan et al. 2025). We find that the activation of lineaments oriented (near-) parallel to the plate divergence direction is in fact possible, if (1) the strength of the crust beneath the lineament is sufficiently reduced and (2) the main rift trend is sufficiently oblique to the overall plate divergence direction. We interpret this to be the result of a local reorientation of the regional extensional strain caused by the obliquity of the MER, which allows for deformation along the otherwise misaligned YTVL. As such, no multiphase scenario is required to explain the development of the YTVL, and a single-phase scenario that is in line with plate tectonic reconstructions can be adopted instead. Moreover, our model results suggest that other lineaments associated with the MER could also be active in the current tectonic regime. These insights may be of relevance to the interpretation of deformation along similar oblique structures associated with the MER, and with other past and present rift systems as well.

Zwaan F. et al. (2025) - Local Strain Reorientation Explains Deformation of Rift-oblique Tectonic Lineaments Along the Main Ethiopian Rift. Tektonika, 3, 40-57, https://doi.org/10.55575/tektonika2025.3.2.86.

S12.

From grains to basins: new trends in clastic sedimentology and provenance studies

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Deep-water depositional-elements prediction using machine-learning algorithms trained on geological analogues

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Keywords: machine-learning, depositional-element, sedimentary log.

The interpretation of sedimentary logs to infer the depositional environment of deep-water sandstones e.g., channels or terminal settings (i.e., lobes or sheets) is a key task for developing subsurface models that capture geobody geometry and sedimentary facies heterogeneity. This is routinely undertaken via the utilization of geological analogues or facies models. This study presents a workflow that automates this process using machine learning techniques trained on an extensive quantitative analogue dataset.

The research uses quantitative facies and bedding data from 205 sedimentary logs representing deep-water channel elements (104 cases) and terminal deposits (101 cases), sourced from 25 deep-water systems and stored in a relational database. These data were used to develop machine learning models trained to classify a facies sequence from a sedimentary log into one of these two element types. The classification is based on 18 quantitative facies and bedding attributes (e.g. thickness and lithology proportions). Given that the number of attributes interpretable from common wireline-log suites is limited, a 'borehole' attribute set was also used in model training, which only includes 5 attributes (sandstone and mudstone thickness and proportion).

Cross-validation shows that both modelling approaches correctly identify element types in more than 75% of the cases. Model performance in the application to an unseen testing dataset resulted in correct identification of 88% of the terminal deposits and 58% of the channel elements, with 69% mean accuracy overall. By contrast, models trained on the 'borehole' set of attributes only yielded a 64% mean accuracy. Model performance was compared to interpretations made by 14 sedimentologists on 12 graphical sedimentary logs selected from the testing dataset. Classifications made by the models (trained on the 'outcrop' attribute set), outperformed the geologists by 5% in accuracy.

These findings suggest that machine learning can, to a certain extent, support and enhance sedimentological interpretation of deep-water depositional environments.

Composition and Provenance of Carboniferous-to-Permian Sandstone withih the Circum-Mediterranean region: Implications for assemblage of Supercontinent Pangaea and its breakup

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Keywords: provenance analysis, sandstone, Paleozoic.

Carboniferous to Permian sandstones were studied within the Paleozoic Circum-Mediterranean area (Spain, Morocco, Sardinia, Puglia, and Sicily), providing key detrital modes during the Variscan Orogeny and the Paleotethyan closure. In Spain (Criniti et al., 2023) and Morocco (Criniti et al., 2024), the Carboniferous Culm facies, consisting of synorogenic deep-marine turbidites, is quartzolithic and records high- to medium-low-grade metamorphic content. The source area was a recycled orogen with evidence of volcanic and ophiolitic detritus. These supplies appear to derive from a mid-crustal deformed and thrusted terrane, involved in the plate convergence of the Variscan sensu stricto orogenic system, rapidly exhumed and uplifted. The Late Pennsylvanian-Permian molassic basins in Sardinia reveal compositions ranging from quartzolithic to feldspatholithic upward (Costamagna & Criniti, 2024), consistent with a change in sediment supply, first Variscan-bearing and then volcaniclastic, related to fragmentation attempts that produced intracontinental coeval magmatic activity. The Kungurian flysch of the Lercara Complex in Sicily exhibits a quartzolithic petrofacies, both very low-grade metamorphiclastic derived from post-Hercynian (Variscan) chain sources, and carbonatoclastic, suggesting shallow- to deep-water conditions and a possible connection of the basin to the southern passive margin of the Permian Paleo-Tethys, or rifting along the Gondwanan margin connected to the main Paleo-Tethyan domains. The Upper Permian siliciclastic deposits buried under the Apulia domain (Criniti, 2023) were intercepted in the Puglia 1 well (ENI), at depths from 6110 m to 7070 m. This succession, about 760 m thick, preserves sandstones with quartzolithic composition, where metasedimentary lithic fragments, increasing in grade downward, could be related to the eroded Devonian-Carboniferous Variscan orogen, where metasedimentary rocks frequently occur in the Calabria-Peloritani, Southern Alps, and internal domains of the Circum-Mediterranean orogenic belts. The provenance interpretation of the studied sandstones provides new and previously unknown insights into unsolved stratigraphic issues, provenance relations at a regional scale, and sediment dispersal systems on a global scale for other major orogens, outlining the global processes that occurred during the construction of the supercontinent Pangaea and its subsequent breakup and fragmentation.

Costamagna L.G. & Criniti S. (2024) - Interpreting siliciclastic sedimentation in the upper Paleozoic Mulargia-Escalaplano Basin (Sardinia, Italy): influence of the tectonics on the provenance. J. Palaeogeog., 13, 18-34, https://doi.org/10.1016/j.jop.2023.10.005.

Criniti S. (2023) - Detrital modes of buried Permian sandstones of the Puglia 1 well (Puglia Region, Southern Italy). Rend. Soc. Geol. It., 59, 119-124, https://https://doi.org/10.3301/ROL.2023.19.

Criniti S. et al. (2024) - Detrital signatures of the Ghomaride Culm Cycle (Rif Cordillera, N Morocco): new constraints for the northern Gondwana plate tectonics. Mar. Petrol. Geol., 165, 106861, https://doi.org/10.1016/j.marpetgeo.2024.106861.

Crinit S. et al. (2023) - New constraints for the western Paleotethys paleogeography-paleotectonics derived from detrital signatures: Malaguide Carboniferous Culm Cycle (Betic Cordillera, S Spain). Sed. Geol., 468, 106534, https://doi.org/10.1016/j.sedgeo.2023.106534.

Provenance analysis in unravelling complex stratigraphic records - the Paleogene - Neogene transition at southernmost border of the Sila Piccola (Catanzaro area)

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Keywords: Cenozoic, tectonics, CARG.

The usage of provenance analysis for assessing major tectonic events in collisional orogens is a standard methodology. In many cases, in fact, changes in sedimentary production and accumulation are strictly correlated to changes in regional stress regimes that drive the evolution of collisional belts. In this sense, provenance analyses become a useful tool in the identification of stress pattern deformations, its surficial response and the consequent evolution of drainage pattern across millions of years of sedimentary history.

In the framework of the activities carried out for the realization of the CARG 575 sheet Catanzaro, a provenance analysis workflow combining fieldwork, clast counts, image analysis and petrographic analysis, has been carried out, investigating four main clastic successions accumulated across the Paleogene - Neogene transition at the southern border of the Sila Piccola.

The obtained results indicate that, until the beginning of the Oligocene, drainage pattern in the central part of Calabria was strictly controlled by the convergent and collisional processes driven by the closure of the Tethys, inducing the erosion and transportation of the uppermost layers of the Sila-Serre nappe. At the beginning of the Neogene, when the westward subduction process began, drainage pattern was deeply influenced by the unroofing processes involving the lowermost roots of the Sila-Serre nappe. Toward the end of the Miocene (Messinian), metaophiolitic nappe came to the surface and underwent to erosion, filling up small basins whose depth was controlled by tectonics and rapid sea level drop.

From deposition to exhumation, linking the evolution of the Adriatic foredeep with slab dynamics: Insight from the Macigno Fm., Cinque Terre, Italy

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Keywords: foreland basin, Northern Apennines, thermochronology,

The Northern Apennines are a classic retreating-subduction orogen formed during the Oligo-Miocene Adria-Europe convergence, characterized by a northeastward-migrating underfilled foredeep basin. The emplacement of the Ligurian wedge induced flexural subsidence and deposition of the thick (~2.5 km) Macigno Formation within the Adriatic foredeep. While thrust loading by the Ligurian wedge accounts for the initial subsidence and burial history, the mechanisms controlling subsequent foredeep evolution and exhumation remain debated. End-member models invoke either continuous rollback-driven upper-plate extension or a more complex geodynamic evolution involving slab tearing and/or delamination, potentially culminating in a major tectonic reorganization during the Early Pliocene. Our study addresses this controversy by providing new thermal constraints on the burial and exhumation history of the Oligo-Miocene Adriatic foredeep. We investigate the Macigno (Tuscan domain) and Canetolo (Subligurian domain) formations in the Cinque Terre area, where the foredeep succession is overlain by the Ligurian Units. By integrating new vitrinite reflectance measurements with zircon and apatite (U-Th-Sm)/He ages (ZHe and AHe), we reconstruct the thermal evolution of the basin and constrain the timing and rates of burial and subsequent exhumation. New vitrinite reflectance (R□) data (~0.5-0.7%) from the bottom, middle, and upper Macigno in the Cinque Terre Area indicate maximum burial depths of ~3 to 5 km for the unit, assuming a geothermal gradient of 25 °C km□¹. These conditions were likely sufficient to reset shallow thermochronometers (AHe), while indicating that the Macigno Fm. remained at relatively shallow structural levels and experienced limited burial during the northwestward stacking of the Ligurian wedge. In contrast, ZHe data collected from structurally deeper portions of the Macigno toward the northwest indicate significantly greater burial, sufficient to reset the zircon (U-Th-Sm)/He system. Macigno Fm. burial was followed by rapid Late Miocene-Pliocene exhumation, previously attributed to extensional tectonics (Balestrieri et al., 1996; Fellin G. et al., 2007). We evaluate two possible geodynamic mechanisms for this event: (i) continued rollback-related extension and (ii) slab delamination. The latter mechanism may explain rapid surface uplift and exhumation in the Northern Apennines hinterland domain without requiring substantial reheating of the upper crust. Combined AHe and ZHe cooling ages will place new constraints on the geodynamic evolution of the Northern Apennines during Late Miocene-Pliocene exhumation.

Balestrieri M.L. et al. (1996) - Insights on the thermal evolution of the Ligurian Apennines (Italy) throughfission-track analysis. J.of the Geol.l Society. London, Vol. 153, 419-425.

Fellin G. et al. (2007) - Thermochronologic evidence for the exhumational history of the Alpi Apuane metamorphic core complex, northern Apennines, Italy. Tectonics, 26, TC6015, https://doi.org/10.1029/2006TC002085.

Sedimentary signatures of microtidal processes in fluvial deposits: new insights from the lower Po River (Italy)

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Keywords: microtidal regime, fluvio-tidal interaction, tidal sedimentary structures.

In rivers subject to microtidal conditions, such as those characterizing the Mediterranean basin, tidal processes are commonly considered unable to produce recognizable sedimentary signatures. Yet, this assumption has rarely been tested through detailed investigations of modern river systems. This is particularly prominent in lowland fluvial systems lacking clear geomorphic evidence of tidal activity, such as in coastal, meandering, river-fed channels that show neither funnel-shaped planforms nor cuspate bends—two key indicators of tidal control on morphodynamic processes.

This study examines how weak tidal currents can nevertheless leave identifiable depositional signatures within the 180-km-long Fluvial-Marine Transition Zone of the Po River (Italy). Although the distributary channels of the Po River Delta do not display neither funnel-shaped planforms nor cuspate meanders, hydrological measurements reveal tidal modulation of river stages up to several tens of kilometers inland, particularly when river flow rates are low. Field observations document heterogenic deposits with sand-mud couplets, rare bidirectional ripples, and cyclically organized cross-strata interpreted as products of semidiurnal tidal modulation acting on migrating fluvial bedforms. These features occur even above the average intertidal zone, suggesting that flood-enhanced water levels facilitate the inland propagation of tide-modulated sedimentation. The results demonstrate that diagnostic tidal sedimentary structures may form in environments where tides exert minimal influence on large-scale river morphology, highlighting the need for caution when inferring morphodynamic controls solely from sedimentary structures.

This work is part of the research project “Ensuring resilience of the Po River Delta to rising relative sea levels using nature-based solutions for building land and mitigating subsidence (NatResPoNΔ)”, a PRIN 2022 PNRR project funded by the European Union - NextGenerationEU.

Dam-induced sediment connectivity disruption in the upper Yellow River: insights from detrital apatite fission-track thermochronology

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Keywords: detrital thermochronology, sediment connectivity, Yellow River.

Dam construction represents one of the most pervasive anthropogenic disturbances affecting river systems worldwide. This study presents apatite fission-track (AFT) thermochronological data from modern sediments collected along a segment of the upper Yellow River and its tributary, the Wei River, compared with bedrock data from the northeastern margin of the Tibetan Plateau, considered the primary potential sediment source for the region. Results reveal marked variations in age populations along the upper Yellow River, in sharp contrast with the substantial stability observed along the Wei River. This discrepancy is interpreted as a direct consequence of large-scale cascade damming in the former and the near-complete absence of hydraulic infrastructure in the latter. Artificial barriers have reduced longitudinal connectivity, disrupted sediment flux, and altered both hydrological dynamics and local ecosystem functioning. Contrary to prevailing interpretations, the provenance patterns documented here do not support a dominant sediment supply from the Tibetan Plateau across the entire studied reach. Instead, they point to predominantly local contributions from adjacent mountain ranges and Cenozoic basins. The loss of sediment connectivity along the main channel is particularly evident at the local scale, where downstream sediment composition becomes progressively enriched in material delivered through lateral tributaries. These findings highlight the need to integrate high-resolution provenance analyses into environmental assessments of large river systems, and to develop water management policies that account for the cumulative ecological and geomorphological consequences of anthropogenic river fragmentation.

Short-term erosion patterns at the transition between flat and normal subduction in the central Chilean Andes: insights from detrital apatite fission-track analysis

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Keywords: detrital thermochronology, mineral fertility, Chilean Ande.

Convergence between the Nazca and South American plates in central Chile is characterized by along strike variations of the subduction angle from flat subduction, between 27°S and 33°S, to normal subduction south of 33°S. Slab flattening has been attributed to the subduction of the buoyant Juan Fernández Ridge in the Nazca Plate, which is located in the southern end of the flat slab segment. This process would be responsible for an eastward migration of the asthenospheric wedge and consequent lack of Quaternary arc volcanism in the Andean region characterized by slab flattening. The exhumation of the Chilean Andes has been the subject of many previous studies based on bedrock thermochronology methods (e.g., Rodriguez et al., 2018; Stalder et al., 2020). However, these approaches did not address the potential impact of slab flattening on modern erosional exhumation.

Here we present the preliminary results of a study that aims to highlight possible short-term differential erosion in the transition region from flat to normal subduction on timescales typical of bedload river transport (10^3-10^5 yr). The study is based on fission-track analysis of detrital apatite from modern river sediments and ancient river terraces. Modern river sediments were collected - following the sampling strategies recommended by Malusà & Fitzgerald (2019) - in river basins cutting across the main tectonic domains of the Chilean Andes (Coastal Cordillera and Main/Frontal Cordillera): the Huasco and Elqui river basins, in the region characterized by flat subduction, and the Aconcagua and Maipo river basins, in the regions on top and to the south of the subducted Juan Fernández Ridge. Our approach exploits the size of grain-age populations rather than the age of mineral grains, which is utilized as a provenance tracer to constrain sediment budgets and erosion patterns. Grain-age distributions are compared by statistical methods to determine the percentage of mineral grains derived from different sub-basins. This percentage, when integrated with the area of each sub-basin and its mineral fertility, which is independently derived, can be used to calculate the relative erosion rates of the sub-basins. Relative erosion rates can be converted into absolute rates after integration with gauging data or cosmogenic-derived sediment fluxes for selected basins.

This is an outcome of the project “ITAL - Innovations in thermochronology applied to the Andean natural laboratory. The research was conducted with funding from the Ministry of University and Research as part of the call for proposals relating to the scrolling of the final rankings of the PRIN 2022 call.

Malusà M.G. & Fitzgerald P.G. (2019) - Fission-track thermochronology and its application to geology (Vol. 393). Cham, Switzerland: Springer.

Rodríguez M.P. et al. (2018) - Latitudinal and longitudinal patterns of exhumation in the Andes of north-central Chile. Tectonics, 37(9), 2863-2886.

Stalder N.F. et al. (2020) - The relationships between tectonics, climate and exhumation in the Central Andes (18-36 S): Evidence from low-temperature thermochronology. Earth-Science Reviews, 210, 103276.

Turbidite sedimentation in wedge-top basins and implications for paleo-carbon sequestration: insights from Sicily

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Keywords: organic matter, wedge-top basins, carbon sequestration.

Wedge-top basins, developing during mountain building, are key settings to investigate the interplay between tectonics, sedimentation, and organic matter preservation. These basins typically form under compressional to post-collisional regimes, where active subsidence, rapid sediment supply from uplifting orogenic fronts, and variable paleogeographic and climatic conditions combine to create environments prone to accumulation of organic-rich sediments. In particular, high sedimentation rates, restricted circulation, and periodic anoxia can enhance organic matter preservation, making these basins significant for investigating organic carbon sequestration in deep marine sediments.

This contribution focuses on wedge-top basins of Nebrodi Mountains (northern Sicily) with emphasis on flow characteristics and linked organic matter accumulation and preservation, in the frame of PRIN-PNRR 2022 project: *Testing the efficiency of submarine landslides on organic carbon sequestration over geological times* (TOOLS). These basins preserve sedimentary successions that record syn- to post-orogenic stratigraphic and depositional signals. Stratigraphic and sedimentological data, together with inorganic and organic petrography and geochemistry, reveal the influence of tectonic activity, sediment supply, basin subsidence, and environmental/climatic conditions controlling distribution and preservation of organic-rich facies.

In particular, the Nebrodi case study highlights how wedge-top basins offer effective conditions for paleo-carbon sequestration. Analysing the controls on organic carbon sequestration in the geological record is crucial for understanding carbon sequestration in present-day analogues.

Sandstones at the micro-scale: Evidences of a REE- and Ba-bearing hydrothermalism in a Palaeocene-Eocene sandstone of the Cormons Flysch (Friuli Venezia Giulia) recognised via SEM

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Keywords: monazite, hydrothermalism, flysch.

In the Friuli Venezia Giulia region, western Slovenia and Istria peninsula (Croatia) a conspicuous Upper Cretaceous to Eocene flysch succession outcrops. Several Authors studied the different succession via mineralogical, petrological and geochemical methods. In the past, numerous historical reports showed the presence of droplets of native mercury in the flysch layers of these areas (Zucchini & Muscio, 2026).

Given this, we decided to analyse such weathered sandstones characterised by an intense red-purple and yellowish colour. Some thin sections have been analysed at the microscope showing they are medium to large sandstones with quartz prevailing over feldspars and low rock fragments content. Carbonates are present as clast, bioclasts and cement. Heavy minerals as zircon and Cr-spinels are present. Subsequently, the thin sections have been studied via SEM including chemical EDS analyses.

Within the grains it is easy to find several magnetite framboids, sometimes formed around pyrite nucleus. Magnetite also fills chambers of planktonic foraminifera. Apart from the Fe-oxide and carbonates, authigenic Ti-oxides are present. It is noteworthy the presence of authigenic barite, widespread in the samples as tiny (usually less than 10 μm) lamellae. Barite is mainly present in the red-coloured part of the sandstones. Quite peculiar is the diffuse presence of monazite (approximatively approaching a $Ce0.5,La0.3,Nd0.2PO_4$ composition) crystals smaller than 5-10 μm. In some cases, Th can be present as well in very low amount. Crystals of monazite in the range 20-30 μm, can be present as well and could be considered as detrital. Rare xenotime crystals with variable HREE content are also present. A cluster of small zircons (less than 10 μm in size), possibly authigenic, is restricted in an area close to some monazite crystals.

The presence of authigenic barite, Ti-oxide, monazite, xenotime and zircon suggests, for the first time, the presence of a possible hydrothermalism in the sandstones of the Cividale area.

Dolenec et al. (2000) showed the possibility that something peculiar (volcanic processes, sea floor hydrothermal activity) happened at the Palaeocene-Eocene boundary resulting in an Ir anomaly associated with perturbation in C and O isotopic records in the Goriška Brda area (about 10 km from the here studied area). Zucchini & Muscio (2026) related the native mercury occurrences to a system of Alpine faults reactivated in a post-Eocene time mentioned by Venturini & Tunis (1989). It is possible that these faults were the path for both the native mercury and the hydrothermal fluid that caused the REE- and Ba- mineralization in the here studied sandstones.

Dolenec T. et al. (2000) - Ir anomalies and other elemental markers near the Palaeocene-Eocene boundary in a flysch sequence from the Western Tethys (Slovenia). Terra Nova, 12, 199-204.

Venturini S. & Tunis G. (1989) - Nuovi dati ed interpretazioni sulla tettonica del settore meridionale delle Prealpi Giulie e della regione al confine tra Italia e Iugoslavia. Gortania, 10, 5-34.

Zucchini R. & Muscio G. (in press) - Mercurio nativo nelle Prealpi Giulie (Italia Nord-orientale): Dati storici, nuove ricerche e ipotesi. Gortania, 48. ISSN 2038-0410.

Styles of accretion at the bend of a sinuous turbidite slope channel (channel-levee Complex 5, Tachrift system of NE Morocco)

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Keywords: lateral accretion package, outer-bank bar, turbidite counter bar.

Beside Lateral Accretion Packages (LAPs), long recognized as the dominant architectural element of meandering turbidite channels yet poorly documented at outcrop, other bar types (i.e., outer-bank bars and counter bars) have been documented in the subsurface (Nakaima et al., 2009) or predicted by modelling works (Janocko et al., 2013) but their deposits never described in detail.

This contribution reports on variously accreted deposits from the fill of a sinuous channel belonging to the Tachrift System (upper Miocene of the Taza-Guercif Basin, NE Morocco), which owing to exceptionally exposed multiple outcrops, offer the opportunity to document their composition and clarify their depositional meaning.

Detailed correlation of fifty-nine logs from three outcrops spanning a left-turning bend allow recognition of four stratigraphic units recording channel establishment and levee development, aggradation and bend translation and expansion, and switching of the parent channel.

Results show that lateral-accretion packages (LAPs) formed at the inner bank represent the main intra-channel depositional element, co-occurring with equally sandstone-rich and coarse-grained deposits accreted at the outer bank. The best exposed and larger example of LAPs occurs in two correlated exposures c. 500 meters apart along-stream, which most likely straddle the bend apex. In the upstream outcrop, cut-and-fill features and sandstone amalgamation make it difficult to recognize lateral accretion. Here, LAPs consist of bedsets of amalgamated sandstones bounded by thalweg-dipping erosional surfaces that are lined up with mud-clast breccias in the deeper part of the channel fill. In the downstream outcrop, the correlated LAPs become lithologically more layered along most of their profile. Moving up accretion dip to the LAP top, they comprise finer-grained, and more structured sandstones alternating with mudstones.

In the downstream outcrop, LAPs transition into a mud-rich heterolithic deposit characterized by trough-cross inclined stratification, which dips at a high angle to mean downstream paleocurrent. This deposit extends over a distance of a few hundred meters, straddling the inner- to outer-bank transition, and is interpreted as the expression of bank-attached bars (here termed turbidite counter-bars) forming in a flow separation zone.

This recently published work (Marini et al., 2025) provides insights into longitudinal heterogeneity of LAPs and lithological composition of outer-bank bars and turbidite counter bars never before observed at outcrop.

Janocko M. et al. (2013) - Turbidity current hydraulics and sediment deposition in erodible sinuous channels: laboratory experiments and numerical simulations. Marine and Petroleum Geology, 41, 222-249, https://doi.org/10.1016/j.marpetgeo.2012.08.012.

Marini M. et al. (2025) - Temporal and spatial changes in style of accretion at the bend of a sinuous turbidite slope channel (channel-levee Complex 5, Tachrift System of NE Morocco). Journal of Sedimentary Research, 95(2), 286-313, https://doi.org/10.2110/jsr.2024.052.

Nakajima T. et al. (2009) - Outer-bank bars: a new intra-channel architectural element within sinuous submarine slope channels. Journal of Sedimentary Research, 79, 872-886, https://doi.org/10.2110/jsr.2009.094.

Sedimentology and magneto-biostratigraphy of the channelised turbidites of the El Rhirane System (Upper Miocene; Taza-Guercif Basin, NE Morocco)

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Keywords: channelised turbidites, Taza-Guarcif Basin, paleomagnetism.

The Taza-Guercif Basin (TGB) of Northern Morocco represents the Mediterranean part of the Rifian Corridor, a seaway that in the Late Miocene connected the Atlantic Ocean to the Mediterranean Sea. Current paleogeography models indicate TGB was located immediately to the east of a structural sill that was key in regulating the Mediterranean Sea dynamics.

Two turbidite systems with a common southerly sediment source are documented in the southern TGB, namely the Tachrift System (TS) and the El Rhirane System (ERS), which crop out 1.5 Km apart to the east and to the west of the Zobzit River, respectively. While TS, late Tortonian-early Messinian in age, was the subject of magneto-biostratigraphic studies in the late '90s (Krijgsman & Langereis, 2000) and is currently being investigated for its exceptionally exposed slope channel complexes (Felletti et al., 2020), ERS has received little attention to date. The relationship between the two systems is unclear, with earlier works interpreting ERS as non-channelised and relatively older and thinner than TS, implying a complex and potentially dynamic palaeobathymetry.

This contribution reports on the sedimentology, magnetostratigraphy, and foraminiferal and nannofossil biostratigraphy from a composite section of the El Rhirane System, aiming at clarifying its relationship with TS and better defining the complexity of the southern edge of the TGB.

Sedimentary logging and facies analyses suggest that, albeit comparatively thinner, ERS stratigraphy is similar to that of TS, with several superimposed leveed channel-fills, each up to a few tens of m-thick, encased in hemipelagic marlstones. Stratigraphic changes in the orientation of palaeocurrent indicators suggest local palaeoflow evolved from north-eastward to northward and parallel to mean TS paleoflow.

Paleomagnetic analyses allowed defining a magnetic polarity stratigraphy comprising several reversals. Based on identification of key planktonic foraminifera (FO *G. suturae*, FCO of *G. miotumida*) and nannofossil (FO of *A. primus* and *N. amplificus*) bioevents, the magnetic polarity stratigraphy was correlated with the Chrons C4r.1n-C3Ar of the Geomagnetic Polarity Time Scale (Ogg, 2020), suggesting ERS was largely coeval to TS.

All in all, the channelised nature of ERS and correlation with TS indicate the southern slope of the TGB hosted a multilateral slope channel system, whose depositional pattern was, at least upon inception, conditioned by a complex slope morphology.

Felletti F. et al. (2020) - The Tachrift channel-levée turbidite complexes (Tortonian) of the Taza-Guercif basin (South Rifian Corridor, NE Morocco). Journal of Maps, 16, 902-917, https://doi.org/10.1080/17445647.2020.1844088.

Krijgsman W. & Langereis C.G. (2000) - Magnetostratigraphy of the Zobzit and Koudiat Zarga sections (Taza-Guercif basin, Morocco): implications for the evolution of the Rifian Corridor. Marine and Petroleum Geology, 17, 359-371, https://doi.org/10.1016/S0264-8172(99)00029-X.

Role of marine gateways and straits on climate, carbonate factory, and sediment distribution

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Keywords: mixed silicilastic-bioclastic, Plio-Pleistocene, straits.

Marine basins can be interconnected by relatively narrow passages (e.g., gateways and straits) of variable depth, which control surface, intermediate, and deep-water circulation and, by extension, the spatial and temporal distribution of shallow- and deep-water deposits. Gateways and straits play also a crucial role in regulating climate equilibrium at both global and regional scales by controlling the exchange of water, heat, salt and nutrients between ocean basins and sub-basins such as the Mediterranean Sea.

Geological changes in gateway geometry can significantly alter global ocean circulation patterns and associated heat transport, resulting in climate variations that have a profound impact on carbonate factory development, while sediment transport and redistribution are primarily controlled by hydrodynamic processes. Variations in bioclastic production may subsequently affect sedimentation patterns, because biogenic particles respond differently to hydrodynamic processes compared to purely siliciclastic sediments.

Changes in the geometry and structure of the Gibraltar Strait area after the Messinian Salinity Crisis, combined with variations in the relative sea level, climate, and bottom-currents circulation likely modulated the Atlantic Water Inflow (AWI) entering the Mediterranean, influencing locally shallow seas and coastal areas. In recent years, several studies have focused on Pliocene-Pleistocene deposits accumulated in coastal or strait areas, around the Mediterranean Sea characterised by a compositional mixing (*sensu* Chiarella et al., 2017) of siliciclastic and bioclastic particles.

The increase in bioclastic particles arguably reflect the activation and growth of local cool-water carbonate factories, which could represent a response to climatic and oceanographic changes possibly linked to the opening, and subsequent evolution of the Gibraltar Strait since the end of the Messinian Salinity Crisis.

This project aims to reconstruct paleoenvironmental conditions where different central and western Mediterranean Pliocene-Pleistocene mixed siliciclastic-bioclastic deposits accumulated by analysing their triggering mechanisms and potential genetic regional relationships. This will be achieved by selecting a range of representative examples of Plio-Pleistocene mixed successions among the more than 50 systems described onshore in the Western Mediterranean area in different tectonic settings.

Chiarella D. et al. (2017) - Types of mixing and heterogeneities in siliciclastic-carbonate sediments. Mar. Petrol. Geol., 88, 617-627, https://doi.org/10.1016/j.marpetgeo.2017.09.010.

SEM-EDS observations of quartz arenites concretions in a collapsed cave from the Trieste Karst

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Keywords: SEM-EDS, quartz arenites, Trieste Karst.

Several sandy deposits constituted almost exclusively by quartz can be found in the Karst of Trieste. Such deposits fill caves (sometimes collapsed) and consist of loose sediments and concretions (mostly spherical).

In this study, we focused on some concretions from a deposit found in a collapsed cave in the locality of Zolla (TS). Thin section analyses confirm they are quartz arenites, with carbonate cement. Among the main constituents, feldspar crystals and muscovite flakes are also present.

To investigate the inclusions in quartz and the heavy mineral assemblage, SEM-EDS analyses have been performed. In quartz crystals, mineral inclusions such as zircon, monazite and cobaltite are sometimes present. Only one inclusion (monazite) has been found in a K-feldspar crystal.

The heavy minerals are silt-size (up to about 60 μm but commonly below 40 μm). Among the ZTR minerals, zircon and rutile are the most abundant and up to 60 μm, while tourmaline is rare. In zircon crystals, inclusions can be present (albite).

Opaque minerals are represented by abundant chromite $(Mg_{0.5}Fe_{0.5})(Cr_{1.3}Al_{0.7})O_4$ and ilmenite. Among the transparent heavy minerals, rare apatite, garnet, epidote, tourmaline and one titanite crystal have been recognised. One of the most interesting observation is the presence of minute monazite crystals $(La_{0.5},Ce_{0.25},Nd_{0.2},Th_{0.05})PO_4$, less than 15 μm in size. Only SEM observations allowed to recognise such minerals.

The area of the Trieste Karst is surrounded by sandstone deposits (flysch) where the same heavy mineral assemblage can be recognised. It is supposed that, possibly, a river developed during an interglacial period. This river eroded the flysch formation and successively entered some caves filling them with this sandy material.

Most important is the fact that, by using SEM, we were able to recognise many heavy minerals smaller than 20 μm, not recognisable otherwise. This fact suggests the use of SEM to further explore the heavy mineral assemblage of siliciclastic deposits for better constrain them.

Limitations of detrital zircon provenance in the Amazon basin: River morphometry and statistical representativity

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Keywords: provenance, zircons, river morphometry.

The Amazon River is the largest fluvial system in terms of drainage area and water discharge. Its major tributaries flow from a diverse geological framework with distinctive source signatures; nevertheless, detrital zircon provenance has commonly proven ineffective in developing a satisfactory source-to-sink model. We believe there are two major factors that hinder a correct provenance interpretation: river morphometry and statistical representativity. To test these hypotheses, we present a new set of 24 detrital zircon geochronology samples (U-Pb dating by LA-ICP-MS) collected along the main river and close to the mouths of the major tributaries from the Upper Solimões down to the river mouth, which we compare with the extensive literature data.

The Amazon River has a morphological peculiarity, namely the extremely low slope along a large part of the river trunk (at the mouth of the Rio Negro, still 1500 km from the sea, the river level at low-water season is about 15 m, i.e. the gradient of the Lower Amazon is c. 1 cm/km). This suggests that the extensive flooding of the drainage may rework and erode previously overbanked sediments, with an upstream movement of sediment and a blurring/masking of the tributary fingerprint signal. In addition, zircon populations may differ as a result of analytical artefacts arising from laboratory procedures for grain selection and isotopic data reduction. For instance, the relative proportion of Andean Cenozoic grains is consistently underrepresented in a literature dataset despite near-identical sampling locations. The over- or under-representation of young or old age populations has been shown to be a mere statistical artefact.

With these premises in mind, we develop an updated provenance model by combining the datasets and comparing them with data from rivers in the Andean region, which drain smaller and more characteristic domains. We then apply this model to the previously published detrital zircon record from cores recovered in the deep-sea Amazon Fan during Ocean Drilling Program (ODP) Leg 155, exploring its implications for drainage evolution during the latest glacial-interglacial period.

The Amazon basin is a perfect example with which to warn the scientific community of the risk of blindly applying a source-to-sink model without thorough consideration of river morphometry and statistical representativity.

Sedimentary facies and depositional environment of the turbidites of the Sora area (Valle Roveto, central Apennines, Italy) in the context of the Latium-Abruzzi "turbidite complex"

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Keywords: sedimentary facies, turbidites, armoured clasts.

The turbidites of the Sora area belong to the so-called Latium-Abruzzi "turbidite complex". This comprises outcrops of deep-water clastic deposits that extend along a NW-SE band around 50 km wide and over 150 km long in the central Apennines, from the Salto Lake to the northern part of the Campania region. In the NW it outcrops widely, while the outcrops become more discontinuous to the SE, where they occur mostly within the Valle Latina (Sacco River valley) and Valle Roveto (upper Liri River valley). They are interpreted, respectively, as the Tortonian and Messinian fill of the NE-migrating foredeep related to the Apennine chain, with overall sediment transport direction from NW to SE.

As part of the research work in support of the geological mapping of the sheet 390 "Frosinone" which is currently ongoing, a review of the published literature and new sedimentological fieldwork were undertaken. A 7x4 km area on the left bank of the Liri River to the north and east of the town of Sora is characterised by discontinuous outcrops of turbidites with sedimentary facies which are distinctive when compared with those to the north-west along the Valle Roveto, to the south-east toward Atina, and to the south-west in the Valle Latina. The first unusual character is their grain size. Most of the Valle Latina and Val Roveto turbidites are characterised by fine- to medium- and rarely coarse-grained sandstones. However, in this area east of Sora, grain size is up to granules (2-4 mm), and the clasts are very angular and characterised by relatively high proportions of carbonates. Although architectural relationships are difficult to observe because of limited exposure, most of the coarser beds have erosive bases, often into an heterolithics thin-bedded substrate. These bed bases are often characterised by the presence of well-rounded cm-sized armoured mudstone clasts. The grains armouring the clasts are very angular and can be variable in size from coarse sand to granules. Additionally, very limited palaeocurrent indicators (primarily groove casts) suggest that palaeoflows are more complex than those observed in the Valle Latina and Valle Roveto, that are usually directed from NW toward the SE.

These observations suggest that the depositional environment of the turbidites east of Sora was characterised by the presence of a relatively proximal coarse-grained source of clastic sediment, a newly reported feature in the southern part of the Latium-Abruzzi "turbidite complex". The architecture was likely channelised, and this local depositional system appears to interfinger with the finer-grained sediment transported along the basin axis from the north. This study helps constrain the palaeogeography of this sector of the Apennine chain during its advancement, illustrating the key contribution that sedimentology, by studying the synorogenic clastic deposits, can provide to orogenic evolution models.

Ability of siliciclastic Gilbert-type deltas to encode tectonic signals

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Keywords: delta stratigraphy, Time Series Analysis, tectonic signal.

Numerical and physical models reproduce rapidly accumulating clastic deltas to investigate how, in a source-to-sink system, external forcing, such as tectonics and climate, survive the signal's degradation operated by autogenic processes, before to be recorded into a stratigraphic record. Here, we present the spectral analysis of time series of some environmental proxies, such as rock-magnetic properties and grain-size, of three Pleistocene clastic deltas. Specifically, we build age models and explore three diverse tectonic and climatic settings, located in Pennsylvania (USA), Utah (USA), and in NE Sicily (Italy). The study aims at understanding how tectonic activity could be translated into an environmental input strong enough to emerge from the attempts of the autogenic processes to shred the signal during the sediment production, transport, and final deposition.

We find that time series of proxies collected along short ($\sim 10^0$-10^1 m) deltas, sourced from a sub-glacial meltwater system, do not show any cyclicity, being dominated by autocorrelated noise and resulting from autogenic depositional mechanisms.

In contrast, longer time series of proxies collected from larger (10^1-10^2 m) deltas are structured under periodic signals rising above the statistical thresholds for autocorrelated/uncorrelated noises. Changes in frequency of spectral power data reflect a potential earthquake-induced environmental disturbance as confirmed by late Quaternary surface faulting offsetting the delta stratigraphy.

In active tectonic setting, we find that the power spectral analysis reveals a statistically robust peak in the anti-correlated noise realm, whose periodicity well matches the earthquakes recurrence time proposed for the region.

We finally propose a sediment production model consistent with periodic recruitment, transport, and deposition of magnetic minerals in response to alternating climate-forced and tectonically-triggered sediment inputs.

The case of Avisio River (Dolomiti, Italy): How the parent rocks lithology impacts the daughter Sediment grain size

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Keywords: sediment grain-size, sedimentary petrography, sediment generation.

Grain size of clastic sediments is commonly interpreted as the result of physical processes active during transport and deposition, such as hydraulic sorting and sediment bypass. In contrast, the role of parent rock lithology is often considered secondary. In this study, we investigate if and how the lithology of source rocks controls the grain-size distribution of daughter sediments directly at the source, through the combined analysis of parent rocks outcrops, corresponding detritus, and daughter sediments.

The study was conducted in a relatively small catchment area of the Avisio River in Valle di Fassa (Dolomites, Italy), covering 147.7 km² in planar view and 185.4 km² accounting for topography. The limited size of this basin allows us to minimize the influence of sediment transport, and to regard the analysed sediments as directly generated at the source. The catchment exposes three main lithological groups, all outcropping in similar proportions: (i) dolostones, (ii) mafic to intermediate volcanic rocks, and (iii) limestones and sandstones.

We used a multidisciplinary approach combining: (i) GIS-based geospatial analysis to quantify the distribution of source lithologies within the catchment, (ii) field-based characterization of outcrops through 3D modelling, fracture-spacing measurements, and Schmidt hammer testing to assess rock strength and weathering behaviour, (iii) grain-size analysis of detritus collected at the base of outcrops through image analysis and sieving, and (iv) compositional and grain-size analyses of sediments collected from a sandy-gravelly bar of the Avisio River. Sediment samples were analysed through pebble counts, petrographic analysis, sieving, and microscopic point counting, both as bulk material and as each of the individual grain-size fractions obtained.

The results obtained reveal a strong relationship between parent-rock lithology, weathering style, and daughter-sediment grain size. Dolostones are overrepresented in gravel fractions, whereas volcanics clasts dominate sandy fractions. This trend is consistent across the analysed grain-size classes: in particular, fractions coarser than 1 mm are enriched in dolostone grains, while finer fractions are predominantly volcanic. None of the analysed sediment samples reproduces the lithological proportions observed in the GIS-derived source-area geology.

These findings indicate that sediment grain size at the source is strongly controlled by lithology-dependent weathering and fragmentation processes. Therefore, different grain-size fractions preserve substantially different compositional "images" of the same source area. This has important implications for provenance studies and paleo-geological reconstructions, as well as for facies tract and sediment-routing models, challenging the assumption that grain-size variations in depositional systems are controlled exclusively by physical processes acting during transport and deposition.

High-resolution three-dimensional reconstruction of the Holocene coastal aquifer of the Emilia-Romagna coastal plain, northern Italy

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Keywords: 3D sequence stratigraphy, coastal aquifer, numerical groundwater modeling.

Coastal aquifers hosted in low-lying coastal plains represent strategic groundwater reservoirs in the shallow subsurface and are highly vulnerable to salinization processeses. High-resolution reconstructions of aquifer geometry and lateral continuity are therefore essential for assessing saltwater intrusion pathways and supporting sustainable groundwater management. This is particularly relevant in subsiding and artificially drained settings such as the Emilia-Romagna coastal plain (5,000 km²), where the general stratigraphic architecture of the Holocene costal aquifer has been extensively documented. The Holocene succession consists of a transgressive-regressive wedge in which barrier, beach-ridge, and delta-front sands form the main aquifer units, laterally interfingering with lagoonal, prodelta, and alluvial fine-grained deposits acting as aquitards. This stratigraphic complexity generates a highly heterogeneous aquifer system with marked lateral facies variability. To better constrain this heterogeneity, we developed a regional-scale 3D reconstruction of the phreatic coastal aquifer by integrating a large subsurface dataset including 283 continuous sediment cores, 532 CPT/CPTU profiles, and 46 water wells from the Regione Emilia-Romagna database. Stratigraphic correlation and interpretation were conducted based on sequence-stratigraphic concepts (Campo et al., 2020) to map transgressive and highstand sand bodies composing the aquifer system. Spatial coordinates (X, Y, Z) were systematically extracted to define the top and base of the aquifer-bearing sands and subsequently interpolated into a structural grid at 1x1 km regional scale. This spatial resolution is specifically designed to provides robust empirical constraints for numerical groundwater-flow and transport models (e.g., MedSWI), allowing realistic estimation of aquifer thickness, connectivity, and internal heterogeneity. By replacing generalized, automated thickness approximations with high-resolution stratigraphic surfaces, this approach can significantly improve the assessment of freshwater vulnerability and saltwater intrusion in complex coastal settings.

Campo B. (2020) - Late Quaternary sequence stratigraphy as a tool for groundwater exploration: lessons from the Po River Basin (northern Italy). AAPG Bulletin, 104(3), 681-710.

A new conceptual model to improve the geological interpretation of detrital zircon datasets through the integration of U-Pb and Raman analyses

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Keywords: detrital zircon geochronology, alpha damage, Adamello.

We present a simple conceptual model to improve geological interpretations of detrital zircon datasets through the integration of U-Pb and Raman analyses. The model compares alpha damage predicted from U-Pb data with actual damage resulting from damage accumulation and (partial) annealing measured by Raman spectroscopy. Previous studies have primarily focused on calibrating a zircon Raman geochronometer based on the analysis of standard crystals that exhibit a well-defined geological history of continuous damage accumulation and little or no annealing after crystallization (e.g., Härtel et al., 2021). In contrast, zircon crystals affected by annealing events have received less attention (e.g., Resentini et al., 2020). However, due to its high resistance and durability, zircon can typically survive multiple sedimentary and metamorphic cycles, and zircons that have undergone reheating and annealing after crystallization are by far the most prevalent in the sedimentary record.

We tested our model by analyzing bedrock zircon grains of the Cenozoic Adamello composite batholith, a natural laboratory where the progressive emplacement of successive, radiometrically dated magmatic bodies has thermally influenced both the metamorphic country rocks and the previously emplaced igneous rocks under well-constrained geological conditions. Our results on bedrock zircon were then exported to a synthetic detrital zircon population to test how the impact of reheating can be detected in detrital zircon datasets. We found that the application of our model allows increasing the resolution of provenance discrimination to a level approaching the information inferred from bedrock data. This suggests that an approach to detrital zircon geochronology complementing detrital U-Pb ages with Raman spectroscopy could be routinely used to improve sediment provenance analysis in the lack of independent geological constraints, opening new perspectives for detrital provenance studies.

Härtel B. et al. (2021) - Zircon Raman dating: Age equation and calibration. Chem. Geol., 579, 120351, https://doi.org/10.1016/j.chemgeo.2021.120351.

Resentini A. et al. (2020) - Zircon as a provenance tracer: Coupling Raman spectroscopy and UPb geochronology in source-to-sink studies. Chem. Geol., 555, 119828, https://doi.org/10.1016/j.chemgeo.2020.119828.

Magnetic fabric constraints on paleoflow direction and deformation in a hadal trench-fill basin of the Japan Trench

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Keywords: hadal trench-fill basin, magnetic fabric, IODP3 Exp. 503.

Hadal trench basins act as final depositional sinks for sediments transported by gravity flows in active subduction margins. The resulting sedimentary sequences represent a valuable archive of earthquake-triggered event deposits and deformation related to tsunamigenic coseismic slip propagation to the trench (STT events). Thus, these basins offer a unique record of the long-term history of megathrust earthquakes in subduction zones.

International Ocean Drilling Programme (IODP[3]) Expedition 503 targeted a trench-fill basin of the central Japan Trench at Site C0028. The recovered continuous (178 m thick) stratigraphic sequence includes the full trench-fill succession and a portion of the underlying sedimentary cover of the incoming Pacific Plate.

In this context, magnetic fabric analysis has been widely used to characterize the depositional processes and internal deformation of different types of event deposits, such as slumps, turbidity currents, and mass transport deposits. Here, we combine anisotropy of magnetic susceptibility (AMS) with sedimentological and structural measurements to (i) characterize paleoflow directions/provenance of event deposits, and (ii) indentify deformed intervals throughout the trench-fill and underlying incoming plate sediment.

Magnetic fabric analysis from the trench-fill reveals a dominant sub-horizontal to slightly dipping (~30°) magnetic foliation and a mainly oblate fabric (0 30°) of the magnetic foliation and lineation, marking internal variations in flow process, shearing and soft-sediment deformation within individual events. These signatures may therefore represent evidence for disruption of the primary sedimentary texture by STT events.

Our findings highlight the potential of this magnetic fabric dataset to characterize changes in depositional environments, paleoflow dynamics, and deformation processes associated with long-term megathrust earthquake activity in the Japan Trench.

Depositional history of the Permian-Triassic clastic systems of the Baztan area (Navarra, N Spain): multi-scale characterization at the transition between the Western Pyrenees and the Cantabrian Mountains

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Keywords: Baztán Basin, tectono-sedimentary evolution, clastic systems.

The Baztán area (Navarra, N Spain), situated at the transition between the Western Pyrenees and the Cantabrian Mountains, represents a crucial sector for deciphering the tectono-stratigraphic relationships between these two major orogenic systems. This study presents a multi-scale characterization of clastic systems, integrating detailed stratigraphic logging and high-resolution sedimentological analysis with clay mineralogy (XRD), structural fieldwork, and UAV-derived Digital Outcrop Models (DOMs). Through the analysis of eight stratigraphic sections, we provide a comprehensive facies description and define three Permian (P1, P2, P3) and three Triassic (T1, T2, T3) tectono-sedimentary units, bounded by regional unconformities.

The sedimentary facies characterization of the Permian succession reveals the direct expression of Variscan heritage, related to the first three Alpine tectonic pulses (I, II, III). Initial stages (P1-P2) are dominated by high-energy debris-flow deposits, breccias, and lacustrine facies within narrow, fault-controlled troughs. The stratigraphic architecture shows a clear evolutionary trend from proximal alluvial fan systems to braided fluvial networks (P3), the latter being uniquely characterized by syn-sedimentary volcanic activity. This evolution of lithofacies associations, supported by pollen assemblages in the upper units, reflects the progressive infilling of the basins and the expansion of fluvial drainage, controlled by the interplay between syn-sedimentary tectonics and increasing climatic aridification.

The Triassic succession (T1-T3), associated with the fourth tectonic pulse (IV), marks the shift to Alpine dynamics, with a facies architecture that transitions from basal clastics to marl-dominated sequences. The integrated stratigraphic and sedimentological record consistently points to strong affinities with the central-eastern Pyrenean domain (Aragonese-Catalan Pyrenees) rather than the Cantabrian Range. By defining these depositional models and facies belts, this study redefines the Baztán area as the westernmost expression of the Pyrenean Permo-Triassic system, providing a key reference for reconstructing the lateral continuity and structural evolution of both orogenic belts.

A new turbidite facies-tract scheme including supercritical, hydraulic jump and hybrid-slurry facies: interactions between basin morphology and criticality

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Keywords: turbidites, supercritical flows, basin morphology.

The rationale behind this work is to discuss the recent turbidite facies-tract scheme by Tinterri (2025) that puts strong emphasis on the relationship between basin geometry and criticality. This scheme has also prompted a revisiting of the concept of efficiency, emphasizing the key role of the tectonically controlled basin morphology on the flow processes, highlighting how the basin shape (favouring or hindering flow evolution) can control the facies-tract type, which, in turn, may become diagnostic of a well-determined basin type and physiography.

The studies carried out in the last twenty years on turbidite deposits in tectonically controlled foredeep basins have indeed shown that any basin modification due to the tectonics is always associated with a concomitant modification in the type of facies tract and that there are various types of beds (such as hybrid-slurry beds and contained-reflected beds) that are strictly related to the basin's morphology. Likewise, the studies carried out on turbidite deposits in confined and narrowed foredeeps and wedge-top basins have shown that, in these strata, sedimentary structures indicating supercritical flows and their transformation into subcritical flows, through possible hydraulic jumps, are quite common.

In particular, in these settings, supercritical flows tend to be favoured by lateral confinements parallel to the paleocurrents, while flow decelerations and hydraulic jumps are favoured by morphologies transversal to paleocurrents. These transverse physiographies can be slope breaks or adverse slopes varying in scale from regional tectonic structures to depositional features such as thick mass-transport complexes and lobes.

Furthermore, the growing knowledge of supercritical flow processes and structures that has been gained over the last fifteen years supports this evidence clearly showing that supercritical conditions can be much more common in density-stratified flows than in open- channel currents thanks to the effects of the reduced gravity characterizing the densimetric Froude number. For these reasons, upper flow regime structures must be more common in the geological record than previously thought, making these structures in turbidites the rule rather than the exception.

In conclusion, new and classical outcrop studies in foreland basins, together with growing information from the literature, are brought forward as evidence of the need for a new facies-tract scheme that includes depositional modes produced by decelerating, supercritical turbidity currents and other important processes, such as transitional sand-mud and contained-reflected flows. The facies tract scheme discussed in this work aims to link all these matters, which are particularly relevant for tectonically controlled basin configurations and vice versa.

Tinterri R. (2025) - A new turbidite facies-tract scheme including supercritical and transitional sand-mud flows: an outcrop perspective from Mediterranean-type foreland basins. Journal of Sedimentary Research, 95, 239-272.

Sedimentary dynamics during the Carnian Pluvial Episode: new insights from the southern Dolomites and Carnia (Southern Alps)

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Keywords: Carnian Pluvial Episode, sequence stratigraphy, mixed carbonate-siliciclastic systems.

The Carnian age (Late Triassic) was globally affected by an episode of climate change known as Carnian Pluvial Episode (CPE), which consisted of multiple climatic perturbations occurring in a relatively short time span. These events partially overlapped with major eustatic sea-level variations, with intermixing effects on sedimentation.

The Southern Alps succession records both climatic and eustatic sea-level changes within a complex depositional system composed of carbonate and siliciclastic deposits. Most studies have focused on the central-northern Dolomites and Julian Alps, while the southern connection with the hinterland remains poorly studied. To fill this gap, localities from the southern Dolomites and Carnia were selected and analysed with a multi-disciplinary approach.

Detailed stratigraphic and sedimentological analyses allowed to infer the depositional environments and their evolution in space and time: several key marker horizons were identified, and multiple siliciclastic intervals were classified. Stacking patterns analysis allowed to the reconstruction of the sequence stratigraphic architecture and to establish long-distance correlations, compensating the paucity of biostratigraphic data.

Deltaic and fluvial depositional systems linked to a relatively proximal terrigenous shoreline were identified, which influenced the typical sedimentary dynamics of the CPE within carbonate and mixed depositional settings, resulting in a stratigraphic and sedimentological complexity that warrants further investigations. To better understand the factors controlling sedimentation, petrographic analyses and investigations of local subsidence rates are currently underway.

Quantifying fluvial bar geometry using 3D Digital Outcrop Models: a case study from the Eocene Tremp-Graus Basin, Southern Pyrenees

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Keywords: fluvial sedimentology, Tremp-Graus Basin, 3D modelling.

Constraining the three-dimensional architecture and planform configuration of fluvial bars is fundamental to predicting the internal organization and heterogeneity of channel-belt deposits and, at a larger scale, to understanding how fluvial architecture evolves along a depositional system. Despite their significance for paleoenvironmental reconstruction and subsurface analogue modelling, quantitative datasets documenting how bar architecture and dimensions vary downstream remain scarce in the geological record, both because complete proximal-to-distal successions are rarely exposed continuously and because two-dimensional outcrop sections fail to fully characterize three-dimensional sedimentary bodies (Gibling, 2006; Cabello et al., 2018).

Three-dimensional digital outcrop models, integrated with field-based observations, provide a powerful alternative by allowing the geometry and spatial organization of fluvial bars and channel-fill deposits to be analyzed quantitatively where laterally extensive outcrop exposures are preserved. This approach is applied to the fluvial successions of the Eocene Tremp-Graus Basin (Southern Pyrenees, Spain), which offers an ideal setting for this type of study, as it preserves a near-continuous and well-exposed proximal-to-distal fluvial succession (Puigdefabregas & Van Vliet, 1978; Chanvry et al., 2018). The studied outcrops, located toward the proximal part of the system, retain primary sedimentary structures and bar geometries sufficiently intact to serve as reliable indicators of changes in past depositional processes and sediment transport (Cabello et al., 2018; Chanvry et al., 2018).

Variations in bar width-to-thickness ratios, internal stacking patterns, and planform geometries are compared across outcrops spanning more proximal to relatively distal settings, allowing downstream changes in flow conditions, sediment transport, and accommodation space to be reconstructed and documented along the fluvial system. By expanding the quantitative datasets of fluvial bar geometries documented in the Tremp-Graus Basin (Cabello et al., 2018), this study contributes to a more comprehensive understanding of how fluvial architecture responds to changes in depositional setting.

Cabello P. et al. (2018) - From conventional outcrop datasets and digital outcrop models to flow simulation in the Pont de Montanyana point-bar deposits (Ypresian, Southern Pyrenees). Marine and Petroleum Geology, 94, 19-42, https://doi.org/10.1016/j.marpetgeo.2018.03.040.

Chanvry E. et al. (2018) - The influence of intrabasinal tectonics in the stratigraphic evolution of piggyback basin fills: Towards a model from the Tremp-Graus-Ainsa Basin (South-Pyrenean Zone, Spain). Sedimentary Geology, 377, 34-62, https://doi.org/10.1016/j.sedgeo.2018.09.007.

Gibling M.R. (2006) - Width and thickness of fluvial channel bodies and valley fills in the geological record: a literature compilation and classification. Journal of Sedimentary Research, 76(5), 731-770, https://doi.org/10.2110/jsr.2006.060.

Puigdefabregas C. & Van Vliet A. (1977) - Meandering stream deposits from the Tertiary of the southern Pyrenees. In: Miall, A.D. (ed.), Fluvial Sedimentology. Canadian Society of Petroleum Geologists Memoir, 5, 469-485.

Detrital zircon geochronology constraining the fingerprint of the Tuscan metamorphic unit in the Monticiano-Roccastrada Ridge (southern Tuscany)

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Keywords: UPb dating, provenance, Paleozoic.

The meta-sedimentary rocks of the Tuscan metamorphic unit preserve a detrital record of sediment routing, basin evolution, and long-term interactions between tectonics and surface processes along the western margin of the Adria Plate during the Paleozoic and Mesozoic. These successions were deposited unconformably onto a pre-Variscan basement and were subsequently involved in Alpine deformation during the Cenozoic, obscuring the original stratigraphic relationships. Nevertheless, the predominance of greenschist-facies metamorphism, with only localized high-pressure conditions, allows the preservation of primary sedimentary facies and mineralogical signatures that retain information on sediment sources, transport pathways, and depositional environments.

In the Monticiano-Roccastrada Ridge (southern Tuscany), the stratigraphic succession records middle-late Paleozoic to early Mesozoic deposition across a range of tectono-sedimentary settings, from deep-marine basins to continental alluvial systems. This variability reflects spatial and temporal changes in subsidence, sediment supply, and accommodation linked to tectonic activity along the northern Gondwana active margin. However, the age and architecture of the lower part of the succession remain debated, mainly due to limited exposure and discontinuous stratigraphic contacts.

Within the framework of the CARG geological mapping project (Foglio 307, Roccastrada), we integrate detailed field mapping, petrographic analysis, and detrital zircon U-Pb geochronology to reassess stratigraphic correlations and provenance patterns. Results from these meta-sedimentary units contribute to a refined reconstruction of the paleogeographic and tectonic evolution of the northern Gondwana margin, a key but poorly preserved segment of the Mediterranean geological record.

S13.

Deformation processes and seismicity in active orogenic belts: Multi-scale, multi-temporal, and interdisciplinary insights

CONVENERS & CHAIRPERSONS:

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Imaging fluid-controlled crustal heterogeneity in an active orogen: seismic attenuation and scattering tomography across the Calabrian Arc boundaries

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Keywords: seismic attenuation and scattering, fluid circulation, crustal deformation.

Seismic attenuation tomography represents a powerful tool to investigate the physical properties of the crust and to identify heterogeneities related to fluid circulation, lithology, and active deformation processes in orogenic belts. In this study, we present a regional-scale analysis of seismic attenuation and scattering across the Southern Apennines-Northern Calabria boundary and the north-eastern Sicilian region (southern Italy), aiming to provide a multi-scale perspective on crustal deformation and fluid-controlled processes.

Frequency-dependent attenuation patterns are analyzed using earthquake waveforms to derive spatial variations in seismic energy dissipation and Peak Delay. These parameters are interpreted in terms of fracture connectivity, fluid saturation, and structural complexity, following the theoretical framework of coda-wave attenuation and scattering (Aki & Chouet, 1975). By integrating attenuation and scattering observations, we aim to bridge short-term seismic wave propagation properties with long-term tectonic and geological structures.

Results from the Southern Apennines-Northern Calabria boundary reveal contrasting attenuation regimes reflecting distinct crustal domains. The Southern Apennines are characterized by relatively high Peak Delay values and limited attenuation anomalies, consistent with highly fractured and weakly consolidated sedimentary sequences with limited effective fluid circulation. In contrast, Northern Calabria exhibits low Peak Delay and high attenuation values, suggesting wave propagation through more coherent crystalline rocks affected by active fluid circulation, possibly associated with overpressurized systems or permeable structural pathways.

The observed decoupling between scattering and intrinsic attenuation highlights significant crustal heterogeneity separating geodynamically distinct sectors of the orogen. The spatial correlation between attenuation anomalies, low seismic velocities, and thermal signatures further emphasizes the role of fluids in controlling seismic wave attenuation and modulating crustal deformation. Ongoing analyses in north-eastern Sicily, at the southern edge of the Ionian subducting slab, aim to extend this framework and evaluate similarities and differences across multiple segments of the system, contributing to a broader understanding of deformation processes and seismotectonic segmentation in the study area.

Aki K. & Chouet B. (1975) - Origin of coda waves: source, attenuation, and scattering effects. J. Geophys. Res., 80 (23), 3322-3342, https://doi.org/10.1029/JB080i023p03322.

Along-strike rheological segmentation and stress partitioning in the Irpinia fault system: insights from microseismicity, attenuation, and structural geology

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Keywords: fault segmentation, seismic attenuation, crustal heterogeneity.

Fault segmentation strongly influences earthquake rupture propagation, yet the physical controls governing along-strike variability within active fault systems remain poorly constrained. In this work, we investigate the Irpinia fault system (Southern Apennines, Italy), responsible for the 1980 Mw 6.9 Irpinia earthquake, integrating seismic attenuation, elastic properties, stress inversion, focal mechanisms, and repeating-earthquake analyses within a common along-strike framework.

Recent microseismicity studies progressively revealed systematic differences between the Cervialto and Marzano sectors in terms of seismic clustering, source properties, focal mechanism variability, and fault-network complexity. We complement these observations with new attenuation and stress-field analyses derived from ~6,300 microearthquakes recorded between 2007 and 2025. Peak delay (PD) and coda attenuation (Qc^{-1}) reveal persistent lateral contrasts across the Senerchia Fault (SF), a ~N-S striking normal fault that marks the boundary between the Monte Cervialto and Monte Marzano segments of the Irpinia fault, to the north and south, respectively. The fault separates a northwestern low-scattering, mechanically coherent crustal domain from a southeastern heterogeneous and highly dissipative crustal volume.

These attenuation patterns spatially correlate with previously observed Vp/Vs contrasts, variations in repeater occurrence, Bouguer anomaly gradients, and changes in the geometry of the Apulia Carbonate Platform. Stress inversion results additionally reveal subtle but systematic variations in stress tensor geometry and stress ratio across SF, suggesting local stress partitioning within an otherwise coherent regional extensional regime.

Our results indicate that SF represents more than a geometric discontinuity within the Irpinia fault system. Instead, it acts as a first-order crustal boundary separating mechanically distinct domains characterized by different fault coupling, structural organization, and attenuation properties. The observed segmentation likely reflects inherited crustal architecture and may influence stress accumulation, rupture propagation, and seismic behaviour along strike.

Multi-segment faulting and seismic potential in the Central Apennines: insights from physics-based, geologically-constrained earthquake simulations

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Keywords: multi-segment rupture simulation, long-term synthetic seismic catalog, 2016-2017 Central Italy seismic sequence.

The Central Apennines represent one of the most significant areas in Italy from a seismotectonic perspective and have been the focus of numerous geological, seismological, and numerical modeling studies. This region, belonging to the Italian extensional province, has experienced several moderate-to-high magnitude seismic sequences associated with normal faulting, including the 1997 Colfiorito (Mw 6.0), 2009 L'Aquila (Mw 6.1), and 2016 Central Italy (Mw 6.5) earthquakes.

Despite the wide availability of geological and paleoseismological data, as well as the documentation of numerous historical events (CPTI15; Rovida et al., 2022), which have helped define the main deformational characteristics and the seismic hazard framework of the area, uncertainties still persist regarding the seismic potential of active faults, particularly in terms of maximum expected magnitude.

For this reason, it is essential to investigate multi-segment seismicity, i.e., the ability of a seismic rupture to propagate across multiple fault segments, even if geometrically separated, resulting in longer rupture lengths and thus higher-magnitude events.

The presence of a complex pattern of surface faults, together with structural complexities such as gaps and step-overs, can help assess the likelihood of rupture propagation between different segments, allowing the estimation of both the probability and recurrence times of high-energy events.

Starting from the fault geometries available in the QUIN database (Lavecchia et al., 2022), we reconstructed three-dimensional models, which were subsequently tested using the physics-based multi-cycle earthquake simulator MSQsim (Zielke & Mai, 2023). The simulator was specifically implemented to reproduce non-planar and geometrically complex fault architectures, thereby providing a more realistic representation of fault systems constrained by geological and seismological data. This approach enables the generation of long-term synthetic earthquake catalogs that account for intricate fault geometries and the occurrence of multi-segment rupture events. In particular, we considered several segmentation pattern scenarios and different elements of structural interconnection, both at the surface and at depth.

The results show that synthetic earthquake catalogs derived from complex and articulated fault geometries, which more faithfully reproduce natural heterogeneities, are more consistent with observations of recent seismicity, including the earthquake magnitude-frequency distribution. This study highlights the importance of a more comprehensive understanding of surface structural geology and emphasizes the need for detailed mapping of active faults and their structural complexities in order to better constrain seismic potential.

Lavecchia G. et al. (2022) - QUaternary fault strain INdicators database - QUIN 1.0 - first release from the Apennines of central Italy. Sci. Data, 9, 204.

Rovida A. et al. (2022) - Catalogo Parametrico dei Terremoti Italiani (CPTI15), versione 4.0 [Data set]. Istituto Nazionale di Geofisica e Vulcanologia (INGV).

Zielke O. & Mai P.M. (2023) - MSQSim: a Multicycle Earthquake Simulator. Bull. Seism. Soc. Am., 75, 939-964.

From tectonic inversion to subduction initiation: Seismic and geodetic constraints on the nascent Africa-Eurasia boundary in the western Mediterranean

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Keywords: Africa-Eurasia convergence, geodesy and seismicity, tectonic inversion.

In the western Mediterranean, progressive continent-continent collision between the Africa (AF) and Eurasia (EU) plates has led to the near-cessation of Tethyan subduction across large sectors of the convergent margin. As a result, AF-EU-related compressional deformation has progressively migrated toward the southern passive margins of the Mediterranean back-arc basins (Tyrrhenian, Liguro-Provençal, Algerian, and Alboran), driving a diachronous tectonic inversion that propagated from west to east, initiating at ~8 Ma in the western basins and at ~2 Ma in the Tyrrhenian.

We present a reconstruction of the nascent AF-EU plate boundary based on earthquake focal mechanisms and GNSS velocities (ITRF14 reference frame), integrated with pre-existing structural and tectonic data, along a transect spanning from the eastern Ionian Sea to the Gulf of Cadiz. The boundary is geometrically irregular and sinuous, reflecting the pervasive reactivation of inherited structures with variable kinematics. Assuming future northward tectonic vergence toward the Eurasian foreland, we identified a series of salients (Tyrrhenian, Algerian, and Betic), recesses (Oran and Fès), and strike-slip transfer zones (Ionian, Trans-Alboran, and Gibraltar) articulating the boundary along strike.

A systematic discrepancy between the far-field AF-EU motion and the local contractional directions inferred from seismic and geodetic data is documented throughout the boundary, and is interpreted as reflecting the dominant mechanical control of inherited weak structures at this immature stage of subduction initiation. Among all boundary segments, the Algerian offshore sector exhibits the highest seismicity rates and the most consistent present-day northward vergence, supporting its role as the likeliest locus of incipient subduction nucleation in the western Mediterranean. However, the region-wide average convergence rate (~5 mm/yr) currently appears insufficient to sustain the transition toward a fully mature subduction system. These findings offer new constraints on the early-stage evolution of convergent plate boundaries and bear broader implications for deciphering the structural inheritance and long-term geodynamic trajectory of the western Mediterranean.

Anisotropic and isotropic pore fluid diffusion and spatio-temporal evolution of 2009-2016 Central Italy seismic sequences

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Keywords: seismic sequences, pore fluid pressure diffusion, Central Apennines.

The processes governing the spatio-temporal evolution of seismic sequences are actively investigated. In particular, three main triggering mechanisms are believed to govern this evolution: static, dynamic and pore fluid pressure diffusion triggering. In the North-Central Apennines, overpressurized fluids are present at seismogenic depths and several authors have investigated whether pore fluid pressure diffusion is related to the two major seismic sequences that struck Central Italy: the 2009 L'Aquila (AQ) sequence and the 2016-2017 Amatrice-Visso-Norcia (AVN) sequence. Here, we extend previous studies (e.g., Malagnini et al., 2012; Peter, 2024) by modelling the isotropic/anisotropic seismic diffusivity (Antonioli et al., 2005) and the centroid migration pattern (Baccheschi et al., 2020) to investigate the relation between the seismicity evolution, the geological setting and the active fault geometry. To do that, we benefit from the most recent three high-precision location seismic catalogues.

The 2009 AQ and the 2016-2017 AVN sequences show a contrasting behaviour. Both sequences result in high values of isotropic seismic diffusivity but respond differently when anisotropic diffusion is considered. The 2009 AQ seismicity shows a general isotropic diffusion pattern, while the AVN shows a strongly anisotropic diffusion. Maximum seismic diffusion is generally aligned with the main Apennine trend (NW-SE), along the principal active fault systems. In some cases, however, seismicity occurs along the orthogonal NE-SW direction, suggesting a possible role for the so-called "anti-Apennine" structures, usually considered of secondary importance for seismicity. Centroid migration also highlights marked differences between the two sequences. During the foreshock phase of the 2009 AQ sequence, seismic activity migrated progressively through space, while during the aftershock phase of the same 2009 AQ sequence and throughout the 2016-2017 AVN sequence, seismicity propagated more abruptly and rapidly. Additionally, most aftershock sequences show poor fits to fluid diffusion models, with isotropic and anisotropic permeabilities several orders of magnitude greater than typical fault rock permeabilities.

This work provides a direct comparison between the two seismic sequences, applying for the first time anisotropic diffusion models to the 2009 AQ sequence, and centroid migration analysis to the 2016-2017 AVN sequence. These combined approaches offer new insights into the complexity of earthquake triggering mechanisms in Central Italy. In particular, the analysis presented in this work suggests that fluid diffusion, if present, played a secondary role compared to static and dynamic stress transfer processes in the propagation of aftershocks.

Antonioli A. et al. (2005) - Fluid flow and seismicity pattern: Evidence from the 1997 Umbria-Marche (central Italy) seismic sequence. Geophysical Research Letters, 32(10), 2004GL022256, https://doi.org/10.1029/2004GL022256.

Baccheschi P. et al. (2020) - The preparatory phase of the Mw 6.1 2009 L'Aquila (Italy) normal faulting earthquake traced by foreshock time-lapse tomography. Geology, 48(1), 49-55, https://doi.org/10.1130/G46618.

Malagnini L. et al. (2012) - Control of pore fluid pressure diffusion on fault failure mode: Insights from the 2009 L'Aquila seismic sequence. Journal of Geophysical Research: Solid Earth, 117(B5), 2011JB008911, https://doi.org/10.1029/2011JB008911.

Peter R.R. (2024) - Seismic Sequences Possibly Related to Fluid Diffusion: Amatrice-Norcia 2016 sequence, Italy. Università degli Studi di Padova. Master's thesis.

Multi-parameter seismic attenuation tomography of the Calabrian Arc: Insights into crustal heterogeneity and active deformation in a complex orogenic belt

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Keywords: seismic attenuation, Calabrian Arc, active deformation.

Active orogenic belts are shaped by the interaction between inherited lithospheric structures, ongoing crustal deformation, and present-day seismicity. In this context, seismic attenuation imaging provides valuable constraints on the physical state of the crust, as it is sensitive to heterogeneity, fracturing, fluid circulation, and variations in seismic wave propagation. The Calabrian Arc, in Southern Italy, represents a complex and seismically active sector of the central Mediterranean orogenic system, making it a key region for investigating the relationships between crustal structure, deformation processes, and seismic hazard.

Here, we present results from 3D multi-parameter seismic attenuation tomography of the Calabrian crust using the MuRAT framework, including methodological developments implemented in MuRAT4. The study is based on a relocated local-earthquake dataset of approximately 490 events recorded between 2015 and 2024 by local and national seismic networks. The dataset includes three-component waveforms recorded by 108 seismic stations, combining the UNICAL local network and the INGV national seismic network. Event selection was designed to improve spatial and depth coverage while reducing clustering effects. P- and S-wave arrivals were manually picked, and earthquakes were relocated to obtain a robust dataset suitable for attenuation imaging.

MuRAT characterizes seismic energy loss through complementary parameters derived from different portions of the seismic waveform: Peak Delay, mainly sensitive to scattering, and the quality factors Q and Qc, related to total and coda attenuation, respectively (De Siena et al., 2014). These parameters were estimated at multiple frequencies to investigate the frequency dependence of attenuation processes and to identify the most consistent tomographic patterns.

The attenuation images show coherent lateral variations across the Calabrian Arc, with marked contrasts between onshore and offshore sectors. Peak Delay maps highlight spatially variable scattering, with stronger anomalies mainly observed in the central-southern sector of the Calabrian Arc and along the Ionian offshore margin. Q and Qc models show significant variations in seismic energy dissipation across the study area, with anomalies located near major structural transitions, particularly along the offshore margins and across the transition between the Calabrian crust and adjacent offshore domains. Overall, these results indicate that attenuation tomography can provide independent constraints on the physical properties of the crust and contribute to the interpretation of active deformation processes. By integrating attenuation models with geological and seismotectonic information, including the distribution of present-day seismicity and the main crustal structures, this study provides a framework for refining the interpretation of fault-related processes, crustal heterogeneity, and seismic behaviour in the Calabrian Arc.

De Siena L. et al. (2014) - Seismic energy envelopes in volcanic media: towards quantitative scattering and absorption imaging. Phys. Earth Planet. Inter., 230, 9-20, https://doi.org/10.1016/j.pepi.2014.01.001.

Empirical synthesis of coda wave from correlation of ambient seismic noise

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Keywords: seismic noise, polarization analysis, ambient noise correlation.

The reconstruction of Green's functions through ambient seismic noise correlation is nowadays widely employed for the extraction of ballistic waves. However, it remains less clear how well coda waves are reconstructed, despite the fact that this part of the signal is extensively used for monitoring velocity changes in the Earth's crust. A full understanding of the propagation regime(s) governing this portion of the signal is essential for the application of appropriate kernels in the spatial inversion of velocity changes and thus for resolving key geophysical processes occurring within the crust, such as those preceding large earthquakes.

We investigate this topic by analysing seismic noise correlations at a single broadband station in the L'Aquila area, integrating multiband ambient noise processing with polarization and time-frequency analysis. This study is based on the three-component noise cross-correlation functions computed in a single-station configuration.

Two frequency bands (0.5-1 Hz and 1-3 Hz) are examined, and the robustness of the results is evaluated through multiple random stacking realizations. Cross-correlation functions are stacked and analysed using a sliding-window approach, allowing the temporal evolution of wavefield properties to be tracked within a consistent framework.

Within each time window, a covariance matrix of the three components is constructed and decomposed into eigenvalues and eigenvectors. From this decomposition, polarization parameters are derived, including rectilinearity, ellipticity, planarity, azimuth and incidence angle. These parameters describe the evolving geometry of the reconstructed wavefield and provide insights into directional and kinematic variations of the seismic noise field.

Additional observables, such as H/V spectral ratios and component energy distributions, are computed within the same time-frequency framework to complement the polarization analysis and improve constraints on signal variability. Particle motion is further characterised through hodogram analysis in selected windows with high rectilinearity, while azimuthal distributions are summarised using weighted rose diagrams.

3D characterization of crustal physical properties in the Montello-Collalto area (eastern Southern Alps, Italy) using laboratory-derived seismic velocities

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Keywords: 3D geological model, 3D velocity model, samples velocity measurements.

Seismic velocity models derived from earthquake arrival-time data are characterized by spatially variable resolution depending on several factors related to the seismic network coverage and the parameters adopted in the inversion. However, the use of these velocity modeling approaches can lead to a loss of resolution in the shallow depths that can significantly affect the accuracy of the earthquake's location. In this work, we focus on the Montello area, aiming to integrate laboratory rock-physics measurements, geological modelling, and earthquake-location analysis by developing a geologically constrained 3D seismic velocity model.

The Montello-Collalto sector is located along the external front of the eastern Southern Alps (Italy), within a fold-and-thrust belt active since the Middle Miocene (Picotti et al., 2022). The area is characterized by moderate-to-high seismic hazard (e.g. 1695 Asolo event, Mw 6.5). Nevertheless, the geometry and activity of the main seismogenic structures remain debated because of the sediment cover and the present-day low seismicity. The presence of an Underground Gas Storage (UGS) located at 1.5 km depth within the Montello anticline, seismically monitored by the National Institute of Oceanography and Applied Geophysics - OGS (Priolo et al.,2015), provides an additional motivation for improving the local velocity model, since accurate earthquake locations are crucial for both seismotectonic investigations and UGS seismic monitoring.

We developed a new velocity model designed to better constrain the shallow crustal layers by integrating laboratory measurements performed on rock samples representative of the local stratigraphic sequence.

Specifically, 22 samples were collected during fieldwork in the study area and subsequently analysed at ETH Zürich. P- and S-wave velocities were measured using the pulse-transmission method under varying confining pressures, during both loading and unloading phases, from 5 to 200 MPa. The laboratory-derived velocity values were scaled to better represent the lithological volumes and then implemented within a dedicated 3D geological model of the study area based on Picotti et al. (2022) interpretation. This approach provides a detailed and physically constrained characterization of seismic velocities in the upper ~10 km of the crust, corresponding to the depth range most relevant for investigating the earthquake distribution close to the UGS operations and the Montello thrust system.

The newly developed 3D velocity model will be validated through the generation of synthetic seismograms and the subsequent relocation of seismic events. Ultimately, the model may be exported and integrated into other geological and seismological modelling workflows, contributing to the refinement of the current geological interpretation of the area and to a better understanding of the seismic behaviour of the main potentially seismogenic structures.

Picotti V. et al. (2022) - The Montello thrust and the active mountain front of the eastern Southern Alps (northeast Italy), Tectonics, 41, e2022TC007522, https://doi.org/10.1029/2022TC007522.

Priolo E. et al. (2015) - Seismic Monitoring of an Underground Natural Gas Storage Facility: The Collalto Seismic Network. Seismol. Res. Lett., 86(1), 109-123, https://doi.org/10.1785/0220140087.

Kinematic evolution of the Kefalonia transform fault zone in response to subduction margin dynamics: comparison between analogue modelling and field observations

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Keywords: active faulting, subduction, analogue modelling.

The Central Mediterranean is a great natural laboratory for many processes related to subduction. Along the Dinaric-Hellenic margin, the rigid Adria microplate indents the Eastern Alps and Dinarides in the north, while the southern part subducts beneath the advancing Hellenides. In between, the Kefalonia Transform Fault System (KTFS) marks the current position of this unique transition between subduction of more buoyant continental lithosphere in the Albanides and less buoyant oceanic lithosphere along the Hellenic subduction system. The resulting differential convergence along the Ocean-Continent Transition (OCT) is thought to have caused vertical tearing or bending of the subducting slab, and the KTFS is considered to be the surface expression of the early-stage propagation of a vertical slab tear from the subducting lithosphere to the overriding plate. However, the existence of a slab tear is debated, and the poorly constrained structural evolution of the KTFS prevents to understand how the upper plate accommodates deformation above the OCT.

In order to constrain the kinematic evolution of the KTFS its relation to the subducting OCT, we investigated the mechanisms underlying the dynamic formation of a vertical slab tear using onshore field observations, structural analysis, and analogue modelling.

From structural analysis, we find that the KTFS developed as a right-lateral transpressional system characterised by strain partitioning into thrusting and strike-slip faulting since at least the late Pliocene. As the margin along the KTFS progressively rotated clockwise due to differential convergence rates, the margin-normal component of deformation, accommodated by thrusts, decreased, while shear strain, accommodated by strike-slip faulting, increased. This ongoing strain partitioning is supported by focal mechanisms and offshore seismic-reflection data. The geometry of the fault system onshore and offshore, coupled with distinct partitioning of the strain along the KTFS, suggest the absence of a slab tear below the fault.

In the analogue experiments, we analysed two experimental end-members (i.e., model (A) ocean and continent in lateral contact Vs model (B) separated by non-Newtonian, transitional material) and compared them with the natural observations and the geometry of the subduction system. In both models the rigidity of the continental segment has a critical role in the type of deformation we observe during continental subduction, and controls the amount of stretching, rotation, and continental subduction. The transition zone in model (B) localises deformation, minimising shear and extensional deformation of the continent. At the end of the experiment, the subduction front geometry of model (B) better reproduces the actual eastern Adriatic margin in correspondence of the KTFS, and the deformation observed on the continental plate is consistent with the structures observed on the field, indicating a certain level of coupling between slab and overriding plate.

This similarity without achieving slab tearing suggests that a slab bend may be sufficient to reach the present natural configuration. Consequently, a slab tear may be absent or its extent be limited to a deeper section of the slab.

Recent/active tectonics in the eastern sector of the Hyblean Plateau (Sicily, Italy) from onland/offshore structural data integration

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Keywords: Hyblean Plateau, active tectonics, historic earthquakes.

This study investigates the recent tectonic evolution of a seismically active foreland domain in SE Sicily (Italy) through an integrated field and offshore structural data analysis. In detail, field surveys were performed on the longest tectonic lineament onshore known as the Siracusa-Sortino faults belt. Although this structure is listed in national databases (ITHACA) as an active and capable fault based solely on limited morphological evidence, its late Quaternary activity and seismic potential have remained unconstrained so far. New structural measurements document fault segmentation and their kinematic, revealing a dominant normal-faulting stress regime characterized by a nearly vertical σ_1, consistent with the Quaternary extensional setting of the Hyblean Plateau. The youngest deposits displaced by the faults system consist of middle Pleistocene marine sediments preserved onshore. Post-lithification fracturing and the absence of syn-tectonic stratal architecture in the hanging wall may indicate fault activity during the late Pleistocene. To further assess the potential late-Quaternary tectonic activity of the faults belt, a morphometric analysis was performed using high-resolution topographic data. Geomorphic anomalies support the interpretation that some fault segments may have remained active until post-Middle Pleistocene times. High-resolution offshore seismic profiling across the ideal prolongation of the investigated tectonic lineament confirms fault activity during the Late Quaternary. Evidence of seafloor rupture provides additional support for linking the fault belt to high-energetic historical seismic events occurred in the area. Overall, the integration of structural, morphometric, and offshore seismic data provides new insights into the active tectonic shaping southeastern Sicily.

Decoding crustal stress and strain accumulation: Insights from GNSS data and analytical force balance solutions

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Keywords: active tectonics, GNSS, force balance.

Over the past three decades, the geodetic community has witnessed an exponential increase in available data, driven by the expansion of initial GPS-only networks into modern, multi-constellation Global Navigation Satellite Systems (GNSS) deployed for both scientific and civilian applications. This rapidly growing data wealth offers unprecedented opportunities to test diverse hypotheses regarding the geodynamic processes that drive deformation across diffuse plate boundaries, such as those in the Central Mediterranean. Notably, the enhanced spatial coverage of dense GNSS networks yields significantly improved resolution over the spatial gradients of horizontal velocity (strain rates), which directly relate to underlying crustal stress systems.

Current approaches to modeling geodetic data are dominated by dislocation-based methods, which often require subjective choices regarding the underlying structure and can result in poorly physically constrained interpretations. In this presentation, I will show how employing simple analytical solutions of the force balance equation provides a robust, physically constrained alternative to interpret geodetic data. By doing so, we can extract critical insights into crustal stresses, lithospheric rheology, and active strain accumulation. I will showcase the application of this approach to highly active tectonic regions within the Apennines and Albania. Ultimately, these regional examples highlight the pivotal role of gravitational stresses in focusing crustal deformation and controlling the spatial distribution of active strain accumulation.

Active fault deformation in the Etna volcano-tectonic domain from the GNSS UniCT-Network (2016-2026)

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Keywords: geodetic data analysis, GNSS UniCT-Network.

Since 2014, the Geodynamics & Geomatic Laboratory research group of University of Catania, has been monitoring active faults on the flanks of Mount Etna using the UniCT-Net geodetic network (De Guidi et al., 2018). At present, it consists of 45 benchmarks and two permanent GNSS stations these last located on the hanging wall block of the Nizzeti Normal fault.

All GNSS measurements have been processed using the GAMIT/GLOBK software (Herring et al., 2015; http://www-gpsg.mit.edu), to obtain velocity fields that describe both aseismic and coseismic deformation affecting the main discontinuities of the eastern flank.

A significant deformation of the volcanic edifice occurred at the end of 2018 during the volcano-tectonic unrest. This unrest triggered the reactivation of the Fiandaca fault (Mw 4.9 on December 26, 2018) and the Pernicana Fault (Ml 4.1 on January 8, 2019) and the subsequent strong aseismic slip occurred along the Etna's shear lineaments.

The results, obtained since 2014 to present days, reveal a marked differential velocity field. In particular, the east component prevails to the north one and ranging from 1 to 60 ÷ 80 mm/year, showing significant difference during volcanic and seismic unrest phases. Moreover, following the 2022 transient acceleration (slow slip event) has been clearly recorded by the permanent stations located on the hanging wall of the Nizzeti fault.

Finally, these observations, within the context of the complex interaction between tectonics, volcanic activity, and gravitational processes, offer new insights for the study of the kinematic and mechanical behaviour of Mount Etna's fault systems

De Guidi G. et al. (2018) - The unstable eastern flank of Mt. Etna volcano (Italy): first results of a GNSS-based network at its southeastern edge. J. Volc. Geotherm. Res., 357, 418-424.

Herring T.A. (2015) - Introduction to AMIT/GLOBK,Release 10.6. Massachusetts Institute of Technology, Cambridge MA, 1-50.

New insights into the structural architecture of the Middle Aterno Valley Fault System (Central Apennines, Italy): A Multi-Method approach

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Keywords: active tectonics, fault, Central Apennines.

The Apennines are one of the world's most important natural laboratories for studying crustal deformation in active tectonic settings. In the Central Apennines, Quaternary extension is accommodated by high-angle normal fault systems that control the development of intermontane basins and generate the regional seismicity. Within this framework, the Middle Aterno Valley fault system occupies a key tectonic position close to some of the most seismically active structures of the Central Apennines, including the fault systems associated with the historical and prehistorical earthquakes of L'Aquila, Sulmona, Avezzano, and the Gran Sasso area. Despite its tectonic relevance, however, no historical earthquakes have been confidently linked to the faults of the Middle Aterno Valley.

This study provides new constraints on the geometry, segmentation, kinematics, and recent activity of the Middle Aterno Valley fault system, highlighting the relationships between tectonic structures and Plio-Quaternary deposits. The investigation combines detailed structural mapping, mesostructural and morphotectonic analyses, high-resolution LiDAR-based microtopographic investgation, and paleostress inversion techniques. Attention was devoted to the quantitative investigation of fault-related geomorphic deformation through densely spaced serial topographic profiles extracted from high-resolution digital terrain models.

The results reveal a more complex tectonic framework than previously recognized. A previously unmapped fault strand was identified basinward of the Roccapreturo fault. This structure shows a comparable along-strike length and coherent kinematics with the main fault alignment, suggesting possible mechanical interaction and distributed accommodation of extensional strain. These findings significantly refine the structural architecture of the area, clarifying the organization and segmentation of active fault strands and their relationships with Plio-Quaternary sedimentary successions.

Microtopographic analyses based on serial topographic profiles spaced every 100 m allowed the quantification of cumulative surface deformation likely related to the post-LGM period. The reconstructed deformation pattern documents long-term tectonic activity and indicates that surface faulting has strongly influenced the geomorphic evolution of the valley. Paleostress inversion results are fully consistent with the regional extensional regime affecting the Central Apennines and indicate a dominant NE-SW-oriented extension.

Overall, this work improves the understanding of the tectonic and paleogeographic evolution of the Middle Aterno Valley and provides new insights into the seismogenic potential of its fault systems. The study also has important implications for seismic hazard assessment in the Central Apennines, emphasizing that apparently "silent" fault systems may still represent active structures capable of accommodating significant crustal deformation over Quaternary timescales.

High-resolution morpho-structural mapping: a key tool for active tectonics research

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Keywords: field mapping, active tectonics, Central Apennines.

High-resolution morpho-structural mapping represents a fundamental first step in active tectonics studies, providing the primary framework for the recognition and characterization of deformation at the Earth's surface. Classical field-based geological mapping remains essential, as it allows the direct identification of tectonic landforms such as fault scarps, offset geomorphic markers, and deformation zones that are not always fully resolved by remote sensing datasets. This approach is crucial not only for the detection of active structures, but also for defining the regional-scale fault architecture, including the spatial organization, segmentation, and kinematic relationships between major fault systems. In this perspective, morpho-structural mapping represents a key baseline for subsequent quantitative analyses, such as slip-rate estimates, seismic hazard assessments and geomorphic indices. Such as approach is applied on the Middle Aterno Valley Fault System (MAVFS) in the Central Apennines. Located South of L'Aquila Quaternary basin, the MAVFS is a key area to investigate how crustal deformation has been accommodated in recent times. As a whole, MAVFS extends for 20 km in length and 2.5-3 km in width, and it is characterized by a NW-SE trending, high-angles normal fault system consistent of a master fault and subsidiary structures including synthetic and antithetic fault planes accommodating crustal deformation during Quaternary. This is supported by clear relationships between fault system arrangements, landform evolution and fault-related alluvial fans mapped in the area of interest. Such as arrangement is coherent with the extensional tectonic regime described for surroundings active fault systems which were able to generate one of the main destructive earthquakes associated to the 2009 L'Aquila sequence. This approach provides robust basis to perform further advanced investigations contributing to the identification of areas potentially affected by seismic activity and supports a more robust evaluation of earthquake-related hazard. In addition, field observations provide essential ground truth for the interpretation of high-resolution topographic and remote sensing data, improving the reliability of tectonic models at different spatial scales.

The role of surface topography in the formation of fault damage zones

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Keywords: faults, earthquakes, numerical modelling.

Active fault zones hosted in carbonate rocks commonly contain damage zones that can reach several hundreds of meters in thickness. These zones are often composed of *in-situ* shattered rocks (ISRs or rocks fragmented into clasts

We exploit existing and newly acquired field geology data on fault damage zone distributions in the Central Apennines (Italy), and perform dynamic earthquake rupture simulations with SeisSol (https://seissol.org). The fully dynamic earthquake simulations rely on the discontinuous Galerkin method, which enables the treatment of complex 3D geological structures, nonlinear rheologies (including off-fault plastic yielding), and highly accurate seismic wave propagation (Käser et al., 2010). The numerical models integrate laboratory-derived fault friction laws with simplified and realistic representations of fault geometry and surface topography, allowing us to investigate how topographic relief influences stress concentrations and the accumulation of plastic strain around faults during seismic rupture propagation.

Our study focuses on the 25 km long Campo Imperatore fault system in the Gran Sasso Massif area (Central Apennines, Italy), where the damage zones are pronounced and well mapped (Demurtas et al., 2016; Fondriest et al., 2020). We use the simulations to discuss the formation and distribution of ISRs with respect to (1) earthquake magnitude (up to Mw 7.0), (2) topographic features (valleys, etc.), (3) fault geometry, and (4) wall-rock lithology (e.g., limestones and dolostones). Our results indicate that simulations assuming a flat topography produce a relatively simple and limited strain distribution around the fault, with most of the plastic strain concentrating at the fault tips and within the hanging wall. In contrast, simulations incorporating realistic topography generate a more complex strain pattern, characterized by additional plastic strain accumulation within valleys, creeks, and both in the hanging wall and in the footwall. The formation of the damage zone is related to the presence and interference of trapped waves (intense near-field motions) between the fault surface and the free surface at the interface between the atmosphere and the Earth's crust.

We conclude that the surface topography, acting as a lens for elastic waves in the near field, concentrates elastic wave energy into limited volumes of rock, allowing the attainment of anomalous accelerations capable of fracturing the rock. This type of study therefore has implications also for seismic hazard studies and the estimation of local ground motions.

Demurtas M. et al. (2016) - Structure of a normal seismogenic fault zone in carbonates: The Vado di Corno Fault, Campo Imperatore, Central Apennines (Italy). Journal of Structural Geology, 90, 185-206, https://doi.org/10.1016/j.jsg.2016.08.004.

Fondriest M. et al. (2020) - Structural Complexity and Mechanics of a Shallow Crustal Seismogenic Source (Vado di Corno Fault Zone, Italy). Journal of Geophysical Research: Solid Earth, 125(9), e2019JB018926, https://doi.org/10.1029/2019JB018926.

Käser M. et al. (2010) - SeisSol - A Software for Seismic Wave Propagation Simulations. In High Performance Computing in Science and Engineering, Garching/Munich 281-292, https://doi.org/10.1007/978-3-642-13872-0_24.

Recent surface deformation in the Western Balkans derived from High-Resolution Radar Interferometric Time-Series

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Keywords: active faults, tectonic geodesy, InSAR.

The transition from collision to subduction between the Adria and Eurasia plates along the western Balkans generates complex deformation in the upper plate. Along the Dinarides, thrusting along the coast transitions into extensional deformation toward the hinterland. Farther southeast, in northwestern Greece, deformation is dominated by Aegean back-arc extension associated with the retreat of the Hellenic Trench (Royden & Faccenna, 2018). This heterogeneous deformation field is reflected in the variable distribution and orientation of faults (NE-SW thrust along the coast, NS-, and EW-normal in the hinterland) (D'Agostino et al., 2022). Both compressional and extensional tectonic settings are associated with large earthquakes (moment magnitude Mw > 6) in recent years, including the 2019 Mw 6.4 Durrës earthquake in Albania and the 2021 Mw 6.3 Tyrnavos sequence in Thessaly, Greece.

To investigate the regional surface deformation field, we exploit Sentinel-1 Synthetic Aperture Radar (SAR) imagery acquired between 2016 and 2023 in two viewing directions to derive interferometric surface displacement time series using the Persistent and Distributed Scatterers approach (Gomba et al., 2025). Using trajectory modeling and rate decomposition, we remove the co-seismic displacement signal associated with recent large earthquakes and retrieve east and vertical, inter- and post-seismic surface deformation rates at 80 m spatial resolution. The deformation rates are tied to a stable Eurasian using pointwise displacement rates obtained from high-precision GNSS measurements.

From Albania to North Macedonia, we observe a gentle increase in eastward rates, highlighting the transition from shortening to extension towards the hinterland, in agreement with the earthquake focal mechanisms and an independent GNSS-strain-rate field (D'Agostino et al., 2022). This long-wavelength signal is overprinted by a ca. 100 km-wide deformation anomaly associated with the inter- and post-seismic phase of the 2019 Durrës earthquake (Matraku et al., 2023).

Towards NW-Greece, westward rates increase gradually by ~5 mm/yr, consistent with back-arc extension of the Hellenic arc and trench retreat. This area hosts E-W to NW-SE-oriented active normal fault systems. Abrupt rate changes of ~2 mm/yr are observed across the E-W-oriented Corfu fault system, suggesting shallow left-lateral slip along the fault.

D'agostino N. et al. (2022) - Active tectonics and fault evolution in the Western Balkans. Geophysical Journal International, 231(3), 2102-2126, https://doi.org/10.1093/gji/ggac316.

Gomba G. (2025) - Open-Access Global Ground Deformation Dataset for Tectonic High-Strain Zones Based on Sentinel-1 Interferometry.

Matraku K. et al. (2023) - The 26 November 2019 Durrës earthquake, Albania: coseismic displacements and occurrence of slow slip events in the year following the earthquake. Geophysical Journal International, 234(2), 807-838, https://doi.org/10.1093/gji/ggad101.

Royden L. & Faccenna C. (2018) - Subduction orogeny and the Late Cenozoic evolution of the Mediterranean Arcs. Annual Review of Earth and Planetary Sciences, 46(1), 261-289, https://doi.org/10.1146/annurev-earth-060115-012419.

Assessing the seismic potential of the Crati Basin (northern Calabria) in the context of the actual geodetic velocity field

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Keywords: block modeling, Northern Calabria, active tectonic.

The Crati Graben is a tectonic depression located in northern Calabria (southern Italy) filled by Pliocene - Holocene marine and continental deposits, (Tansi et al., 2016). The geometry of the Crati Graben is controlled by two major N-S striking normal faults: The West Crati Fault (WCF) and the East Crati Fault (ECF), these accommodate the present day ~ E-W oriented extensional strain affecting this area and have been considered among the most likely sources of high intensity historical and instrumental earthquakes, including the 1184 Crati Valley earthquake (Mw ~ 6.8) and the 1854 earthquake (Mw ~ 6.3), (Rovida et al., 2025). According to Tansi et al. (2016) and references therein, the Crati Basin developed within a regional NW-SE trending left-lateral transcurrent fault system that dissected the Calabrian Arc. This strike-slip system (Falconara Carpanzano fault) promoted extensional and transtensional deformation, overprinting the earlier compressional tectonic framework related to the development of the southern Calabrian Arc orogenic system. Considering this complex seismotectonic setting, we propose a multidisciplinary approach to asses the seismic potential of the Crati Basin border faults since the capacity of these in determine future earthquakes is still unkonw, nevertheless the WCF is considered as a debated seismogenic sources in the DISS databse (Database of Italian Seismogenic Sources). In our study we use structural, seismological, geodetic data and available seismic lines of ViDEPI project which we have recently reinterpreted. We moreover apply a kinematic block modeling approach (Mccaffrey, 2002), by inverting GNSS data to estimate interseismic blocks motion and long term slip rate on the WCF and ECF. Our findings suggest the presence of an extensional velocity gradient in the Crati Basin mostly accomodated by ~ 1.5 mm/yr extensional dip-slip rate on the ECF and by ~ 1 mm/yr on the WCF. Our model also allowed us to determine the interseismic coupling degree on fault planes, estimate the associated slip deficit, and investigate the relationship between seismic moment release and seismic moment accumulation rate over time in the Crati Basin. The results of our inference suggest that these faults are variably coupled along their extension and may still contribute to generate low to moderate magnitude earthquakes in this area. Conversely, other fault portions appear to accommodate the ongoing strain field predominantly through long-term creeping mechanisms.

DISS Working Group (2025) - Database of Individual Seismogenic Sources (DISS), Version 3.3.1: A compilation of potential sources for earthquakes larger than M 5.5 in Italy and surrounding areas. Istituto Nazionale di Geofisica e Vulcanologia (INGV). https://doi.org/10.13127/diss3.3.1.

Mccaffrey, R., 2002. Crustal block rotations and plate coupling. Plate Boundary Zone, Geodyn, (30), 101-122.

Rovida A. et al. (2022). Italian Parametric Earthquake Catalogue (CPTI15), version 4.0. Istituto Nazionale di Geofisica e Vulcanologia (INGV). https://doi.org/10.13127/CPTI/CPTI15.4

Tansi C. (2016) - Seismotectonics and landslides of the Crati Graben (Calabrian Arc, Southern Italy). Journal of Maps, 12, 363-372, https://doi.org/10.1080/17445647.2016.1223760.C.

Impact of earthquake location accuracy on 3D seismotectonic models in Emilia Region

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Keywords: Northern Apennines, earthquake location, seismotectonics.

The 3D modeling of seismogenic sources commonly relies on correlating geological structures observed at the surface and in the shallow subsurface with the spatial distribution of earthquakes at depth. However, this correlation may represent a significant challenge because of uncertainties affecting both the geometry of deep structures and earthquake hypocenters. This issue becomes particularly critical in regions where seismic stations used for earthquake location are sparse or installed on geological units with markedly different lithological properties, dramatically increasing location errors. Our study investigates the recent seismicity occurring within the Emilia Thrust System (Northern Apennines, Italy), analyzing spatio-temporal clusters extracted from the 2008-2024 background seismicity ($0.4 \leq ML \leq 5.1$), with particular attention to four seismic sequences (e.g., the 2008 Parma sequence Mmax 4.9, the 2024 Langhirano sequence Mmax 4.2). In this sector, earthquakes nucleate at mid-crustal depths (15-30 km). Including seismic stations located in the Po Plain introduces major challenges: the thick, low-velocity Plio-Quaternary sedimentary cover causes lateral heterogeneities and significant travel-time delays. Existing regional 1D and 3D models fail to capture this contrast, leading to biased depth estimates and artificial hypocentral shifts. To address this, we critically re-evaluated the crustal velocity structure. By optimizing velocity models and integrating station corrections computed using the VELEST algorithm, we mitigated sediment-induced delays, minimized depth artifacts and better constrained the seismogenic volumes. This provided a robust basis for high-precision earthquake relocation via the NonLinLoc code. To further refine locations and assess the reliability of inferred fault geometries, we conducted sensitivity tests exploring key relocation parameters (e.g., network configuration, waveform processing and coherence thresholds). Phase picks from a temporary station were added to improve azimuthal coverage and reduce the minimum epicentral distance, and we compared three approaches: NLL-standard, NLL-SSST and NLL-SSST-coherence. Our comparative analysis yielded critical insights into the location process. Applying station corrections from the optimized velocity model produced a significant ~5 km horizontal shift relative to preliminary locations. Furthermore, sensitivity tests showed that both the SSST and coherence approaches relocate events slightly deeper than standard solutions. While SSST reduces spatial uncertainties, the coherence method yields comparable formal errors but significantly enhances cluster compactness and internal consistency. Overall, our results refine the spatial definition of active seismogenic volumes beneath the Emilia Thrust System, providing a robust framework for integrating earthquake distributions with geological structures, improving 3D seismotectonic models of the Northern Apennines.

Seismic swarms and active deformation along the Nebrodi mountain range (NE Sicily): Multi-scale insights

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Keywords: seismic swarms, crustal deformation.

Seismic swarms are spatio-temporal clusters of earthquakes lacking a dominant mainshock and therefore not following the Omori-type aftershock decay typical of traditional mainshock-aftershock sequences. They have been observed in different geological settings, and their triggering mechanisms are commonly attributed to fluid-pressure transients or aseismic slip (De Barros et al., 2020). Most seismic swarms exhibit a characteristic spatio-temporal migration pattern, often delineating pre-existing faults, fracture networks, or volcanic conduits, thereby providing valuable insights into the physical processes governing crustal deformation.

In the present study, we investigated seismicity in the Nebrodi Mts. Area (NE Sicily) by analyzing three seismic clusters which occurred over the past 15 years. The first cluster was studied in detail by Cammarata et al. (2018), who interpreted it as the result of mantle/sub-crustal fluids migrating toward the surface along a complex network of tectonic structures. This interpretation is further supported by the detection of CO_2 degassing and $^3He/^4He$ isotopic ratios, indicative of a deep fluid source (Italiano et al., 2019). The remaining two clusters have not yet been investigated; however, preliminary analysis of INGV earthquake locations revels a shallow seismogenetic volume elongated along the E-W direction, contrasting with the NW-SE structural trend inferred from surface geology. In addition, available focal mechanism solutions and geodetic strain-rate data consistently indicated in the region ongoing diffuse N-S crustal extension, providing additional constraints on the tectonic reorganization of this sector, as also suggested by geological and geomorphological data. Despite this body of evidence, however, a unified and detailed characterization of the seismicity distribution across the three clusters, and its relationship to the ongoing crustal deformation pattern, is still lacking. Furthermore, the possible involvement of deep-seated fluids is still poorly constrained. To address the lack of a unified characterization of seismicity and its relationship with the active deformation field, we analysed recent seismicity by combining earthquake relocation, clustering analysis, and moment tensor inversion to better constrain the spatial distribution of seismicity and the associated faulting mechanisms. In addition, we also collected and analyzed all available GNSS observations covering the study area to provide an update view of the ongoing crustal deformation pattern. The results were jointly interpreted with available geochemical and geological data and framed into the seismotectonic framework of this sector of NE Sicily.

Cammarata L. et al. (2018) - Seismological and structural constraints on the 2011-2013, Mmax 4.6 seismic sequence at the south-eastern edge of the Calabrian arc (North-eastern Sicily, Italy). Tectonophysics, 723, 56-67, https://doi.org/10.1016/j.tecto.2017.11.021.

De Barros L. et al. (2020) - Imbricated aseismic slip and fluid diffusion drive a seismic swarm in the Corinth Gulf, Greece. Geophysical Research Letters, 47(9), e2020GL087142, https://doi.org/10.1029/2020GL087142.

Italiano F. et al. (2019) - Evidence of tectonic control on the geochemical features of the volatiles vented along the Nebrodi-Peloritani Mts (southern Apennine chain, Italy). Geofluids, 2019(1), 6250393, https://doi.org/10.1155/2019/6250393.

A Plate-Boundary view of crustal heterogeneity across Southern California from seismic attenuation imaging

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Keywords: crustal heterogeneity, Southern California.

Southern California is a complex active plate-boundary region where oblique motion between the Pacific and North American plates is accommodated across complex networks of distributed faulting and blind fault systems. Along this margin, active deformation interacts with deep sedimentary basins, inherited crustal structures, geothermal systems, and groundwater circulation, producing strong spatial variations in seismic wave propagation and substantial seismic hazard implications. From the Imperial Valley-Salton Trough and the southern San Andreas fault system to the Los Angeles metropolitan region, basin and fault networks record different expressions of the regional deformation system. Previous studies have shown strong lateral variations in seismic velocity, reflecting changes in basin geometry, sediment thickness, fault architecture, and crustal properties. However, velocity structure alone cannot fully resolve the fine-scale physical properties controlling seismic wave propagation, including fracture density, lithological heterogeneity, pore-fluid distribution, and hydrothermal alteration. Seismic attenuation imaging, therefore, provides complementary sensitivity to crustal heterogeneity at scales relevant to fault dynamics, earthquake processes, and seismic hazard.

We apply seismic attenuation imaging to select Southern California basin-fault systems using dense seismic array recordings of active and passive seismic sources. The analysis is performed using Multi-Resolution seismic Attenuation Tomography (MuRAT4, https://github.com/LucaDeSiena/MuRAT), allowing us to image spatial variations in peak-delay and coda-attenuation measurements as proxies for seismic scattering and intrinsic absorption, respectively. We compare attenuation patterns in transtensional and geothermal settings, such as the Imperial Valley-Salton Trough, with those observed in transpressional and intensely urbanized basin settings, including eastern Los Angeles and the Chino basin. The resulting models are interpreted together with existing velocity models, earthquake distributions, mapped and buried faults, basin structure, and geological constraints. High-scattering volumes may indicate fractured fault-zone rocks, sharp lithological contrasts, or complex sedimentary architecture, whereas high-absorption anomalies may reflect fluid-rich volumes, elevated pore pressure, hydrothermal alteration, or strongly attenuating basin sediments. By comparing different basin-fault systems along the Southern California plate boundary, this work links present-day seismic observations with active deformation, sedimentary basin evolution, and fluid circulation. Imaging seismic attenuation thus contributes to an integrated view of how long-term tectonic deformation and short-term seismic processes interact within a complex active plate-boundary setting.

Borehole and Seismic Reflection data constraints on the Quaternary extensional systems of Vallo di Diano and Val d'Agri (Southern Apennines)

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Keywords: Campania-Lucania Apennines, seismic section interpretation, extensional quaternary fault.

The Campanian-Lucanian Apennines have long been a subject of considerable scientific interest, driven by complex stratigraphic-structural questions and significant mining prospects associated with hydrocarbon accumulation. Furthermore, this sector of the Apennines is affected by recurrent and intense seismic activity, including some of the most powerful historical events, such as the earthquake of December 16, 1857. A broad body of scientific literature suggests that this seismicity is predominantly extensional in nature, associated with Pleistocene-Holocene normal faults dipping both eastward and westward, whose deformation generated NW-SE elongated continental basins.

Within this framework, the study area extends onshore from the eastern flank of Mount Cervati to the eastern border of the Val d'Agri, covering approximately 2500 square kilometers. The primary objective of this work is to unravel the deformational style of the extensional system responsible for the development of two of the main basins in the Southern Apennines: the Vallo di Diano and the Val d'Agri. This analysis constitutes the southern continuation of an ongoing study carried out in the northernmost sector, between the Alburni Mountains and the Irpinian system, where east-dipping normal faults dominate the extensional structural setting, showing clear evidence of a master east-dipping detachment surface.

To better constrain the seismic interpretation, this study implements a customized data-processing workflow organized into three key stages: i) the digitization of log data from legacy paper or raster documents; ii) the time-to-depth calibration of available borehole logs, focusing primarily on Sonic data, complemented by Density and Resistivity logs (where sonic logs are unavailable, a pseudo-sonic log is reconstructed); and iii) the generation of synthetic seismograms utilizing the GeoSyn geophysics software module, integrated within the Kingdom geological platform. The resulting synthetic seismograms are subsequently tied to the nearest seismic profiles provided by Eni, as well as to a series of complementary commercial lines accessible through the Videpi database. This methodological approach yields a synthetic seismogram for each borehole that replicates stratigraphic boundaries in terms of seismic response. By effectively linking well data with seismic profiles, the outcomes of this work will directly contribute to building a comprehensive 3D structural model of active extensional faults in the Southern Apennines.

TRACE-IT - A database of Tectonic and paleoseismic Records with geochemical And Chronological Evidence in ITaly

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Keywords: active tectonics, paleoseismology, geochemistry.

Understanding the spatial and temporal behaviour of active faults requires integrating geological, paleoseismological, and geochemical observations across multiple timescales. Here we present TRACE-IT (database of tectonic and paleoseismic records with geochemical and chronological evidence in Italy), a comprehensive database that comprises published paleoseismological and geochemical data constraining active faulting in Italy, one of the most seismically active countries in the Mediterranean area.

TRACE-IT includes georeferenced data points distributed across the Italian peninsula, providing broad spatial coverage from northern to southern Italy. Data density is highest within the central sectors of the Apennine extensional belt, while additional data are distributed across the Northern Apennines, Calabria, the Alpine front, and northeastern Sicily.

Each data point is provided with geographic coordinates, along with information on the associated fault and the seismogenetic province (sensu Lavecchia et al., 2021). The dataset is derived from trench investigations, quarries, caves, fault scarps, stratigraphic cores, and natural exposures, and comprises a total of 4056 paleoseismic records, from geological, geochemical, archaeological, and modelling constraints.

The data derive from multiple absolute dating methods and geochemical analyses, including radiocarbon (^{14}C), $^{40}Ar/^{39}Ar$ dating, U-Th disequilibrium series, Rb-Sr dating, cosmogenic ^{36}Cl exposure dating, and Rare Earth Elements (REEs) analyses along fault scarps. They also come from geological, stratigraphic, morphological, geomorphological, and structural data analysis. For geochemical analyses, TRACE-IT provides detailed information on sampled materials, stratigraphic context, and sample identification. The database also includes key outputs such as the number and timing of paleoearthquakes, recurrence intervals, elapsed times, slip rates, throw rates, vertical offset values, and reference times. All data are reported with quantified uncertainties. In addition, quality indicators and bibliographic sources are systematically included.

TRACE-IT offers a standardized and traceable framework for investigating fault slip histories, earthquake recurrence, and long-term deformation rates in Italy, by explicitly linking geochemical-derived ages, stratigraphic observations, and paleoseismic events to individual fault segments. The database is designed to support reproducible research in active tectonics, seismic hazard assessment, and physics-based earthquake modelling. It can be easily expanded to incorporate new data and methods. Developed as an open and expandable resource, TRACE-IT supports a wide range of applications and represents a significant step toward data-driven research in active tectonics in Italy.

Lavecchia G. et al. (2021) - Regional seismotectonic zonation of hydrocarbon fields in active thrust belts: A case study from Italy. In: Bonali F.L., Mariotto F.P., Tsereteli N. (Eds), Building Knowledge for Geohazard Assessment and Management in the Caucasus and other Orogenic Regions, Dordrecht, Netherlands, Springer, 89-128, https://doi org/10.1007/978-94-024-2046-3_7.

The 2016-2017 Central Italy earthquake sequence: a decade of integrated research from depth to satellite observations

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Keywords: central italy earthquake, seismogenic fault, InSAR.

The 2016-2017 central Italy earthquake sequence provides a unique natural laboratory for investigating the relationships between deep crustal structures, seismic ruptures, and surface deformation. The sequence, dominated by the Mw 6.0 Amatrice (August 2016) and Mw 6.5 Norcia (October 2016) earthquakes, activated the Vettore-Gorzano fault system, producing significant ground displacement. Over the last ten years, extensive datasets acquired through geological, seismological, geodetic, and remote-sensing approaches have made it possible to reconstruct the sequence with a high level of detail.

We integrate several datasets to observe the fault system from different perspectives, spanning from deep crustal processes (seismicity) and tectonic architecture (subsurface geology) to surface expressions (outcropping geology and surface ruptures), and satellite-based observations (InSAR-based techniques). The data are jointly used to investigate the structural framework and deformation pattern along the fault system during and after the seismic sequence.

High-detailed DInSAR-based deformation maps of the three largest earthquakes are reconstructed to characterize both surface ruptures associated with major fault segments and off-fault deformation. The geometry of the main seismogenic faults at depth is reconstructed using seismicity distribution and cross-sections, while at surface we retrieve geological constraints including coseismic ruptures. The analysis highlights distinct rupture behaviors of individual fault segments and their specific contributions to the observed ground deformation.

Post-seismic deformation is instead investigated analyzing SBAS-InSAR time series, together with the spatial distribution of seismicity that occurred following the sequence onset, until 2025. The results show how the hanging wall of the active fault system underwent sustained subsidence during this period, characterized by spatially variable rates.

By bridging insights from the deep subsurface to satellite-based remote sensing, this study provides a comprehensive understanding of the processes driving the 2016-2017 Central Italy earthquakes and its temporal evolution in the last decade.

Basin analysis of the Plio-Quaternary wedge-top basins of southwestern Sicily: implication for depocenter migration and thrust-front propagation

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Keywords: wedge-top basin, southwestern Sicily.

The southwestern Sicily foreland-basin system represents a key sector for investigating the relationships between tectonic structures and sedimentary basin analysis within the external domain of the Sicilian Fold and Thrust Belt (SFTB). This study focuses on the area between the Capo Granitola Fault Zone (CGFZ) and the Sciacca-Kronio Fault System (SKFS), including the adjacent offshore sector. This region is characterized by active tectonics, as documented by the 1968 Belice seismic sequence (Pucci et al., 2023). Moreover, the occurrence of Middle Pleistocene (Chibanian) marine deposits currently outcropping onshore further supports ongoing Quaternary deformation and relatively rapid uplift of the area. These deposits, together with the deformation affecting Middle-Late Pleistocene marine terraces (Ferranti et al., 2021), indicate tectonic activity linked to thrust-related structures and regional compressional deformation.

The study integrates geological mapping, structural cross-sections, well data, seismic reflection profiles, and 3D geological modelling to reconstruct the architecture of the Plio-Quaternary successions and their relationships with the main tectonic structures. The analysis of depositional architecture, subsidence patterns, and accommodation-space development provides key constraints on the tectono-stratigraphic evolution of the basin system. Stratigraphic thickness variations, stratal patterns, and structural trends were analysed to evaluate the role of inherited structural highs and active fault systems in controlling subsidence, accommodation space, and sedimentary architecture.

Plio-Quaternary depocenter geometry and distribution reflect the interaction between thrust-related deformation, transpressional tectonics, and basin evolution within this active sector of the SFTB. Depocenter geometry and stratigraphic thickness variations highlight the influence of tectonic structures on basin configuration and sedimentary evolution. NE-SW-oriented alignments can be recognized in association with the two main tectonic structures affecting the study area (CGFZ and SKFS). Additional minor depocenters are bounded by WNW-ESE-oriented structural alignments related to the Monte Magaggiaro-Pizzo Telegrafo thrust fronts, whose escarpments were likely inherited from earlier extensional tectonics that generated a margin characterized by approximately E-W-oriented structural trends.

The spatial relationships between structural highs and depocenters suggest that tectonic inheritance exerted a primary control on the evolution of the southwestern Sicily foreland-basin system during the Plio-Quaternary. The integration of surface and subsurface datasets provides new insights into the tectono-stratigraphic evolution of this tectonically active region and contributes to a better understanding of the interactions among tectonic deformation, lithospheric-scal processes, accomodation-space evolution, subsidence history and sedimentation.

Ferranti L. et al. (2021) - Late Quaternary coastal uplift of southwestern Sicily, central Mediterranean sea. Quaternary Science Reviews, 255, 106812, https://doi.org/10.1016/j.quascirev.2021.106812.

Pucci S. et al. (2023) - Geology of the lower Belice River valley, epicentral area of the M > 5 1968 seismic sequence (south-western Sicily, Italy). Journal of Maps, 19(1), 2242725, https://doi.org/10.1080/17445647.2023.2242725.

Variations in styles of crustal deformation in Southern-Central Italy from a Multi-Layer VP and VP/VS structural framework

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Keywords: crustal deformation.

Crustal processes in southern-central Italy are dominated by the subduction of the Adriatic plate beneath the Tyrrhenian plate. Volcanic activity and hazardous seismicity are both associated with this zone of convergence and have been related to fluids migrating upward from the subducting slab. In contrast to the high seismicity rates and non-volcanic CO_2 degassing observed in the Southern Apennines, the region east of the Apennines toward the Gargano Promontory has lower rates of seismicity and no volcanic activity suggesting different structural domains and controls on crustal processes. In this study, we leverage the extensive network of seismic stations in southern-central Italy to determine the multi-layer crustal structure including interface depth and dip, V_P, V_P/V_S ratio, and seismic anisotropy, in a region extending ~200 km across the Italian peninsula. We apply a newly developed method based on the joint forward modeling of receiver functions and vertical autocorrelograms from 9960 teleseismic events recorded at 108 stations.

Receiver functions reveal teleseismic Ps conversions generated at strong impedance contrasts, while autocorrelograms recover P-wave reverberations interacting with the same interfaces. Together, they provide improved constraints compared to receiver functions alone and can be jointly modeled by matching synthetic and observed data to estimate the multi-layer crustal structure near each station. Beneath the Gargano Promontory, the contact between the Apulian Permian-Mesozoic sedimentary sequence and the underlying Adria basement is identified at ~0.5-1 s, and a Moho phase is present around 4 s. Near Mefite d'Ansanto, the top of the Apulian Platform is imaged and Quaternary sediments and volcanics are observed near the Bay of Naples. Beneath the Apennines, two apparent Moho phases are visible at around 3-5 s, likely corresponding to the base of the crust and potentially the base of the subducting slab underneath it. Our unified model of crustal structure overcomes the challenges associated with comparing local studies based on different datasets and methodologies and provides a useful regional framework for evaluating the presence and migration of CO_2-rich fluids through the crust.

Revisiting FMTOMO: a fresh look at travel-time seismic tomography for seismotectonic applications

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Keywords: seismic tomography, Python, seismotectonic.

Seismic monitoring infrastructures are continuously growing, resulting in an increasing amount of recorded seismic data worldwide. Despite the significant development of near-real-time analysis and machine learning-based data processing, the contribution of seismicity to seismotectonic assessment is still often limited to earthquake locations obtained from preliminary, and commonly high-uncertainty, location procedures. More advanced analyses generally require specific expertise in methods, algorithms, and input-output data formats, which can limit the broader use of seismic data in multidisciplinary studies.

In this work, we revisit travel-time seismic tomography as a tool to support seismotectonic investigations, improving the characterization of crustal velocity structures and providing indirect constraints on the geometry of seismogenic sources. Our approach builds on FMTOMO, a Fast-Marching-based tomography code developed more than two decades ago by Rawlinson et al. (2006) and Rawlinson & Urvoy (2006). To make this methodology more accessible to a wider community, we developed a Graphical User Interface (GUI) that provides user-friendly tools for performing, managing, and visualizing regional-scale travel-time seismic tomography.

The GUI is implemented in Python and takes advantage of ObsPy (Beyreuther et al., 2010), which allows seismic data to be read, written, and handled using modern standard formats. This overcomes some of the limitations related to custom input-output files and facilitates the integration of tomography workflows with current seismological data-processing practice. We developed new tools for assessing the applicability of tomography and for adjusting the forward and inversion parameters. The graphical user interface presents both graphical and numerical results, allowing users to verify the geometry of the source-receiver arrangement, ensure adequate ray coverage, check the picking for P and S waves, maintain the boundary conditions of the model, and evaluate both cell size and inversion parameters.

The interface was designed to be as intuitive as possible, while preserving access to the full potential of the original FMTOMO code. Several tools were developed to simplify technical routines, with particular attention to the management and visualization of results. This enables a more straightforward integration of tomographic outputs into multidisciplinary studies at both local and regional scales. By lowering the technical barrier to travel-time tomography, this tool promotes a wider and more effective use of seismic data for imaging crustal structures and improving seismotectonic interpretations.

Beyreuther M. et al. (2010) - ObsPy: A Python Toolbox for Seismology. Seismological Research Letters, 81, 530-533, https://doi.org/10.1785/gssrl.81.3.530.

Rawlinson N. et al. (2006) - Seismic wavefront tracking in 3D heterogeneous media: applications with multiple data classes. Expl. Geoph., 37, 322-330, https://doi.org/10.1071/EG06322.

Rawlinson N. & Urvoy M. (2006) - Simultaneous inversion of active and passive source datasets for 3-D seismic structure with application to Tasmania. Geophys. Res. Lett., 33, L24313, https://doi.org/10.1029/2006GL028105.

Triassic evaporites beyond a detachment: From Mesozoic basin dynamics to modern seismicity, a multi-scale petrophysical framework for the Northern Apennines

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Keywords: Triassic evaporites, distributed seismicity, Northern Apennines.

The Triassic Evaporites (TE) of the Northern Apennines have long been treated as a passive detachment horizon, yet they represent an active, multi-scale driver of fault dynamics and seismic cycle processes, from Mesozoic basin formation to the 2016 Central Italy earthquake sequence.

The TE display a persistent bimodal rheology, defined by the mechanical contrast between ductile Ca-sulphates and rigid dolostones, which governs deformation across multiple spatial and temporal scales. On a geological timescale, the burial-induced dehydration of gypsum to anhydrite triggered Mesozoic salt tectonics through fluid release and rheological instability, driving lateral evaporite redistribution from carbonate platforms toward pelagic basins. This process controlled differential subsidence and shaped the structural inheritance later reactivated during Apenninic shortening, defining the current crustal-scale architecture of the seismogenic layer.

At the scale of the modern seismogenic framework, two petrophysical properties of the TE emerge as first-order controls. First, the anomalously high thermal conductivity of deep-seated anhydrites and dolostones ($\sim$5 W m^{-1} K^{-1}), contrasting with overlying marly-clastic covers, reduces the internal geothermal gradient and deepens the brittle-ductile transition (BDT) to 10-12 km, concentrating regional seismicity within the TE itself. Second, the very low permeability of anhydrite (10^{-19}-10^{-21} m^2) enables trapping of deep-seated CO_2 at near-lithostatic pressures (up to 85% of overburden load), as documented in deep boreholes.

These two properties establish the preconditions for seismic activation during the 2016 sequence: the anomalously deep BDT facilitates stress concentration within the TE, while near-lithostatic fluid overpressure critically reduces effective normal stress on secondary structures. The dynamic trigger is provided by the mainshock-induced strain rate increase (from $\sim10^{-15}$ to $\sim10^{-13}$ s^{-1}), which, as demonstrated by triaxial experiments, promotes transient embrittlement of the TE and drives distributed seismicity away from the main fault planes.

Together, these results, grounded in a comprehensive petrophysical dataset from borehole samples and outcrop analogues, demonstrate that the TE are not a passive structural boundary but an active, multi-scale controller of fault dynamics and seismic cycle processes in the Apennines, with direct implications for seismic hazard assessment in evaporite-bearing orogens worldwide, particularly regarding the underestimation of seismogenic depth and the potential for distributed off-fault seismicity in areas where evaporites are present.

Petrophysical properties of rocks from borehole data: empirical relationships and implications for seismogenic fault characterization

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Keywords: petrophysical properties, borehole data, seismogenic fault characterization.

The physical properties of the host rock (i.e. porosity, lithology, and fluid content) exert a primary control on fault rock development, fault zone permeability, and the mechanical conditions governing fault slip and reactivation. Petrophysical well-log measurements (i.e. Gamma Ray, GR; electrical Resistivity; and P-wave velocity, Vp) provide direct in-situ proxies for these properties at depth and, through rock physics relationships, allow recovery of elastic parameters relevant to fault mechanical models. Despite their importance, direct constraints on the petrophysical and hydraulic properties of rocks at seismogenic depths remain scarce in the Italian Apennines.

We analyzed legacy well-log data from the Monte Civitello 001 borehole, a 5.6 km-deep well drilled in 1989 in the Umbria Apennines (VIDEPI database) located within the TABOO Near-Fault Observatory. This borehole crosses the complete Umbria-Marche succession to the Triassic Evaporites in an area characterized by an intense extensional seismicity. In the framework of the activities supported by EPOS JRU-ITA, we digitized the legacy data to obtain LAS files for Gamma Ray, Resistivity (shallow and deep) and Slowness (then converted into P-wave Velocity, Vp). We performed a statistical analysis to update the borehole stratigraphy and to identify petrophysical signatures of lithological transitions. Therefore, we identified which functional form better describes the available data for each pair of properties, following the most common theoretical models. We also evaluated if a multiple regression that uses both Gamma Ray and Resistivity as predictors of P-wave velocity could offer a better constrained parameter with respect to the single-variable regressions.

Results show that the variations in lithology are strongly marked in the geophysical profiles, reflecting the highly heterogeneous stratigraphy of the Umbria-Marche succession. The high-resolution of the borehole petrophysical profiles also highlights the presence of the ~1 m thick Bonarelli Level. All pairwise relationships are linear, showing consistent values with respect to Apennines and Adriatic domain literature. These equations have been validated against independent datasets, showing a reliable source for recovering synthetic petrophysical values when data from wells are missing. The multiple regression leverages complementary information from Gamma Ray and Resistivity: the first acts as a proxy for clay volume (which controls Slowness and thus Vp), while the latter is correlated with porosity and fluid content (both affecting Vp). These results contribute to characterizing the physical state of the carbonate host rock at seismogenic depths in the TABOO Near-Fault Observatory, supporting process-oriented models of fault mechanics and fluid-fault interactions in the Apennines extensional domain.

S14.

Decoding the earth structure from the upper mantle to the upper crust: Bridging Petro-Structural Observations, Seismological Imaging and Geological Models

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Imaging crustal heterogeneity and seismogenic structures beneath the Emilia-Romagna Region (Northern Italy) using local earthquake tomography

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Keywords: local earthquake tomography, crustal heterogeneity, seismogenic structures.

The Emilia-Romagna sector of the Po Plain is characterized by a multibranched system of buried thrust faults forming an arc-like compressional front. The 2012 Emilia seismic sequence highlighted the need for improved imaging of the upper-crustal structure beneath the Mirandola and Ferrara thrust systems, where recent studies suggest that the mainshocks ruptured moderately dipping thrust systems rooted into the Paleozoic basement down to ~15 km depth (Improta et al., 2023).

As a first step of the workflow, an a priori Vp model was constructed following the multi-dataset approach of Orecchio et al. (2011), by integrating published geological and geophysical constraints, including seismic profiles, together with previous tomographic studies of the Italian lithosphere, the Po Plain, and the 2012 Emilia aftershock sequence. This model was then used as the starting model for the tomographic inversion.

We investigate the 3-D P-wave velocity structure of the Emilia-Romagna region through local earthquake tomography and simultaneous hypocentre relocation, using a dataset of 3,767 local earthquakes recorded between 2000 and 2025 by the INGV permanent and temporary seismic networks. The dataset provides 95,354 arrival-time picks, including 63,332 P-wave and 32,022 S-wave arrivals recorded by 207 seismic stations. Tomographic inversion was performed using the LOTOS algorithm (Koulakov, 2009), which includes iterative coupled relocation-tomography and inversion on multiple rotated grids. Model reliability is assessed through checkerboard resolution tests using an anomaly size of 15 km.

Preliminary results reveal a high-Vp anomaly in the eastern sector of the study area, increasing with depth beneath the Mirandola and Ferrara thrust systems. The resulting model provides new constraints on crustal heterogeneity and seismogenic structures beneath the Emilia-Romagna region and contributes to improving the seismotectonic interpretation of the 2012 Emilia earthquake region.

In addition, relative earthquake relocation using the HypoDD algorithm (Waldhauser & Ellsworth, 2000) was performed to improve hypocentral accuracy and better define the geometry of active fault structures. The relocated seismicity shows tighter event clustering and improved delineation of the Mirandola and Ferrara thrust systems, providing additional constraints for the interpretation of the tomographic results.

Improta L. et al. (2023) - Joint inversion of geodetic and strong motion data for the 2012 Mw 6.1-6.0 Northern Italy earthquakes: Source models and seismotectonic interpretation. J. Geophys. Res. Solid Earth, 128, e2022JB026278, https://doi.org/10.1029/2022JB026278.

Koulakov I. (2009) - LOTOS code for local earthquake tomographic inversion: Benchmarks for testing tomographic algorithms. Bull. Seismol. Soc. Am., 99(1), 194-214, https://doi.org/10.1785/0120080013.

Orecchio B. et al. (2011) - Imaging the velocity structure of the Calabrian Arc region (southern Italy) through the integration of different seismological data. Boll. Geof. Teor. Appl., 52(4), 625-638, https://doi.org/10.4430/bgta0023.

Waldhauser F. & Ellsworth W.L. (2000) - A double-difference earthquake location algorithm: Method and application to the Northern Hayward Fault, California. Bull. Seismol. Soc. Am., 90(6), 1353-1368, https://doi.org/10.1785/0120000006.

Attenuation tomography in the Val d'Agri region

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Keywords: attenuation, tomography, coda waves.

The Val d'Agri region represents a well-instrumented natural laboratory for investigating the interactions among active tectonics, crustal fluids, and industrial operations within a structurally complex sedimentary and carbonate reservoir system of the southern Apennines. Long-term hydrocarbon production, fluid reinjection, and continuous microseismic monitoring provide a unique opportunity to image reservoir-scale heterogeneity and fault-zone properties using passive seismic methods.

In this study, we apply seismic attenuation tomography to a dense local earthquake dataset recorded in the Val d'Agri area between 2020 and 2026, comprising more than 600 local events and over 8000 station-event pairs. The analysis is performed using *MuRAT4*, a new implementation of the Multi-Resolution seismic Attenuation Tomography workflow (Reiss et al., 2022; Talone et al., 2023), designed to image the spatial distribution of seismic energy loss through multi-frequency measurements of direct- and coda-wave amplitudes. The method separately estimates scattering- and absorption-related attenuation parameters, which are sensitive to lithological contrasts, fracture density, rock damage, and fluid saturation, thus providing complementary constraints to conventional velocity-based imaging (Improta et al., 2017).

The resulting attenuation models are analyzed within the geological and structural framework of the basin and integrated with available seismological, geological, and geophysical constraints, including earthquake hypocenter distribution and active fault systems. This multidisciplinary approach aims to investigate the spatial relationships among attenuation anomalies, structural heterogeneity, fluid circulation, and seismicity, providing new constraints on the physical properties of the shallow crust and on the processes controlling fault-fluid interactions in active reservoir systems.

This work highlights the potential of attenuation tomography as a complementary tool for high-resolution imaging and multidisciplinary characterization of faulted reservoirs and complex tectonic environments, with implications for geo-resource management and seismic hazard assessment.

Improta L. et al. (2017) - Reservoir structure and wastewater-induced seismicity at the Val d'Agri oilfield (Italy) shown by three-dimensional Vp and Vp/Vs local earthquake tomography. Journal of Geophysical Research: Solid Earth, 122, 9050-9082, https://doi.org/10.1002/2017JB014725.

Reiss M. C. et al. (2022) - The interconnected magmatic plumbing system of the Natron Rift. Geophysical Research Letters, 49, e2022GL098922, https://doi.org/10.1029/2022GL098922.

Talone D. et al. (2023) - The attenuation and scattering signature of fluid reservoirs and tectonic interactions in the Central-Southern Apennines (Italy). Geophysical Research Letters, 50, e2023GL106074, https://doi.org/10.1029/2023GL106074.

Crustal structure and associated fluid pathways along major fault systems of the Western Hellenic Arc (Greece) inferred from body wave travel-time tomography

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Keywords: Western Hellenic subduction zone, 3D velocity structure, deep fluid pathways.

The Western Hellenic Subduction Zone (WHSZ) represents one of the most seismically active and tectonically complex regions in the Mediterranean. This zone is defined by the rapid convergence between the African Plate (specifically the Ionian oceanic lithosphere) and the Aegean microplate. The geodynamic setting of the WHSZ is characterized by the consumption of the Ionian oceanic lithosphere beneath the Hellenic Arc, a process occurring at rates significantly higher than the relative motion between Africa and Eurasia due to the slab rollback. Notwithstanding the available local and teleseismic tomographic models provide a overall structure and geometry of the WHSZ, the detailed deep structure of the Western Hellenic Arc remain to be fully investigated. Here, we focus on the area encompassing a large portion of the Western Peloponnese (part of the Aegean overriding plate) bounded by the Gulf of Corinth to the east and the Cephalonia Transform Fault to the west, to better characterize its structural setting and 3D velocity structure. We performed a local earthquake tomography study, based on the linearized, iterative, damped least-squares inversion method. Specifically, we produced high-resolution Vp and Vp/Vs models down to ~20 km depth. The analysis, exploited a catalogue of high-quality location earthquakes recorded from 2016 to 2019 by the permanent and temporary seismic stations, mainly belonging to the Hellenic Unified Seismic Network (HUSN). Our 3D tomographic results show significant lateral and vertical variation in body-wave velocity, identifying a fragmented and patchy low- and high-velocity bodies. In particular, we identified a distinct spatial distribution of these anomalies: shallower layers in the western sectors are characterized by relatively high Vp and Vp/Vs, whereas towards the eastern sector the values of Vp and Vp/Vs decrease and widen. As depth increases, the high and low-velocity bodies progressively migrate toward the east, accompanied by a deepening of low-velocity anomalies. This trend aligns with the geometry of the subducting slab top, estimated at 20-30 km depth in this region and gentle dipping eastward. These results provide importa constraints on the coupling between crustal fault systems and the underlying slab dynamics, offering a better understanding of the geodynamics of the Western Hellenic Arc.

Deep structure of the Central Mediterranean: Moho geometry and Ionian crustal seismogenic volume

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Keywords: Moho, Ionian slab, Central Mediterranean.

The Central Mediterranean represents one of the most geodynamically complex regions in the world, resulting from the ongoing convergence between the African and Eurasian plates. This tectonic framework is further complicated by the coexistence of a collisional system and an active subduction system, the latter involving the Ionian lithosphere. These interactions produce strong lateral heterogeneities in crustal and upper mantle structures, leading to significant variations in the geometry of the Moho discontinuity and in the configuration of the Ionian lithosphere in subduction. Defining these deep structures with high accuracy is essential for improving the understanding of the geodynamic evolution of the region and for better constraining the associated seismic and tsunami hazards.

In this work, we present the most complete and highest-resolution Moho map currently available for the Central Mediterranean, obtained through the integration of multidisciplinary geophysical and geological datasets. The model was developed using P- and S-wave velocity models, gravimetric profiles, interpreted seismic profiles, well data, and seismic profile conversions from two-way travel time (TWT) to depth (e.g., Makris et al., 1986; Scarascia et al., 1994; Catalano et al., 2000; Dellong et al., 2020). The integration of heterogeneous datasets allowed the reconstruction of a coherent and detailed crust-mantle boundary surface, highlighting the main geometrical and structural variations of the Moho across the different tectonic domains of the region.

To further investigate the geometry and characteristics of the Ionian subduction system, we reconstructed the Crustal Seismogenic Volume (CSV) of the subducting Ionian slab using a dataset of optimized earthquake hypocenters. From the seismicity distribution, we derived both the top and bottom surfaces of the crustal seismogenic volume and analyzed their main geometric properties, including dip, azimuth, curvature, and thickness variations represented by the distance between the two bounding surfaces.

In addition, the reconstructed slab geometry was compared with other subduction surfaces proposed in previous studies, allowing the identification of significant similarities and discrepancies related to differences in datasets, methodologies, and earthquake localization procedures. The comparison between models obtained using optimized and non-optimized hypocentral datasets highlights the critical role of accurate earthquake relocation in defining reliable deep structural models.

The resulting models provide new constraints on the deep tectonic architecture of the Central Mediterranean and contribute to a better understanding of the active geodynamic processes controlling the evolution of the Ionian subduction system. These results also represent an important framework for future studies focused on lithospheric dynamics, seismic source characterization, and regional seismic and tsunami hazard assessment.

Makris J. et al. (1986) - A seismic study in the Western Ionian Sea. Ann. Geophys., 4(6), 665-678.

Scarascia S. et al. (1994) - Crustal structures of the Ligurian, Tyrrhenian and Ionian Seas and adjacent onshore areas interpreted from wide-angle seismic profiles. Boll. Geof. Teor. Appl., 36(141-144), 5-19.

Catalano R. et al. (2000) - Central western Sicily structural setting interpreted from seismic reflection profiles. Mem. Soc. Geol. It., 55, 5-16.

Dellong D. et al. (2020) - Geometry of the deep Calabrian subduction (Central Mediterranean Sea) from wide-angle seismic data and 3-D gravity modeling. Geochem. Geophys. Geosyst., 21(3), https://doi.org/10.1029/2019GC008586.

Balanced geological cross sections across the central Apennines reveal an intimate connection between paleogeography and structural inheritance in shaping current seismotectonics

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Keywords: seismotectonics, central Apennines, balanced geological sections.

The Central Apennines in Italy are a high-seismic-hazard region with complex geology. Several seismic sequences, such as the 1997 Umbria-Marche, 2009 L'Aquila-Campotosto, and 2016-2017 Amatrice-Visso-Norcia-Campotosto, linked to post-orogenic extension, have affected the region. Recent literature highlights how inherited structures, such as thrusts and normal faults, may reactivate within the active extensional regime and interact with one another, thereby influencing present-day earthquakes. We built several geological cross sections and 3D structural models along the backbone of the Central Apennines, based on a deep reanalysis and post-processing of commercial seismic profiles, along with stratigraphic and geophysical data from exploration wells. We validated the interpretation by performing restoration and balancing of the geological sections to assess whether the modeled fault geometries were geometrically and kinematically plausible, and to compare the modeling with the observed seismicity recorded along the chain over the last 30 years. Findings help place new, robust geological constraints on the seismogenesis of the Central Apennines, given the striking similarities between recent seismic sequences and the very complex geological and structural arrangement of the Central Apennines. In particular, our results reveal a major issue controlling the seismic behavior of this portion of the chain: vertical and horizontal compartmentalization of the shallow crust by thrusts and segmented, inherited normal faults, the reactivation of pre-existing faults, and the possible role of large thrusts and peculiar units as rheological barriers that can promote the overpressuring of fluids at depth. Our findings open the door to new discussions on a more refined seismic-hazards assessment and tectonic activity in the Central Apennines.

From underplating to delamination in the Apennines: implications for continental crust exhumation

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Keywords: tomography, Apennines.

The mechanisms governing continental lithosphere subduction and the exhumation of subducted material along convergent margins remain poorly understood. Here, we present new geophysical constraints on these processes in the Cenozoic northern Apennines, a key case characterized by the availability of an extensive literature on HP exhumed rocks (Rossetti et al., 1999; Brun & Faccenna, 2008, Giuntoli et al., 2024) and data related to its lithospheric structure.

We combined 3D Vp and Vp/Vs models from Menichelli et al. (2023) with the analysis of new receiver functions to image the heterogeneous lithospheric structure. These data allow us to reconstruct the subduction evolution from its earliest stages, revealing a spatial and temporal transition from underplating of thick, high-velocity crustal material in the back-arc to the rise of low-Vs asthenosphere following delamination.

The novelty of the work resides in showing how, although the seismic data represent only a current snapshot of the continental subduction process, they preserve information about the entire orogenic evolution over the past 20-30 Myr.

Our results indicate that this switch drove a two-step exhumation history: an initial phase of synorogenic burial and crustal thickening during underplating, followed by accelerated HP-LT exhumation triggered by the onset of delamination at ~16 Ma. We propose that underplating characterizes the early stages of continental subduction, promoting lithospheric thickening whereas delamination acts as the key process to unlock the rollback of the slab. The resulting extensional tectonics then provides the driving force for the rapid exhumation of deeply subducted crustal material.

These findings offer a coherent framework linking deep lithospheric processes to surface tectonics in the Apennines, with broader implications for continental subduction zones worldwide.

Brun J.-P. & Faccenna C. (2008) - Exhumation of high-pressure rocks driven by slab rollback. Earth Planet. Sci. Lett., 272, 1-7.

Giuntoli F. et al. (2024) - Dating syn-orogenic exhumation of subducted continental crust: The case of the Northern Apennines. Lithos, 488, 107801.

Menichelli I. et al. (2023) - Lithosphere structure, processes, and physical state of the Alpine-Apennine System. Journal of Geophysical Research: Solid Earth, 3 128(4), e2023JB026411.

Rossetti F. et al. (1999) - Syn-versus post-orogenic extension: the case study of Giglio Island (Northern Tyrrhenian Sea, Italy). Tectonophysics, 304, 71-93.

Tracking stress and fluid dynamics at Etna volcano with 4-D transdimensional anisotropic seismic imaging

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Keywords: 4-D anisotropic seismic imaging, volcanic stress field, Mount Etna.

Crustal forces at volcanoes arise from the interplay of multiple stress sources, some of which evolve under the influence of magmatic system dynamics. In this context, the history of volcanic activity, stress, and crustal architecture are interconnected. However, while surface manifestations of volcanic activity are directly observable, the subsurface conditions and processes that lead to volcanic episodes remain largely uncertain, hampering forecasts of volcanic activity with potential impact on the population. To map the heterogeneous subsurface conditions and dynamics at volcanoes, seismology represents a powerful monitoring tool. Volcanic structure and evolution influence seismic wave velocities, making seismic wave travel times sensitive observables. In this framework, fluid- filled fractures tend to open along the least compressive stress directions, producing direction- dependent seismic wave velocities (seismic anisotropy; Crampin, 1981). Anisotropic seismic imaging - by inverting wave travel times to reconstruct the heterogeneous anisotropic seismic velocities - is the main tool for constraining fluids in aligned fractures and stress fields beneath volcanoes (Del Piccolo et al., 2025). Traditional seismic imaging is based on the inversion of travel-time data grouped into discrete time windows, typically before and after major volcanic events. However, the images produced can be discontinuous and potentially affected by artificial differences arising from the uneven spatial/temporal distribution of the earthquakes. Here, we implement a four-dimensional (4-D) anisotropic seismic imaging technique based on a transdimensional probabilistic approach (Del Piccolo et al., 2024, 2025) to: (1) provide time-continuous mapping of the subsurface seismic speeds, stress, and fluid in aligned cracks beneath volcanoes; (2) account for the spatial/temporal heterogeneous data coverage by employing adaptive 4-D meshes for the reconstructed seismic velocities; and (3) quantify uncertainties through to the probabilistic exploration of multiple seismic velocity models compatible with the data. The method is applied to a dataset of P-wave travel times collected over the last twenty years by INGV-OE at Mount Etna, one of the most active and monitored volcanoes in the world.

Crampin S. (1981) - A review of wave motion in anisotropic and cracked elastic-media. Wave Motion, 3(4), 343-391.

Del Piccolo G. et al. (2024) - Imaging Upper-Mantle Anisotropy with Transdimensional Bayesian Monte Carlo Sampling. Bull. Seismol. Soc. Am., 114(3), 1214-1226.

Del Piccolo G. et al. (2025) - Pressurized magma storage in radial dike network beneath Etna volcano evidenced with P-wave anisotropic imaging. Commun. Earth Environ., 6, 405.

Hydrogen reactions with lower-crustal anorthosites: from experiments to the Lofoten Islands

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Keywords: hydrogen, anorthosite, garnet.

Recent work shows that hydrogen can react with anhydrous crustal and mantle rocks to produce free water and hydrous minerals (Vitale Brovarone et al., 2026). This process is especially relevant to dry lithological domains where access of free water is hampered by physical (e.g., permeability) or geodynamic (e.g. lack of subduction) conditions, such as the lower crust. This work investigates reactions between hydrogen and lower-crustal anorthosites using both piston-cylinder double capsule experiments and natural equivalents from the Lofoten anorthosites. Synthetic anorthite (An) and magnetite (Mt) were reacted with molecular H_2 to assess kinetics (duration of 1.2 vs. 12 days), compositional effects (Mt:An ratio 50:50 vs. 10:90), and temperature dependence (600 vs. 700°C).

Quadrupole mass spectrometry (QMS) showed H_2O produced across all experiments, ranging from 8-18 µmol. Reacting sample with a 50:50 Mt:An ratio at 700°C led to formation of garnet, fayalite, wüstite, and spinel, and ~18µmol H_2O, in agreement with predicted phases and fluid species from thermodynamic modeling. Pockets 2O (~16µmol) was produced despite the duration being $1/10^{th}$ of the original.

Reacting sample with a lower (10:90) mt:an ratio at 600°C resulted in the formation of small garnet clusters with the same Ca-enrichment zoning trend, corundum, epidote needles, and 8µmol of H_2O.

To compare this simplified synthetic system to more complex natural assemblages, we then investigated anorthosites from Lofoten, Norway, particularly with anorthite and garnet-rimmed magnetite. Fluid inclusions of CO_2, CH_4, and N_2 in anorthite suggest it is unlikely that H_2-fluids were involved in the formation of these phases.

Mt-An-H_2 experiments show 1) large agreement with predicted phases from thermodynamic models, 2) H_2O production and formation of pockets lined with garnet, suggesting formation of free water from an initially dry system, 3) introduction of element solubility and mobility, as suggested by garnet zoning from the edge inwards of pockets, 4) a higher Mt:An ratio is kinetically favorable, with incipient spinel formation potentially suggesting open space growth from intragranular fluids. Ongoing fluid inclusion characterization will provide additional insights on the potential availability of H_2 and formation of aqueous fluids.

Vitale Brovarone et al. (2026) - Hydration, not dehydration, recorded by the onset of deserpentinization in subduction zones. Science Advanced (in press).

Using seismic attenuation to track fluid migration and fault structures: Examples from Italy and Türkiye

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Keywords: attenuation, tectonics, fluids.

Seismic attenuation, a measure of the energy loss experienced by seismic waves as they propagate, serves as a powerful proxy for investigating the thermal, structural, and rheological properties of the Earth's crust. Controlled by parameters such as rock composition, temperature, and fluid content, the separation of total attenuation into scattering and absorption provides crucial information on material fracturing and fluid presence. In this study, we track the spatial and temporal variations of attenuation parameters before and during two major seismic sequences: the Central Apennines (Italy, 2016-2017) and the East Anatolian Fault Zone (Türkiye, 2023).

We employ a multi-methodological approach: scattering is mapped using the Peak Delay method via regionalization technique; variations in intrinsic absorption are imaged via coda wave attenuation tomography and, for a large dataset, regionalization. For both case studies, analyses are divided into a pre-sequence and sequence phase to observe variation in space and time.

In the 2016 Central Apennines sequence, the pre-phase shows high scattering as tightly focused along major tectonic features, such as the Monti Sibillini thrust. Following the 2016 Amatrice mainshock, we observe a drop in scattering together with an increase in pore fluid pressure within the Triassic sedimentary succession. Coda-Q mapping further reveals a rapid transition from a steady pre-sequence absorption trend to a dynamic migration of deep CO_2-rich fluids across the fracturing network during the sequence.

In Türkiye, scattering maps successfully delineate a strong lithological contrast across the East Anatolian Fault (EAF) during both phases: the northern sector exhibits high scattering associated with Quaternary sedimentary rocks, whereas the southern sector displays low scattering correlated with ophiolitic rocks. Coda-Q variation in space does not detect main changes; however, the timelines before the Mw7.8 event identify attenuation changes that correspond to moderate pre-sequence events in the area. This indicates that seismic attenuation records a temporal fingerprint of evolving crustal conditions.

These findings demonstrate that attenuation imaging is not only useful for structural geology but also for capturing crustal modifications beyond the general post-earthquake damage observation.

Improving the physical interpretability of tomographic models through trans-dimensional local earthquake tomography

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Keywords: seismic tomograhy, Bayesian methods.

The interpretation of tomographic models is frequently hampered by inherent ambiguities, especially when they lack reliable values of absolute velocities and associated uncertainties and/or when the geometries of subsurface structures are blurred by limitations intrinsic to the inversion methods and by the assumed subsurface parametrization.

Advances in non-linear Bayesian tomography are opening new opportunities for high-resolution 3D and 4D imaging of subsurface structures. Further improvements can be achieved by incorporating thermodynamic relationships between temperature, composition, mineralogy, density, and seismic velocities directly into the Bayesian framework, thereby restricting the solution space to petrologically and thermally consistent models.

Regardless of whether the seismic data are inverted to derive seismic velocities or directly petrophysical parameters, the development and refinement of Bayesian methods tailored to each specific type of tomography represent essential prerequisites, allowing the limitations of linearized approaches to be overcome.

Here, we show how the use of a trans-dimensional Bayesian approach applied to local earthquake tomography—that is, the joint determination of Vp and Vs structures and earthquake locations from local arrival-time data—outperforms linearized methods. Results obtained in fault regions, including the Alto Tiberina Fault and Parkfield, volcanic areas such as Mt. Etna and Campi Flegrei, and orogenic settings such as the Apennines, consistently demonstrate a notable increase in the level of detail of the imaged subsurface structures, a better fit between absolute velocity values and borehole measurements, and substantial differences in the estimation of the Vp/Vs ratio. This latter point is particularly relevant, given that the Vp/Vs ratio can be used, for example, as a proxy for fluid detection.

Furthermore, we show that some specific technical issues related to the use of local earthquake data must be carefully addressed. For instance, the coupling between velocity structure and earthquake locations cannot be neglected, especially in the presence of strong velocity heterogeneities, as expected in volcanic settings. Surface topography must also be properly accounted for, in order to correctly model ray tracing in areas characterized by steep topographic gradients.

Crust-mantle transition and Moho gap beneath the Eastern Alps: Insights from receiver functions pseudo-tomography

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Keywords: Eastern Alps, receiver functions, Moho gap.

The Eastern Alps represent a key transition zone between the tip lines of the collisional Alpine and Dinaric belts, two independent subduction zones, which are still alive at low rates of convergence (1-2 mm/yr). This oblique crustal-lithospheric overlap has been stretched by the westermost extensional Pannonian Basin, where the nature and the geometry of the crust-mantle transition remains debated (Castellarin et al., 2006). In particular, the presence of a "Moho gap", characterized by the absence of a clear seismic discontinuity, has been reported in previous studies (Spada et al., 2013), but its origin and spatial extent are still unclear.

In this study, we investigate the geometry of the crust-mantle transition beneath the Eastern Alps using receiver functions derived from the AlpArray Seismic Network (Hetényi et al., 2018). More than 12,000 receiver functions recorded at 87 stations are inverted to obtain 127 one-dimensional S-wave velocity profiles along nine transects across the study area. These profiles are integrated into a pseudo-three-dimensional shear-wave velocity model down to 100 km depth.

The resulting model reveals a strongly heterogeneous lithospheric structure and confirms the presence of a diffuse or locally unresolved crust-mantle transition in the central part of the study region, as inferred from S-wave velocity profiles obtained through receiver function inversion. This zone of weak or missing Moho signal spatially correlates with the area of the Tauern Window and with the region previously identified as the Moho gap. In this sector, the transition from crustal to mantle velocities is gradual, and mantle-like velocities are not always reached within the investigated depth range.

In contrast, a well-defined Moho is observed toward both the northern foreland and the Pannonian domain, where the crust becomes progressively thinner, consistent with previous velocity models (Molinari et al., 2020). The overall geometry highlights the coexistence of crustal thickening beneath the Alpine belt, diffuse crust-mantle transitions in its central sector, and lithospheric thinning toward the east.

These results provide new constraints on the three-dimensional architecture of the Eastern Alpine lithosphere and suggest that the "Moho gap" is closely linked to the complex tectonic processes affecting the central Alpine region, including continental subduction, crustal stacking, and lithospheric deformation associated with Adriatic indentation.

Castellarin A. et al. (2006) - Structure of the lithosphere beneath the Eastern Alps (southern sector of the TRANSALP transect). Tectonophysics, 414(1-4), 259-282.

Hetényi G. et al. (2018) - The AlpArray seismic network: a large-scale European experiment to image the Alpine Orogen. Surveys in Geophysics, 39(5), 1009-1033.

Molinari I. et al. (2020) - 3D crustal structure of the Eastern Alpine region from ambient noise tomography. Results in Geophysical Sciences, 1, 100006.

Spada M. (2013) - Combining controlled-source seismology and receiver function information to derive 3-D Moho topography for Italy. Geophysical Journal International, 194(2), 1050-1068.

Trans-lithospheric imaging of the Tuscan magmatic province

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Keywords: tomography, seismology, geothermal.

The Tuscan Magmatic Province (TMP), Italy, is an ideal natural laboratory to investigate how mantle processes, tectonics, magmatism and geothermal systems are coupled across scales, from the upper mantle to shallow geothermal reservoirs. Building on recent work that images thousands of cubic kilometres of magma and partial melt stored in the mid-crust beneath southern Tuscany, we first frame the TMP within a geodynamic context using tele seismic tomography. We then bridge these deep structures to the upper crust by harvesting data collected by broadband regional networks and dense nodal arrays performing high-resolution ambient-noise tomography across the TMP. This integrated trans-lithospheric imaging reveals how sub-vertical low-velocity conduits rooted in the mantle and lower crust feed mid-crustal magma and supercritical fluid domains, and how these, in turn, connect upwards to permeable fault zones and reservoirs currently exploited for geothermal energy. Our results highlight the importance of combining regional and nodal-scale tomographic models with geological and geophysical observations to reduce interpretational ambiguities, quantify the volume and distribution of magmatic and fluid phases in the TMP. Our multiscale seismic imaging shows how an integrated passive seismic approach could help addressing some long-standing questions and better constrain the nature of the interplay between long- and short-term geological processes.

Compositions and dynamics of a continental crust-mantle transition

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Keywords: Ivrea-Verbano Zone, dunites, Nd-Sr-O isotopic compositions.

The compositions and dynamics of the crust-mantle transition remain a major challenge in unraveling the building of the Earth's lithosphere. In oceanic settings, this interface is typically marked by a dunite horizon mostly formed through reactive porous melt flow, whereas oceanic arc-related transitions are dominated by peridotite-pyroxenite alternations and amphibole-rich cumulates. The continental crust-mantle transitions are noticeably still poorly constrained, due to limited exposure.

The Ivrea-Verbano Zone from Italian-Swiss Alps exposes a nearly complete section of lower continental crust and includes the Permian Mafic Complex (~8 km thick), a gabbroic intrusion whose basal levels host mantle peridotite bodies. This study presents new petrological and geochemical data on the mafic-ultramafic rocks adjacent to the mantle bodies, aiming at constraining the building and the evolution of the continental crust-mantle transition. The mantle-gabbro transition (Contact Series, up to 150 m thick) is compositionally heterogeneous and consists of websterites, gabbronorites and, close to the mantle peridotites, minor dunites. The Mafic Complex gabbronorites adjacent to the Contact Series host several dunite lenses, which are up to a few tens of meters thick and are crosscut by websterite veins and gabbronorite dykes.

Based on trace element and Nd-Sr-O isotopic compositions, we show that the mantle magmas forming the websterites of the Contact Series were derived from a depleted mantle source, although they typically record crustal contamination and/or melt-rock reaction processes. The Contact Series dunites (Fo_{87} olivine + accessory orthopyroxene, clinopyroxene, spinel and sulfides), consistently possess a depleted Nd-Sr-O signature. On the other hand, the Mafic Complex dunites (Fo_{85} olivine + accessory clinopyroxene, amphibole, phlogopite, spinel and sulfides) display enriched Nd-Sr isotopic compositions coupled with slightly elevated $\delta^{18}O$. Despite these compositional differences, clinopyroxene from both dunite-types displays spoon-shaped REE patterns similar to clinopyroxene in replacive mantle dunites from ophiolites. Websterites and gabbronorites within the Mafic Complex dunites are chemically and isotopically similar to some of the Contact Series counterparts.

We speculate that the original continental crust-mantle transition consisted of a continuous dunite horizon that was subsequently modified by the following sequence of events: (i) diffuse reactive percolation of olivine-saturated melts possessing different isotopic signatures; (ii) reactive formation of websterites locally associated with assimilation of crustal material; and (iii) dissection of the ultramafic, reacted horizon by gabbronorite intrusions related to the early growth of the Mafic Complex.

Transient high stresses during the earthquake cycle in the lower crust and their preservation in the geological record

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Keywords: lower-crustal earthquakes, microstructures, seismogenic faults.

Field studies established that seismicity in the lower crust is linked to brittle failure of dry, strong rocks. This implies build-up of differential stresses to gigapascal levels, but this requirement contrasts with the current models of continental lithosphere deformation, which typically favour a distributed flow of weak viscous lower crust. Thus, the mechanisms capable of generating transiently high stresses in the lower crust and the magnitude of stresses released during lower-crustal earthquakes are fundamental research questions.

Nusfjord (Lofoten, northern Norway) is one of the few localities worldwide that exposes lower-crustal exhumed earthquake sources, where pseudotachylytes (quenched frictional melt produced during seismic slip) and mylonites (product of aseismic viscous creep) formed at a depth of ca. 30 km. Seismicity occurred during the collisional stage of the Caledonian orogeny, around 420 Ma ago (Zertani et al., 2024), in stiff, granulitic anorthosite host rock. Pseudotachylytes occur in rigid blocks of anorthosite bounded by a network of ductile shear zones and are interpreted to record earthquakes nucleation triggered by transient gigapascal-level stress amplifications in the stiff lenses of anorthosite during coeval aseismic creep in the ductile shear zones (Campbell et al., 2020). While the stress amplification model is supported by field observations, quantification of the magnitude of stress amplification in the Nusfjord shear zone network remains unresolved. Furthermore, the effects of short-lived high-stress deformation on the rock microstructure is a matter of debate.

Here we present a suite of numerical models tailored to the geology of the Nusfjord earthquake source, to test how variations in geometry, material properties, and loading conditions impact magnitude and rate of stress amplification. We demonstrate that for a wide range of conditions, gigapascal-level stress amplification in the Nusfjord stiff blocks is inevitable. Strain rate in the bounding shear zones is the decisive factor for stress amplification: at realistic strain rates of 10^{-12} - 10^{-10} s^{-1} sufficiently high stresses for earthquake nucleation are reached within 10^{0}-10^{2} years (Zertani et al., 2025). The release of such high stresses during the coseismic processes impart various types of damage to seismically shocked mineral grains, including the generations of new lattice defects (dislocations). Diopside clasts in Nusfjord pseudotachylytes retain internal residual stress heterogeneity ranging between ~200 MPa and ~800 MPa (measured with HR-EBSD), which correlates with the density of dislocations generated during the propagation of the earthquake rupture (van Schrojenstein Lantman et al., 2025). Thus, extremely high stresses can be generated transiently in the lower crust and are partially preserved in the microstructure of seismogenic fault rocks.

Campbell L.R. et al. (2020) - Earthquake nucleation in the lower crust by local stress amplification. Nature Communications, 11, 1322, https://doi.org/10.1038/s41467-020-15150-x.

van Schrojenstein Lantman H.W. et al. (2025) - Residual stress in diopside: insight into localized transient high stress in seismogenic faults in the lower crust, Lofoten, Norway. Journal of Structural Geology, 200, 105517, https://doi.org/10.1016/j.jsg.2025.105517.

Zertani S. et al. (2024) - Dating fossil lower-crustal earthquakes by in-situ apatite U-Pb geochronology. Earth and Planetary Science Letters, 630, 118621, https://doi.org/10.1016/j.epsl.2024.118621.

Zertani S. (2025) - Lower-crustal earthquakes: strain rate controls the magnitude and rate of stress amplification in rigid blocks. Geophysical Research Letters, 52, e2024GL114350, https://doi.org/10.1029/2024GL114350.

Fluid reservoir detection in tectonic and geothermal environment

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Keywords: attenuation, fluids, tectonic, geothermal.

Seismic imaging has long been a fundamental tool for understanding the role of fluids within the Earth's crust and upper mantle. Fluids strongly influence fault mechanics, crustal deformation, and the development of geothermal and magmatic systems. Over the years, traditional travel-time tomography, together with more recent advances in seismic noise tomography enabled by increasingly dense seismic networks, has significantly improved our ability to image the subsurface, revealing spatial variations in elastic and anelastic properties.

In this framework, seismic scattering and intrinsic absorption have emerged as powerful and complementary proxies for characterizing fault zones and identifying fluid-rich domains. Scattering is primarily associated with structural heterogeneities and wave trapping processes that redistribute seismic energy within the coda, whereas intrinsic absorption is directly sensitive to the presence of fluids. These parameters can be estimated through peak delay time and coda-Q analyses, as implemented in the open-source MuRAT code. The joint interpretation of scattering and absorption is increasingly becoming a standard approach in seismology, as it provides a more comprehensive view of subsurface processes by constraining different physical properties within the same volume. This methodology has already proven effective in a variety of geological settings, including tectonic, volcanic, and geothermal environments.

In this presentation, we illustrate the results of two recent applications of this approach in different geological contexts: the High Agri Valley (Southern Italy), representative of an active tectonic setting, and the Hengill geothermal field (Iceland), a well-known high-enthalpy geothermal system. By comparing these case studies, we highlight how the combined analysis of scattering and absorption can effectively delineate fluid distribution and structural complexity. These insights not only improve our understanding of active geodynamic processes, but also provide valuable constraints for assessing geothermal potential and guiding future exploration strategies, particularly in regions such as Italy where sustainable energy development is a growing priority.

Calcite-quartz mylonites and shear zone rheology: Case studies from the Alpi Apuane

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Keywords: carbonate rheology, calcite-quartz mylonite, shear zone.

Ductile shear zones provide direct insights into how deformation localizes and how rock rheology evolves in the middle to lower crust. In mixed-composition carbonate rocks, strain localization is primarily governed by the interplay between dynamic recrystallization, grain-size reduction, phase mixing and fluid-rock interaction, which progressively change the mechanical behaviour of the aggregate (Platt & Behr, 2011; Cross & Skemer, 2017). This study investigates the interaction of these processes during strain localization by focusing on two calcite-quartz shear zones in the Alpi Apuane Metamorphic Complex. The two shear zones affect the same meta-cherty limestone protolith but developed at different temperature conditions and record contrasting high-strain fabrics, providing an opportunity to assess how progressive strain, temperature and microstructural evolution control effective rock rheology during deformation. An integrated approach combining field structural analysis, microstructural observations, flow stress estimates with paleopiezometry, extrapolation of experimental flow laws to natural conditions, and numerical modelling of boudinage was applied.

Field data reveal that deformation in a multilayer carbonate-chert system was initially expressed as folding under simple shear and progressively focused along fold limbs, where necking and boudinage of competent layers represent the earliest stages of strain localization. Microstructural analyses indicate that, at lower strain, deformation was partitioned between a very weak, fine-grained matrix deforming by grain-size-sensitive mechanisms and relatively stronger calcite- and quartz-rich domains. With increasing strain, progressive necking, grain-size reduction and phase mixing modify the aggregate rheology. In the higher-temperature shear zone (~420 °C), these processes led to a reduction of the viscosity ratio and to a homogeneous, fine-grained fabric dominated by grain-size-sensitive deformation. By contrast, the lower-temperature (~350 °C) shear zone preserves a post-localization stage characterized by persistent strain partitioning and boudinage (Schmalholz et al., 2008). Microstructural evidence of dissolution-precipitation features, micro-porosity and second-phase pinning indicates that fluids contributed to weakening and strain accommodation (Ebert et al., 2007). These results, combined with numerical modelling of boudinage and paleopiezometry, support a model in which the rheological transition in calcite-quartz shear zones is primarily strain-dependent, evolving through the interaction between strain localization, grain-size evolution, phase mixing and fluid-assisted processes, while temperature mainly acts as a secondary catalyst. Boudinage may therefore represent a transitional structure linking early rheological partitioning to late-stage mechanical homogenization in high-strain mixed-composition shear zones.

Cross A.J. & Skemer P. (2017) - Ultramylonite generation via phase mixing in high-strain experiments. Journal of Geophysical Research: Solid Earth, 122(3), 1744-1759, https://doi.org/10.1002/2016JB013801.

Ebert A. et al. (2007) - Microfabrics in carbonate mylonites along a large-scale shear zone (Helvetic Alps). Tectonophysics, 444, 1-26, https://doi.org/10.1016/j.tecto.2007.07.004.

Platt J.P. & Behr W.M. (2011) - Grainsize evolution in ductile shear zones: Implications for strain localization and the strength of the lithosphere. Journal of Structural Geology, 33(4), 537-550, https://doi.org/10.1016/j.jsg.2011.01.018.

Schmalholz S.M. et al. (2008) - Evolution of pinch-and-swell structures in a power-law layer. Journal of Structural Geology, 30(5), 649-663, https://doi.org/10.1016/j.jsg.2008.01.002.

Probing the shallow structure of the Mt. Moncuni ultramafic massif (Italian Western Alps) through the deployment of a dense nodal array

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Keywords: NANT, intermediate-depth earthquakes, pseudotachylites.

Understanding the nucleation environment of intermediate-depth earthquakes in subduction settings remains a major unresolved question.

To address this challenge, we studied the Mt. Moncuni ultramafic massif, in the external sector of the Italian Western Alps (Lanzo tectonic unit). Here, ultra-mafic rocks exhumed from depths >80 km preserve an exceptional geological record of seismic slip—including pseudotachylites formed at 70-90 km depth—nucleated in dry conditions.

We present the methodology and the results of nodal ambient noise tomography (NANT) with a dense nodal array performed within the framework of the PRIN THALES project, aimed at investigating the geology and the nucleation environment of intermediate-depth earthquakes.

Since the region is characterized by a low background seismicity that hampers classical local earthquake tomography, we deployed a dense array of 197 three-component nodes across a 290 km² area for approximately 30 days (December 2022 to January 2023).

Initial data quality checks via power spectral density analysis confirmed an excellent ambient noise signal in the 1-10 second period range suitable for NANT. The array's high sensitivity was further validated by the clear detection of a teleseismic Mw 7.6 event, whose first P-wave delay times indicated a highly heterogeneous upper crust and a prominent high-velocity body in the central region.

Building on these high-quality ambient noise recordings, we developed the first high-resolution 3D shear-wave velocity (Vs) model of the southern Lanzo massif down to 5 km depth using NANT. Our investigation imaged the subsurface structure of the Moncuni body, revealing a massive, coherent high-Vs anomaly (4200-4700 m/s) in the topmost 5 km that we interpret as a mantle sliver with a nearly pristine peridotite core. We also found evidence of sharp discontinuities defining major crustal-scale shear zones. These extreme Vs values and the resolved subsurface geometry provide critical geophysical evidence for the nucleation environment of intermediate-depth earthquakes.

Using the Collalto UGS seismic network as an on-site laboratory to image fluid-related anomalies with seismic attenuation tomography

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Keywords: attenuation tomography, seismicity, underground gas storage.

Seismic waves propagating through heterogeneous crustal media carry information about the elastic and anelastic properties of the rocks they traverse. By analysing different portions of seismograms, it is possible to investigate the physical mechanisms that control wave attenuation, such as scattering and intrinsic absorption. Attenuation tomography has been widely applied in volcanic environments and, more recently, in tectonic settings; however, its interpretation is partly limited by empirical constraints. Laboratory experiments have demonstrated the sensitivity of scattering models to fracture systems and strain accumulation zones (King et al., 2023), whereas similar constraints for absorption remain limited, mainly due to the complexity of reproducing dynamic fluid-rock interactions under controlled conditions.

The Collalto Underground Gas Storage (UGS) area, located in the eastern Southern Alps of northern Italy, offers an ideal setting for a field-scale experiment to test the detection capabilities of these methods. The study area lies within a complex tectonic region, and the seismic network dedicated to monitoring UGS injection and extraction operations, equipped with ten borehole seismometers, provides high-quality seismic records and a seismic catalogue with a magnitude of completeness close to zero around the reservoir. This combination of high-quality data, a well-characterized reservoir, and good knowledge of the local seismotectonic setting makes the area particularly suitable for investigating the sensitivity of attenuation-based imaging to structural features, fluids, and stress-strain partitioning.

We applied the MuRAT3 (De Siena et al., 2014) software package, which allows for attenuation, scattering, and absorption tomography, to image the crustal sector around the Collalto UGS and the Montello thrust system. The analysis is performed at two scales to characterise both the broader seismotectonic framework and the smaller methane reservoir. This multiscale approach allows us to assess whether the identified scattering and absorption anomalies can resolve both regional fault-related structures and local fluid-related features. The scattering anomalies confirm the position and main geometry of the local thrust system. They also provide information on the deformation state of the fault zones, highlighting localized strain near the fault tips. The absorption model shows the position of the UGS reservoir, likely reflecting the attenuation effect of fluids within the permeable reservoir levels. It also reveals a deeper absorption anomaly, similarly interpreted as fluid-related, which spatially anti-correlates with the observed seismicity. The relationship between high absorption values and the spatio-temporal evolution of seismicity provides new constraints for discussing the role of fluids in earthquake occurrence and seismic energy release.

De Siena L. et al. (2014) - Multi-scale reasonable attenuation tomography analysis (MuRAT): An imaging algorithm designed for volcanic regions. J. Volcanol. Geotherm. Res., 277, 22-35, https://doi.org/10.1016/j.jvolgeores.2014.03.009.

King T. et al. (2023) - Mapping faults in the laboratory with seismic scattering 1: the laboratory perspective. Geophysical Journal International, 232, 1590-1599, https://doi.org/10.1093/gji/ggac409.

Lower crustal shear zones: the rheological behaviour of inherited residual anatectic rocks

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Keywords: thermal evolution, ductile-brittle transition.

Rheological models commonly consider the lower continental crust as a weak and ductile layer interposed between the mechanically stronger upper crust and uppermost mantle. However, seismological evidence (Maggi et al., 2000) showed that most earthquakes occur in the continental crust between 10 and 40 km depth, implying that the lower crust can locally sustain significant deviatoric stress.

Recent studies show that the strength of the lower crust is controlled by inherited metamorphic and partial melting processes that developed during different stages of the orogenic cycle. Devolatilization reactions and anatexis enhance crystal-plastic deformation in lower crustal fertile lithologies subject to medium-to-high thermal gradients. A critical scenario in this context is magmatic underplating, where a transient heat source drives partial melting in an already-metamorphosed crust (Maierová et al., 2023), modifying its physical properties and reshaping the brittle-ductile transition through time. Once the high thermal regime ceases, the mechanical behaviour of these rocks changes as they become almost dry and strong, thus prone to brittle failure (Jamtveit et al., 2018).

To investigate the thermo-mechanical evolution of the lower crust during transient heating events, we combine phase-equilibrium thermodynamic modelling with finite-element (FE) continuum simulations. The numerical model represents an idealized 35 km-thick crustal section, initialized using a conductive geothermal gradient of ~20 °C/km. Magmatic underplating is modelled as a single transient thermal perturbation superimposed on the initial conductive geotherm, allowing the thermal state of the lower crust to evolve dynamically through time. These thermal conditions simulate time-constrained peak metamorphic estimates for the late-Variscan lower crust exposed in the Serre Massif of Calabria (Fiannacca et al., 2024 and references therein), and the subsequent thermal relaxation with the development of ductile-brittle shear zones. Forward thermodynamic modelling is used to calculate temperature- and pressure-dependent mineral assemblages, melt fraction, and physical properties. These outputs are coupled to the FE simulations to dynamically update density, heat capacity, porosity, permeability and, consequently, the rheological behavior during heating and cooling at constant strain rates. Porous-flow transport based on Darcy formulation is used as a first-order approximation of melt/fluid redistribution, allowing the evolution of porosity, permeability and fluid velocity to interact with the thermal structure of the crust through time. Progressive lower-crustal melting promotes conductive-advective heat transfer and modifies the rheological architecture of the crustal section. This approach allows us to evaluate how inherited mineral assemblages and melt-present conditions influence the development of weak lower-crustal domains and the evolution of the brittle-ductile transition.

Fiannacca P. et al. (2024) - Calabria coast to coast: a nearly complete cross-section of continental crust, with a 13 km-thick late Variscan batholith. Geological Field Trips and Maps, 16(2-4), 1-84, https://doi.org/10.3301/GFT.2024.09.

Jamtveit B. et al. (2018) - Earthquake-induced transformation of the lower crust. Nature, 556(7702), 487-491. https://doi.org/10.1038/s41586-018-0045-y.

Maggi A. et al. (2000) - Earthquake focal depths, effective elastic thickness, and the strength of the continental lithosphere. Geology, 28(6), 495, https://doi.org/10.1130/0091-7613(2000)282.0.CO;2.

Maierová P. et al. (2023) - Porous Melt Flow in Continental Crust-A Numerical Modeling Study. Journal of Geophysical Research: Solid Earth, 128(8), https://doi.org/10.1029/2023JB026523.

Stress state and Vp/Vs ratios beneath Etna volcano - a new framework for anisotropic Bayesian S-wave tomography of the crust

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Keywords: seismic anisotropy, Etna, shear wave splitting.

In this contribution we present our latest results from anisotropic Bayesian local earthquake joint P- and S-wave tomography of the crust beneath Etna volcano, revealing new constraints on Vp/Vs ratios and stress distribution. The method used addresses two common limitations in seismic tomography.

Firstly, conventional deterministic tomography methods are limited by the underdetermined nature of the inverse problem, requiring damping and smoothing constraints to obtain a unique solution. The wide variety of tomographic models published of Etna volcano show only limited agreement, particularly between recovered Vp/Vs ratios, an important parameter for identifying rock fluid properties. This stresses the importance of identifying the uncertainties of recovered velocity anomalies, a problem that is addressed by our Bayesian approach (Reversible-Jump Markov Chain Monte Carlo sampling). Secondly, many seismic imaging studies still rely on isotropic assumptions, while previous investigations (Lo Bue et al., 2024; Del Piccolo et al., 2025) have confirmed strong anisotropy beneath Mt. Etna. The crust beneath active volcanoes like Mt. Etna is characterized by eruptive fissures, dikes, sills, and fluid-filled microcracks. These structures typically align with the local stress field, inducing seismic anisotropy (with waves traveling faster along fracture planes). Thus, by inverting for anisotropic parameters, we obtain information about the stress state of the volcano. Combining this with information from isotropic velocity anomalies, we get an integrated view on the connection between stress distribution (strength and orientation of anisotropy) and rock fluid properties (Vp/Vs anomalies).

This study extends recent probabilistic P-wave methods (Del Piccolo et al., 2025) by incorporating S-wave data, which are highly sensitive to anisotropy and potentially superior for constraining shallow heterogeneities. The main challenge lies in the processing of S-wave data. Compared to P-waves, high-quality S-wave arrival times are scarcer due to higher noise levels, ray-orthogonal particle motion, and the complexities introduced by shear wave splitting. Consequently, accurate measurement of polarization angles and robust uncertainty quantification are essential. The method used for anisotropic S-wave tomography (VanderBeek et al., 2023) was initially developed for teleseismic imaging of the mantle, but the crustal settings forces us to deal with additional issues such as dissimilar waveforms and higher frequencies. Therefore, in addition to our tomography results of Mt. Etna, we present a new framework for the processing of S-wave data for anisotropic crustal imaging, while highlighting the remaining challenges.

Del Piccolo G. et al. (2025) - Pressurized magma storage in radial dike network beneath Etna volcano evidenced with P-wave anisotropic imaging. Commun. Earth Environ., 6, 1-8, Nature Publishing Group, https://doi.org/10.1038/s43247-025-02328-8.

Lo Bue R. et al. (2024) - Crustal Structure of Etna Volcano (Italy) From P-Wave Anisotropic Tomography. Geophysical Research Letters, 51, e2024GL108733, https://doi.org/10.1029/2024GL108733.

VanderBeek B.P. et al. (2023) - Imaging upper mantle anisotropy with traveltime and splitting intensity observations from teleseismic shear waves: insights from tomographic reconstructions of subduction simulations. Geophysical Journal International, 235, 2640-2670, https://doi.org/10.1093/gji/ggad389.

S15.

Reading orogens across crustal levels: Structural and metamorphic perspectives

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Transient thermal effects of fluid/melt-rock interactions in orogenic systems

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Keywords: fluids, melts, enthalpy.

Reactions involving variable exchange of latent heat are ubiquitous dynamic metamorphic processes: prograde dehydration and melting reactions cause an increase of the effective heat capacity by over an order of magnitude as they advance, while melt crystallization and retrograde hydration leads to transient heat production comparable to radioactive heating in the continental crust. These processes fundamentally modify the thermal evolution of rocks by buffering temperature changes during periods of rapid heating or cooling, thereby decoupling local thermal histories from conductive steady-state estimates. Partial melting consumes large amounts of energy with only minor concomitant temperature increase, stabilising crustal thermal gradients and prolonging near-isothermal high-temperature conditions, whereas crystallization of melts may locally release substantial heat during cooling and emplacement. Similarly, fluid infiltration into metastable mineral assemblages can trigger strongly exothermic hydration reactions, producing transient thermal anomalies and modifying rheology, reaction kinetics, and fluid transport pathways. Here I explore these coupled thermochemical feedbacks using numerical models that explicitly account for latent heat exchange during metamorphic reactions and phase transformations. Particular emphasis is placed on the thermal buffering effects associated with crustal melting and melt crystallization, as well as on metastable hydration of peridotitic rocks during serpentinization. Results demonstrate that transient reaction-driven heating and cooling can significantly perturb local thermal regimes over geological timescales, with implications for interpreting metamorphic P-T-t paths, reaction progress, and the thermal architecture of orogenic systems.

Geometry and kinematics of the SE boundary of the Mont Blanc massif: a story of anisotropy, oblique slip, and strain partitioning

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WITHDRAWN

Garnet-hosted mineral inclusions as records of prograde metamorphism in Western Alps eclogites

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Keywords: solid inclusions, garnet, EBSD.

Mineral inclusions are key recorders of the thermomechanical evolution of subduction zones. By preserving pristine evidence of metamorphic reactions, they provide constraints on how these processes influenced the rheological behaviour of subducting materials, particularly during early subduction stages (Ferrero and Angel, 2018 and references therein).

In this study, we combine petrographic and microstructural analyses, including scanning electron microscopy - energy-dispersive X-ray spectrometry (SEM-EDS), micro-Raman spectroscopy and electron backscatter diffraction (EBSD), to investigate mineral inclusions hosted in garnet from a Western Alps eclogite (see Ghignone et al., 2024). We aim to constrain the origin and timing of inclusions entrapment relative to garnet growth and to reconstruct the prograde evolution of subducted oceanic crust.

Quartz and glaucophane inclusions clustered in garnet cores display resorption textures and, locally, share similar crystallographic orientations. Textural observations coupled with EBSD data suggest that these inclusions represent pre-existing prograde mineral assemblages that were passively entrapped during garnet growth.

EBSD analyses further reveal internal lattice misorientations in garnet, despite the limited deformation observed in the surrounding rock. This suggests that local stress within garnet may develop as a consequence of inclusion entrapment and host-inclusion mechanical interaction, rather than being exclusively related to external tectonic deformation. Inclusion-induced stresses may contribute to mechanical weakening by promoting microfracture nucleation and enhancing fluid infiltration during metamorphism.

Overall, our results indicate that the inclusion-host system records multistage growth and resorption processes capable of generating local stress heterogeneities and transient porosity. The integration of crystallographic and microstructural approaches provides new insights into deformation and fluid-related processes operating during the prograde evolution of oceanic crust in fossil subduction systems.

Ferrero S. & Angel R.J. (2018) - Micropetrology: Are Inclusions Grains of Truth?. J. Petrol., 59, 1671-1700, https://doi.org/10.1093/petrology/egy075.

Ghignone S. et al. (2024) - Mineralogical and petrological constraints and tectonic implications of a new coesite-bearing unit from the Alpine Tethys oceanic slab (Susa Valley, Western Alps). Lithos, 472/473, 107575, https://doi.org/10.1016/j.lithos.2024.107575.

Preservation of rheologically weak fine-grained aggregates from Alpine deformation within a subcontinental mantle slice

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Keywords: rheological weakening, subcontinental mantle, Alpine deformation.

In metamorphic rocks, development of fine-grained aggregates commonly results in a switch from grain size-insensitive to grain size-sensitive (GSS) deformation mechanisms, that associated with phase mixing in polymineralic rocks, are primary drivers of strain weakening and localization of ductile flow. Grainsize reduction required for GSS can result by subgrain rotation recrystallization or by metamorphic reactions that are fostered by fluid-rock interactions and that commonly lead to development of symplectitic aggregates, efficiently triggering GSS. Yet, some fine-grained aggregates can persist undeformed, even after enduring complex tectonic histories and entire metamorphic cycles. To investigate the factors preventing deformation of such fine-grained aggregates, we studied eclogitic aggregates preserved within the ultramafic Arpisson body, a subcontinental mantle slice embedded in pervasively deformed eclogitic micaschists and mafic granulites of the Mt. Emilius klippe, Western Alps (Benciolini, 1996). The websterite-rich ultramafic body preserves record of pre-Alpine lithospheric stretching and exhumation followed by Alpine subduction to eclogite facies conditions. During the first stage, the original enstatite-diopside-olivine-spinel assemblage, with protogranular to porphyroclastic texture, was transformed along a 10m-wide shear zone into an ultramylonitic enstatite-diopside-olivine-anorthite-kaersutite assemblage arranged in a mm-thick alternation of kaersutite-anorthite and pyroxene-olivine layers. Electron backscatter diffraction analysis on pyroxenes documents dynamic recrystallization by subgrain rotation in diopside and enstatite porphyroclasts, that led to formation of the fine-grained (10 - 20 μm) matrix. As a result, GSS creep with grain boundary sliding (GBS) and creep cavitation was activated, leading to phase mixing, as suggested by presence of kaersutite and plagioclase at triple junctions. GBS and kaersutite formation within cavities suggests fluid-rich conditions during shear, with amphibole-rich veins likely representing conduits for initial fluid percolation. The Alpine overprint is recorded by replacement of plagioclase by fine-grained, hydrous aggregates of quartz-jadeite-kyanite-zoisite, and formation of omphacite-rich veinlets likely representing fluid pathways during high pressure metamorphism. Despite the pervasive eclogitic deformation of the surrounding lithologies (Pennacchioni, 1996) and the grainsize reduction of the Arpisson ultramafites along the pre-Alpine shear zone by combined pre-Alpine dynamic recrystallization and Alpine static replacement of plagioclase, the pre-Alpine mylonite was not re-exploited in shear at eclogite-facies conditions. These observations suggest that grainsize reduction alone can be occasionally inefficient in localizing strain, and that additional factors (e.g., significant free aqueous fluid) may be needed to trigger deformation even for fine-grained aggregates.

Benciolini L. (1996) - Eclogitizaed websterite-rich subcontinental mantle slice in the Austroalpine Mt. Emilius nappe. Mem. Sci. Geol., 48, 73-91.

Pennacchioni G. (1996) - Progressive eclogitization under fluid-present conditions of pre-Alpine mafic granulites in the Austroalpine Mt. Emilius Klippe (Italian Western Alps). J. Struct. Geol., 18(5), 549-561.

What drives the exhumation of the continental lithosphere? Insights from 2D geodynamic numerical modelling applied to the Oman Mountains (Saih Hatat Window)

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Keywords: continental subduction, exhumation, high pressure.

Although continental lithosphere can enter the subduction zone, how buoyant continental crust sinks below 100 km of depth and is then exhumed remains hard to understand. Exhumation of continental lithosphere is testified by the occurrence of high pressure rocks exposed in several orogenic belts. Despite the existence of different models describing the exhumation of high pressure rocks, they consider only tectonic settings where both upper and lower plates are either continental or oceanic.

In the Oman mountains, high pressure continental rocks crop out in the Saih Hatat Window surrounded by obducted oceanic lithosphere. Here, oceanic obduction occurred during subduction of continental lithosphere, setting a peculiar framework where a denser lithosphere overrides the subducting lighter continental crust.

In this study we used 2D thermo-mechanical geodynamic numerical modelling to investigate the mechanisms driving the exhumation of continental lithosphere beneath obducted oceanic lithosphere. Numerical simulations reproduce the subduction of continental rocks down to ~150 km of depth, followed by their exhumation guided by slab steepening and rollback. Exhumation is accompanied by slight heating at the bottom of the exhumed continental crust, triggered by asthenosphere flow after the slab dip increased.

Pressure (*P*) - temperature (*T*) - time (t) paths registered by model markers reproduce blueschists- to eclogite-facies peak conditions and heating during decompression, in agreement with *P*-*T*-t estimates from natural samples collected from different continental exhuming-shear zones in the Saih Hatat Window. In addition, regional tomographic models from the Oman region, suggest the presence of a retreating, NE-dipping steep slab beneath the Oman Mountains.

Our models propose slab steepening and rollback as possible mechanisms to guide the exhumation of buoyant but deeply subducted continental lithosphere.

Transient fluid pressure and cyclic brittle-ductile deformation in a block-in-matrix shear zone at blueschist facies conditions

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Keywords: dilational shear veins, transient brittle-ductile deformation, subduction zones.

Fluid-pressure cycling driving alternating brittle-ductile deformation is a mechanism that can explain the occurrence of slow slip and tremors (SST) in subduction zones. In subduction channels, lithologies with contrasting rheology govern bulk strength; however, the processes that control slip localization, alternating brittle failure, and ductile flow at depth remain poorly constrained.

The Liguro-Piemontese oceanic-derived metasediments (Western Alps), deformed under blueschist-facies conditions (300-350°C, 0.8-1.3 GPa; Agard et al., 2021), represent natural exhumed analogues for investigating these processes. Here, we analyzed a block-in-matrix shear zone by integrating statistical analyses of veins, thermodynamic modeling, and quantitative Electron Backscatter Analysis (EBSD) to gain insights into the occurrence of deep SST.

The shear zone is composed of strong marble blocks wrapped by a weak matrix of graphitic schist, together deformed into sheath folds and veins. Dilational shear veins with a crack-seal texture occur mainly in marble blocks, subparallel and at high-angle to their main foliation. Carpholite and calcite (formerly aragonite) fibers composing veins, together with rock mineral lineations, are oriented NE-SW parallel to sheath fold axes. Locally, foliation-parallel folded carpholite veins suggest cyclical brittle-ductile switching within the carpholite stability field. Vein statistics reveal fractal distribution and clustering, indicating pervasive fluid flow within marble blocks and at marble-graphitic schists contact (Casoli et al., 2026).

At the microscale, veins locally deform into banded ultramylonite enclosing fragmented quartz and carpholite grains. Calcite fibers deform by subgrain rotation recrystallization, exploiting pre-existing grain boundaries. Later grain-size reduction in fine-grained bands leads to incipient activation of diffusion creep, possibly reflecting accelerated creep. Calcite paleopiezometry yields differential stresses of 40-300 MPa and strain rates up to 10^{-8} s^{-1}.

Dilational shear vein growth is compatible with geophysical evidence for a double-coupled mechanism and may represent a potential record of SST. Fluids (i.e. veins) are mainly channelized in marble blocks and/or marble-graphitic schist interface due to the presence of preexisting heterogeneities and by induced fracturing through block-interactions by jamming processes. Ductile deformation occurs by exploiting weak horizons under transient and cyclic pore-fluid pressures that reach sub-lithostatic values, suggesting switching between slow and accelerated creep. These results delve into fluid-assisted deformation processes associated with SST at depths >30 km.

Agard P. (2021) - Subduction of oceanic lithosphere in the Alps: Selective and archetypal from (slow-spreading) oceans. Earth-Science Reviews, 214, 103517, https://doi.org/10.1016/j.earscirev.2021.103517.

Casoli L., et al. (2026) - Block-in-matrix deformation and veining in Alpine subducted oceanic metasediments at blueschist facies conditions. Geochemistry, Geophysics, Geosystems, 27, e2025GC012765, https://doi.org/10.1029/2025GC012765.

Fluid-assisted slip and pressure cycling recorded by calcite veins in a shallow paleo-subduction channel: insights from the Bobbio Tectonic Window (Northern Apennines)

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Keywords: dilational shear veins, shallow subduction channel, episodic tremor and slow-slip events (ETS).

Shallow subduction-zone dynamics are driven by fluids released during diagenesis and mineral dehydration reactions, steering rheological changes and stress perturbations at the plate interface. Geophysical observations suggest that shallow subduction-channel seismicity is spatially heterogeneous and transient, yet the mechanisms controlling deformation and localization associated with episodic tremor and slow-slip (ETS) remain poorly constrained. Given the limited direct observations, exhumed subduction-channel sections offer key insights into these processes.

This study investigates a paleo-subduction channel exposed in the Bobbio tectonic window (Northern Apennines) deformed under anchizonal conditions (~150-220°C). The subduction channel consists of tectonic mélange organized into tectonic slices derived mainly from the frontal part of the overriding plate. The slices are bounded by anastomosing shear surfaces, marked by low-angle NE-vergent Apennine thrusts and by NW-SE-vergent structures with variable dip and kinematics. Fault planes are discontinuously coated by calcite veins showing fibrous crack-and-seal margins and blocky-texture cores. At the microscale, crack-and-seal fibers alternate with micro-cataclastic horizons, injection structures, and microcrystalline-quartz-coated slip surfaces, indicating repeated fluid-driven brittle failure and transient dilation along active shear surfaces. XRF analyses indicate mainly internally derived, rock-buffered fluids.

Such structures are thus interpreted as products of cyclic fluid-overpressure fluctuations that approach or locally exceed lithostatic conditions, promoting repeated brittle failure, transient fluid drainage, and frictional-viscous slip. Brittle deformation and vein development are discontinuous and preferentially localized within marls and along marl-clay interfaces. Clay-rich lithologies likely acted as both fluid sources and low-permeability seals during water expulsion and clay-mineral dehydration. Marls behaved as relatively permeable horizons that preferentially localized transient fluid drainage and brittle deformation.

The Bobbio subduction channel may therefore preserve a fossil record of transient fluid-pressure cycling and cyclic fluid-assisted slip consistent with ETS deformation along the shallow plate interface.

Petrography and Raman spectroscopy of carbonaceous material trapped in garnets of the Ulten Unit crust

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Keywords: carbonaceous material, Raman spectroscopy, Ulten Unit.

Metasedimentary rocks from exhumed continental subduction zones commonly contain carbonaceous material (CM), which is progressively transformed into graphite during metamorphism. Investigating CM in these rocks is therefore important for understanding the global carbon cycle during orogeny.

In this study, we examine samples of garnet and kyanite paragneisses from the Ulten Unit, a Variscan-age tectonic mélange that also includes carbonate-bearing mantle peridotite lenses and migmatitic gneisses. Optical microscopy and micro-Raman spectroscopy were used to characterize the carbonaceous material and Raman-based geothermometry was applied to estimate the peak temperatures recorded by the garnet and kyanite paragneisses. CM inclusions were identified mainly within garnet and kyanite porphyroblasts. In garnet, CM occurs in different microstructural sites: (i) as isolated inclusions, (ii) in concentric rings around the garnet core, and (iii) along inclusion trails confined within the host garnet. Only a few CM grains were found in matrix minerals. A total of 83 CM spectra were collected and processed using RamanCrystalHunter (Nestola et al., 2025).

The results of the Raman-based geothermometry are partly consistent with the high-grade garnet-kyanite assemblage. More specifically, isolated CM inclusions yielded the highest temperatures of about 640°C, whereas inclusions arranged in concentric annular patterns around the garnet core and along trails recorded significantly lower values, mostly below 400°C. These lower temperatures likely reflect late-stage retrograde fluid infiltration along healed fractures.

Our findings suggest that the precipitation of solid carbon phases may have occurred throughout the retrograde P-T path of the Ulten metapelites. These rocks may therefore represent a reservoir of reduced carbon that can be mobilized into fluids responsible for the carbonation of the associated peridotite lenses.

Nestola F. et al. (2025) - RamanCrystalHunter: a new program and database for processing, analysis, and identification of Raman spectra. American Mineralogist, 110, 513-524, https://doi.org/10.2138/am-2024-9457.

Shear zones growth steers seismogenic potential of the lower crust

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Keywords: shear zone, seismogenic potential, pseudotachylyte.

Understanding what controls the seismogenic potential of the lower continental crust is critical for linking crustal rheology, strain localization, and the depth distribution of earthquakes. Variations in seismogenic thickness are commonly interpreted to reflect compositional and rheological heterogeneities within the crust (Craig & Jackson, 2021). In several continental settings, lower-crustal seismicity at depths of 30-45 km has been linked to strong, dry granulitic crust and the reactivation of inherited fault systems capable of remaining seismogenic at lower-crustal conditions (Wimpenny, 2022). The Nusfjord locality (Lofoten, Norway) provides an exhumed analogue of such dry seismogenic lower crust, where strong granulitic anorthosite blocks are dissected by networks of ductile shear zones containing multiple generations of pseudotachylytes formed at ~30 km depth during the Caledonian collision. These pseudotachylytes record repeated lower-crustal earthquake nucleation triggered by transient stress amplifications within stiff anorthosite lenses bounded by aseismically creeping shear zones (Campbell et al., 2020; Zertani et al., 2025).

However, shear zones are commonly overprinted by pseudotachylyte veins along their foliation, and the processes responsible for the interplay between mylonites and pseudotachylytes remain unclear. Field and microstructural analyses show that earthquake ruptures nucleated within stiff anorthosite blocks and preferentially propagated along the shear zone boundary and foliation, without crosscutting entire shear zones. Pseudotachylytes deflected into shear zones were subsequently mylonitized and incorporated into the shear zone matrix. Statistical analysis reveals an inverse relationship between shear zone spacing and thickness: thicker, closely spaced shear zones bound intensely fractured, pseudotachylyte-rich anorthosite lenses, whereas thinner, widely spaced zones surround relatively intact blocks. We interpret this pattern as progressive shear zone growth through repeated pseudotachylyte generation and mylonitization, progressively transforming competent anorthosite blocks into weak shear zones. These observations suggest that lower-crustal seismogenic thickness and potential evolve dynamically with shear zone growth and maturity. Immature networks containing large intact blocks promote transient stress amplification and localized lower-crustal earthquakes, whereas mature anastomosing shear zones - dominated by increasingly growing networks of interconnected high-strain zones - reduce the volume of competent crust capable of hosting seismicity.

In this model, repeated pseudotachylyte generation acts both as a record of transient deep seismicity and as a mechanism driving rheological weakening and the progressive reduction of lower-crustal seismogenic potential through time. The distribution of lower-crustal earthquakes therefore reflects the evolving rheological architecture of dry continental crust, rather than static thermal or compositional variations.

Campbell L.R. et al. (2020) - Earthquake nucleation in the lower crust by local stress amplification. Nat. Commun., 11, 1322, https://doi.org/10.1038/s41467-020-15150-x.

Craig T.J. & Jackson J.A. (2021) - Variations in the Seismogenic Thickness of East Africa. Journal of Geophysical Research: Solid Earth, 126, e2020JB020754, https://doi.org/10.1029/2020JB020754.

Wimpenny S. (2022) - Weak, Seismogenic Faults Inherited From Mesozoic Rifts Control Mountain Building in the Andean Foreland. Geochem Geophys Geosyst 23, e2021GC010270, https://doi.org/10.1029/2021GC010270

Zertani S. et al. (2025) - Lower-Crustal Earthquakes: Strain Rate Controls the Magnitude and Rate of Stress Amplification in Rigid Blocks. Geophysical Research Letters, 52, e2024GL114350, https://doi.org/10.1029/2024GL114350.

Garnet composition and zoning, and implications for P-T paths, at the transition between the the metapelitic sequence and the Migmatite Complex of NE Sardinia

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Keywords: garnet, Variscan orogeny, Sardinia.

In the Palaeozoic basement of Variscan Sardinia, metamorphic garnet mostly occurs in the northern, highest-grade metamorphic sector, hosted in (i) metapelites from the Barrovian metapelitic sequence, (ii) migmatites, and (iii) metabasites within the Migmatite Complex.Many of these garnet (and/or garnet-bearing rocks) occurrences have been investigated in the last decades, providing a significant contribution to the reconstruction of P-T conditions, P-T paths, geodynamic setting and to the overall geological comprehension of this belt.

Along the NE coast of the island, the garnet zoning in the Barrovian sequence evolves from poorly to slightly zoned in the garnet zone, to show a well-developed bell-shaped zoning profile in the staurolite + biotite zone within a distance of ca. 25-30 km from south (Lula and Santa Lucia) to north (Sant'Anna), following the direction of increasing metamorphism. A comparison between the P-T paths of the Lula and *Pinnettu* micaschist (respectively belonging to the garnet and staurolite + biotite zone) shows that the less pronounced garnet zoning of the Lula and Santa Lucia micaschists corresponds to P-T paths lacking any kind of prograde information. Contrarily, the *Pinnetu* micaschist is characterized by a more pronounced garnet zoning and thus it preserves evidence of higher peak temperature (as compared to the previous ones), provides a reconstruction of a prograde path and shows features related to garnet dissolution before a second stage of garnet growth. On the other hand, the current lack of *P-T* estimates for pelitic rocks of the NW sector of the MGMC (i.e., the Nurra region), as well as for the few data on the HGMC of the Asinara island, does not allow comparison with the opposite NW sector of this belt.

The migmatite *P-T* paths in the Inner Zone indicate that, in this part of the island, partial melting occurred in a relatively high pressure environment, in the kyanite stability field. However, the P-T conditions (and P-T path reconstructions) of the migmatites have hardly beneficiated from garnet compositional zoning for the very low garnet modal amount and/or for the occurrence of garnet crystals of very small size, that are, consequently, poorly zoned. The recent discovery of pluri-millimetric garnet porphyroblasts in the diatexite-type migmatized orthogneiss of Porto Ottiolu represents a new great opportunity and unique challenge for improving the migmatite P-T path reconstruction based on the information preserved in the compositional zoning of suprasolidus garnet. In this new garnet finding in the migmatite complex, garnet occur as strongly altered millimetric porphyroblasts, either almost completely replaced by biotite or showing striped fabric identified through elongated garnet ribbons growing parallel to recrystallized quartz layers. The garnet porphyroblasts appear as skeletal grains and preserves an anhedral, relic Ca-rich core possibly resulting from suprasolidus dissolution.

Evidence for differential lower crustal reworking in adjacent UHT domains of the Eastern Ghats Province, India

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Keywords: ultrahigh-temperature metamorphism, polyphase deformation, lower crustal reworking.

In the Eastern Ghats Province (EGP) of India, ultrahigh-temperature (UHT) metamorphism of crustal rocks is commonly attributed to collisional tectonics associated with the assembly of the supercontinent Rodinia. However, the relationship between polyphase deformation, exhumation, and contrasting metamorphic evolution among adjacent UHT domains remains poorly constrained. This study integrates structural, microstructural, and phase-equilibrium data from the Vizianagaram sector of the southern Eastern Ghats Province to evaluate the tectono-metamorphic evolution of this domain and its relationship with the adjacent Anantagiri block. Field analyses reveal a complex deformational history involving at least four deformation events. An early gneissic segregation fabric (S1), interpreted to be associated with peak UHT metamorphism event (D1), was subsequently folded during a compressive deformation (D2), producing recumbent F2 folds and a subhorizontal axial planar S2 foliation. These structures were later refolded during D3 deformation into plunging F3 folds associated with penetrative S3 fabrics, resulting in Type-3 fold interference patterns. A late D4 deformation event produced steeply dipping shear fabrics (S4) characterized by top-to-SE extension with sinistral sense in the horizontal section, resulting in the rotation of earlier fabrics. Results from phase-equilibrium modelling of the early S1 fabric reveal a peak assemblage spinel + quartz + garnet + ilmenite + sillimanite + melt, which stabilized at peak P-T conditions of ~1050 °C at ~8 kbar of pressure, followed by a decompression-dominated cooling history associated with cordierite growth at lower pressures. The inferred clockwise P-T path of the Vizianagaram block contrasts markedly with the counterclockwise P-T-t evolution reported from the adjacent Anantagiri domain, despite both regions recording similar UHT conditions and overlapping ages (Korhonen et al., 2013; Mitchell et al., 2019), indicating differential lower crustal reworking of adjacent blocks. The decompression-dominated P-T path inferred for the Vizianagaram block may be explained by partial exhumation due to thrusting over the adjacent Paderu block to the west, as supported by the D2 and D3 deformation events. Alternatively, variations in melt fraction, mineralogy, fluid availability, and the presence of mechanically weak zones may have controlled strain partitioning and deformation localization, resulting in contrasting structural orientations despite comparable deformation histories in both terranes. These possibilities collectively suggest that the EGP preserves a heterogeneous and dynamically evolving lower crust rather than a uniformly reworked UHT terrane. The results highlight the importance of integrating structural evolution with metamorphic petrology to understand the tectonic assembly and rheological evolution of UHT terranes.

Korhonen F.J. et al. (2013) - How long-lived is ultrahigh temperature (UHT) metamorphism? Constraints from zircon and monazite geochronology in the Eastern Ghats orogenic belt, India. Precambrian Research, 234, 322-350, https://doi.org/10.1016/j.precamres.2012.12.001.

Mitchell R.J. et al. (2019) - Neoproterozoic evolution and Cambrian reworking of ultrahigh temperature granulites in the Eastern Ghats Province, India. Journal of Metamorphic Geology, 37, 977-1006, https://doi.org/10.1111/jmg.12451.

Mechanically-induced fluid release and surrounding rock response during the seismic cycle in pseudotachylyte-bearing mylonitic orthogneisses of the Dora-Maira Massif (Western Alps)

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Keywords: microstructures, micas, deformation mechanism.

Pseudotachylytes, i.e., glassy veins of quenched frictional melts, in exhumed fluid-undersaturated rocks represent the fossil record of co-seismic deformation. The fabric of pseudotachylytes, together with their relationships to the surrounding rocks, provides constraints on the processes operating during co-seismic fracture-tip propagation, dynamic fault weakening and lubrication and on the thermo-mechanical energy budget (e.g., Di Toro et al., 2005; Toffol et al., 2024).

To investigate the mechanisms related to co-seismic slip, we have investigated pseudotachylyte-bearing mylonitic orthogneisses from the Brossasco-Isasca Unit of the Dora Maira Massif in the Western Alps. Zechmeister et al. (2007) showed that pseudotachylyte veins in these rocks are surrounded by (ultra)cataclastic layers and suggested that frictional melts developed in phengite-chlorite-rich protoliths, but the formation mechanisms of pseudotachylytes have not been detailed.

Microstructural characterization of the same orthogneisses shows quartz ribbons, biotite, and white mica defining an S-C' mylonitic fabric, with K-feldspar, plagioclase and phengitic mica-fish (with decreasing Si content towards the rim) defining a pre- to syn-kinematic assemblage. K-feldspar and plagioclase preserve inherited twinning structures variably overprinted by different twinning laws and sub-grain recrystallisation. K-feldspar and plagioclase also show domino and fish-like microstructures, respectively. Quartz predominantly shows sub-grain rotation recrystallisation, with local grain boundary migration. Phengitic mica-fish are distributed with variable abundance throughout the mylonite, define the banding. They are systematically kinked, comminuted and re-equilibrated as muscovite in proximity to the pseudotachylyte and associated Riedel fractures. The presence of comminuted material may indicate brittle deformation superimposed on viscous flow (Aslin et al., 2019). We observe an increase in biotite modal abundance towards the pseudotachylyte, particularly from being scattered along the mylonitic foliation to preferentially growing along the fracture network, accompanied by an increase in the Mg content. In domains far from the pseudotachylyte, shear fractures are characterized by fine-grained phyllosilicate and oxide infill.

The spatial association between comminuted phengite, biotite growth, and the pseudotachylyte fracture network points to a fluid-mediated reaction front in proximity to the seismic rupture propagation. Biotite growth in the immediate surrounding rock is consistent with exothermic cooling of the frictional melt, suggesting that both fluid release from mechanically broken phengite and heat from frictional melt contributed to the local mineralogical and rheological evolution of the host rock during and after the co-seismic event.

Aslin J. et al. (2019) - Ripplocations provide a new mechanism for the deformation of phyllosilicates in the lithosphere. Nat. Commun.,10(1), 686.

Di Toro G. et al. (2005) - Can pseudotachylytes be used to infer earthquake source parameters? An example of limitations in the study of exhumed faults. Tectonophysics, 402(1-4), 3-20.

Toffol G. et al. (2024) - On-fault earthquake energy density partitioning from shocked garnet in an exhumed seismic midcrustal fault. Sci. Adv., 10(9), eadi8533.

Zechmeister M.S. et al. (2007) - Slow and fast deformation in the Dora Maira Massif, Italian Alps: Pseudotachylytes and inferences on exhumation history. J. Struct. Geol., 29(7), 1114-1130.

CO_2 production during a closed-to-open system transition in the shallow crust: insights from phase equilibrium modelling of andradite- and vesuvianite-rich calc-silicate rocks

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Keywords: calc-silicate rocks, phase equilibria, CO_2.

Subduction- and orogenic-related transport of CO_2, sourced from prograde metamorphic devolatilization reactions, can have a direct impact on geological processes such as magmas production, metasomatism, seismic activity, and chemical zoning of subducted slabs, among others (Schmidt & Poli, 2014). Calc-silicate rocks can particularly exert a strong control on the evolution of the volatile phase, mainly represented by C-O-H fluids (Connolly & Cesare, 1993; Groppo et al., 2017). Provided the complexity of calc-silicate assemblages and related fluid, a phase equilibrium modelling coupled to detailed petrographic evidence is needed to thoroughly evaluate both the *P-T* and the C-O-H fluid evolution. The flux of CO_2-rich fluids, as well as many others fluid and/or gaseous species, is inherently linked to the either transient or steady-state establishment of open system conditions in metamorphic settings. The evaluation of the physical behaviour (i.e., closed vs open) of metamorphic systems is therefore crucial in developing models for assessing the possible escape of the produced fluids.

In this work, we have combined microstructural observations, mineralogical data and thermodynamic modelling on metasomatized calc-silicate lenses from a Variscan core complex in southern Sardinia (Italy), metamorphosed at *HT-LP* conditions at relatively shallow crustal levels (P-T-X_{Fluid}evolution of the rock, and (ii) provide insights into the possible fate of produced CO_2 at very upper crustal open systems. Detailed microstructural observations allowed to constrain two metamorphic stages recorded by the calc-silicate rocks. A first, dynamic stage, likely linked to regional metamorphism, is characterized by a metamorphic peak assemblage consisting of Qz + Kfs + Pl + Grt + Cpx + Wo + Ttn developed at *P-T* conditions of 0.3-0.4 GPa / 625-700°C. These conditions were constrained by *T-XCO2* grids and phase diagrams. Prograde CO_2 amount was also modelled (i.e., ~ 18 wt.%). A second, static stage, variably accompanied by open system metasomatism, occurred at slightly lower pressure conditions, i.e.,T-f(O2) phase diagrams suggest that an increase in oxygen fugacity was needed in order to destabilize grossular-rich garnet before producing andradite. On the other hand, vesuvianite growth was consistent with the increase in both MgO and H_2O chemical potentials. Both these evidence may support that the static stage occurred at open system conditions.

The open system behaviour highlighted by thermodynamic modelling, plus the almost total preservation of prograde and peak wollastonite, may suggest that the prograde CO_2 was released during closed-to-open system transition. Provided that *HT-LP* settings and metasomatic environment are common worldwide, more efforts are needed to quantitatively constrain the fate of degassed species at such shallow crustal levels.

Connolly J.A.D. & Cesare B. (1993) - C-O-H-S fluid composition and oxygen fugacity in graphitic metapelites. J. Metamorph. Geol., 11(3), 379-388, https://doi.org/10.1111/j.1525-1314.1993.tb00155.x.

Groppo C. et al. (2017) - Metamorphic CO_2 production in collisional orogens: Petrological constraints from phase diagram modeling of Himalayan, scapolite-bearing, calc-silicate rocks in the NKC(F)MAS(T)-HC system. J. Petrol., 58(1), 53-83, https://doi.org/10.1093/petrology/egx005.

Schmidt M. & Poli S. (2014) - Devolatilization during subduction. In Treatise on geochemistry. 4: The Crust (pp. 669-701). Elsevier, https://doi.org/10.1016/B978-0-08-095975-7.00321-1.

Meso- and microstructural characterization of the Ponte Brolla outcrop (Southern Steep Belt, Central Alps)

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Keywords: fractures, microstructures, brittle deformation.

The Ponte Brolla outcrop is located in a strategically important area within the Central Alps, as it lies at the intersection of several major regional geological structures. First, it belongs to the Southern Steep Belt, the morphological expression of the backthrust system affecting the Penninic nappes. The area is bounded to the north by the Lepontine Dome and to the south by the Insubric Line. The outcrop is composed of migmatites affected by multiple deformation phases under both ductile and brittle regimes.

The age of migmatite formation is still uncertain; however, partial melting has been demonstrated to have occurred contemporaneously with the emplacement of granitic bodies, particularly the Bergell intrusion dated at approximately 32 Ma. During the Late Oligocene, around 25 Ma, the Southern Steep Belt developed. This event is recorded by the steep north-dipping foliation observed in the migmatites. During this stage, a mylonitic belt formed initially under amphibolite-facies conditions and later evolved under greenschist-facies conditions, producing low-angle stretching lineations. Field observations indicate that both foliations share consistent orientations and are interpreted as the result of dextral strike-slip movement. This strike-slip activity was synchronous with the tectonic uplift and rapid cooling of the Central Alps during the Late Oligocene to Early Miocene. The end of mylonitization can be dated as synchronous with cooling below 300°C, approximately between 20 and 18 Ma.

Subsequently, dextral strike-slip deformation continued under brittle conditions, leading to the development of a complex cataclastic system accompanied by fluid circulation, which locally promoted vein formation. These structures are kinematically related to the Periadriatic Line and the Centovalli Line, located slightly farther west. Bulk analysis of altered fractures show an enrichment in K_2O and a depletion in MgO, Fe_2O_3, and CaO. The mineral assemblage consists of quartz, plagioclase, chlorite, hornblende, and biotite. Biotite progressively disappears with increasing alteration.

The youngest recorded deformation event also belongs to the brittle regime but is markedly different in nature. It consists of a system of extensional fractures, possibly related to stress-field relaxation associated with the development of the Rhône-Simplon Line. The youngest fractures display a bleached alteration halo. SEM analyses show that they contain cataclasites cemented mainly by epidote, with cockade structures developed within dilational jogs. The brittle deformation can therefore be divided into two main types: a cataclastic phase associated with fluid circulation and vein emplacement, and a later phase related to brittle extensional fracturing.

Reconstructing the early Paleozoic evolution of the Austroalpine Domain: Structural, geochemical and geochronological constraints from the Klopai Pluton area (Ötztal-Stubai Nappe, Eastern Alps)

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Keywords: Austroalpine Domain, Ordovician magmatism, tectonometamorphic evolution.

The Austroalpine Domain in the Eastern Alps consists of Mesozoic (meta)sedimentary cover units overlying a polymetamorphic crystalline basement characterized by Variscan high- to medium-grade metamorphism. Both were heterogeneously overprinted by Alpine metamorphism. Locally, even older than Variscan relicts are preserved in the crystalline basement, representing a key archive for reconstructing the Paleozoic evolution of the Eastern Alps. During the Paleozoic these terranes were located along the northern Gondwana margin, where contrasting tectonic regimes have been described. Most sectors record passive-margin sedimentation related to rifting and ocean opening, whereas others preserve evidence of active subduction and magmatism also associated to orogenic processes (Cenerian Orogeny). Reconciling these processes remains a major geodynamic challenge.

A notable example of this complexity is the Ötztal-Stubai Nappe, extending across northern Italy and western Austria. Within this framework, a ~25 km² area near Reschen Pass (Venosta valley, BZ) preserves potential pre-Variscan features that escaped younger deformation and metamorphism. These include the Klopai Pluton with its migmatites-bearing metamorphic aureole that affect host paragneisses. Their coexistence provides a unique opportunity to investigate relationships among magmatism, metamorphism, and deformation during the early Paleozoic.

Detailed field mapping indicates that the Klopai Pluton is largely undeformed and locally preserves primary intrusive contacts. New U-Pb zircon LA-ICP-MS dating constrains emplacement of the Klopai Tonalite to ca. 460 Ma. Cordierite-bearing assemblages preserved within host paragneisses along the pluton margins are interpreted as relicts of a contact metamorphic aureole. The surrounding migmatites, mainly metatexites, likely formed through syn-intrusion partial melting of the host rocks were later overprinted by Variscan metamorphism. Garnet-bearing pegmatitic dikes, interpreted as highly evolved fluid-rich melts related to the Klopai magmatic system, intrude both the main intrusive mass and the country rocks. Previously published Sm-Nd Grt ages on the pegmatitic dykes suggest that the present structural configuration was already established during the Ordovician.

Geochemical analyses of major and trace elements from the magmatic lithologies associated with the Klopai Pluton indicate a subduction-related tectonic setting, supporting the interpretation that the Cenerian Orogeny was still active during the Ordovician. These new data provide an important starting point for investigating the early Paleozoic tectonometamorphic evolution of the Austroalpine Domain and contributes to a better understanding of pre-Alpine crustal processes in the Eastern Alps.

Timing of rotation in the Albano-Hellenides: Implications for the kinematic evolution of the Aegean orocline

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Keywords: Albano-Hellenides, oroclinal bending, paleomagnetism.

The Albano-Hellenides constitute the western limb of the Aegean orocline and preserve evidence of large vertical-axis rotations associated with orogenic curvature.

Paleomagnetic studies from the external Ionian and Kruja zones of the Albano-Hellenides indicate ~40° clockwise (CW) rotation relative to Africa/Adria, although the timing of this rotation remains debated. Previous models alternatively proposed multiple rotation phases or a progressive post-middle Miocene rotational history, potentially overprinted by local thrust-related and strike-slip deformation.

Here we present new paleomagnetic data from 41 sites sampled within the virtually continuous Eocene-early Pliocene sedimentary succession of the Tragjasi thrust sheet (Ionian zone, SW Albania). The sampled strata are exposed along the backlimb of a ~50 km-long anticline, subparallel to the regional orogenic trend and located away from major strike-slip faults, providing a favourable setting to isolate the regional rotational signal from local tectonic overprint.

Our results show a consistent ~35°±9° CW rotation recorded by Eocene to early Pliocene sediments, indicating that rotation in the external Albanides initiated no earlier than the late early Pliocene (~4 Ma). These constraints suggest that the curvature of the western Aegean arc developed during the latest stages of deformation of the external fold-and-thrust belt, contemporaneously with rapid slab retreat and increased subduction rates in the Hellenic domain.

Integration of paleomagnetic data with geophysical constraints on slab geometry and regional kinematic reconstructions developed in GPlates further indicates that post-Messinian deformation involved synchronous rotation of the Albano-Hellenides and Peloponnese domains. We relate this kinematic reorganization to slab-driven processes, including enhanced slab pull linked to Ionian oceanic lithosphere subduction and progressive slab tearing beneath the southern Dinarides. These results highlight the strong coupling between upper-plate deformation, oroclinal bending, and slab dynamics during the late Cenozoic evolution of the Aegean orogenic system.

Ductile to brittle deformation localization during exhumation of polymetamorphic units along the Sestri-Voltaggio Zone (Ligurian Alps, Italy)

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Keywords: exhumation, rheological contrast, deformation localization.

Tectonic and erosional unroofing processes are key players for the exhumation of rocks. However, the mechanisms governing the transition from ductile to brittle deformation during progressive exhumation from deep crustal levels remain poorly understood. Specifically, it is unclear how deformation partitions spatially, kinematically and rheologically during the ascent of rocks en-route to the surface. By means of a multiscalar approach, we investigate how structural and rheological inheritances helped localize deformation across crustal levels. The Sestri-Voltaggio Zone (SVZ) in the Ligurian Alps offers a unique lithological and structural record of a complete subduction-exhumation cycle, providing insights into the rheological behaviour of exhuming rock masses. The SVZ is a c. 20 km long N-S tectonic feature characterized by a stark lithological and metamorphic variability, with metaophiolites and related cover sandwiched between and/or juxtaposed against continental units. The current structural grain of the SVZ stems from a complex polyphase exhumation history wherein late brittle structures selectively overprinted earlier ductile features formed under blue-to-greenschist facies conditions. Field data show the presence of competent metagabbro and limestone units systematically boudinaged and enveloped within a matrix of phyllite, calcschist, and serpentinite. At the regional scale, brittle contacts follow and exploit the geometry of the competent units, hinting to the role played by other factors other than Andersonian stresses. Primary fabrics are recognized in metagabbros (as magmatic mineral relicts and D_1-related blueschist foliation) and in calcareous bodies (where S_0 is only partially affected). A composite fabric characterizes the less competent matrix, in which a D_2-related foliation dominates. The latter is folded, and when approaching sub-vertical tectonic contacts, its strike and dip become parallel to them. This might imply that inherited fabrics have represented a significant anisotropy that was later exploited to assist and govern the localization of later brittle deformation. Microtectonic analysis unravels the metamorphic conditions controlling exhumation-related fabrics. In mafic bodies, epidote veins cross-cutting the blueschist foliation indicate that brittle deformation initiated under greenschist-facies conditions, where epidote was texturally stable. In this case, pre-existing fabrics did not play a key role in localizing the deformation. Conversely, foliated fabrics in phyllite and calcschist accommodate most of the strain along phyllosilicate-rich layers, within which porphyroclasts passively rotate. The overall structural and lithological record of investigated units along the SVZ provides insights into the exhumation mechanisms of a polydeformed tectonic sequence, emphasizing the role of rheological contrast in steering deformation partitioning and localization during progressive embrittlement of the shear system.

Exhumation of UH*P* rocks recorded by garnet microstructures

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Keywords: garnet microstructures, exhumation, ultra-high pressure metamorphism.

The Brossasco-Isasca Unit (BIU) in the southern Dora-Maira Massif is widely regarded as the archetype of ultra-high-pressure metamorphic terranes. Its pressure-temperature evolution has been extensively investigated across a variety of lithologies, leading to robust constraints on both peak metamorphic conditions and the prograde evolution of the unit (e.g., Ferrando et al., 2009; Ferrando et al., 2017; Groppo et al., 2019). While burial-related processes are now well established, exhumation-related processes have received comparatively less attention, particularly in lithologies other than the renowned pyrope-bearing whiteschists.

This study focuses on the exhumation history of a garnet + kyanite -bearing phengitic micaschist from the BIU. We show that, despite the preservation of the peak metamorphic assemblage, garnet microstructures provide key insights into the processes operating during exhumation from the coesite stability field toward lower-pressure conditions. In particular, we demonstrate that garnet underwent brittle fragmentation during ductile exhumation and discuss the possible mechanism(s) responsible for this process.

Petrographic evidence further reveals that mono- and poly-mineralic inclusions preserved within garnet domains grown in the coesite stability field record not only the prograde-to-peak evolution, but also, and perhaps more importantly, the processes associated with exhumation. These observations highlight the critical importance of detailed petrographic investigation for correctly interpreting the significance of mineral inclusions and avoiding the misattribution of exhumation-related phases to the prograde metamorphic assemblage.

Ferrando S. et al. (2009) - Metasomatism of continental crust during subduction: The UHP whiteschists from the southern Dora-Maira massif (Italian Western Alps). J. Metam. Geol., 27, 739-756, https://doi.org/10.1111/j.1525-1314.2009.00837.x.

Ferrando S. et al. (2017) - Dissolving dolomite in a stable UHP mineral assemblage: Evidence from Cal-Dol marbles of the Dora-Maira massif (Italian Western Alps). Am. Mineral., 102, 42-60, http://dx.doi.org/10.2138/am-2017-5761.

Groppo C. et al. (2019) - What's in the sandwich? New P-T constraints for the (U)HP nappe stack of southern Dora-Maira massif (Western Alps). Eur. J. Mineral., 31, 665-683, http://doi.org/10.1127/ejm/2019/0031-2860.

The Alpine subduction-exhumation history of the Voltri metaophiolite (Ligurian Alps): New evidence from lawsonite-bearing blueschists (CARG Sheet 212)

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Keywords: italian CARG project, lawsonite-blueschist, Ligurian Alps.

This contribution presents a multidisciplinary study integrating geological field mapping, structural and microstructural analyses, and petrological investigations to constrain the tectonic evolution of the western margin of the Voltri Massif (VM) metaophiolite (Western Ligurian Alps, Italy).

This sector of the VM is characterized by the occurrence of tectonic slices of serpentinites including eclogites, lawsonite-bearing eclogites, and blueschist-facies metabasite, thus recording different pressure-temperature paths related to Alpine subduction processes (e.g.; Cortesogno et al., 1977; Malatesta et al., 2017; Scarsi et al., 2017).

Geological mapping and field investigations, carried out for the CARG Sheet No. 212 "Spigno Monferrato", led to the identification and sampling of newly mapped mylonitic metabasites cropping out in the north-western sector of the sheet, along the boundary between the Voltri Massif and the outer units (e.g. the blueschist ophiolitic Montenotte Unit and Briançonnais Units). These tectonic contacts are partly sealed by the sedimentary succession of the Tertiary Piedmont Basin, although locally affected by later tectonic reactivations.

Field observations combined with laboratory analyses allowed the identification of two main types of foliated metabasite with distinct textures and mineral assemblages. Metabasite (I) is characterised by medium- to fine-grained, mm-thick layers of garnet + omphacite with a cataclastic texture, within a fine-grained foliated matrix defined by mm- to cm-thick layers of glaucophane + pargasite + chlorite + titanite ± apatite. Metabasite (II) is characterised by cm-thick blue levels of Na-amphibole + lawsonite ± epidote, alternating with greenish to white (mm- to cm-thick) layers with Fe-epidote + albite + chlorite, defining a composite fabric. Both metabasites are cut by sets of ptygmatic epidote- and carbonate-bearing veinlets.

Minerochemical characterization, protolith identification, and estimation of peak metamorphic P-T conditions, integrated with field and structural data, provide new constraints on the tectono-metamorphic evolution of this sector of the Ligurian Alps. The intimate association of adjoining tectonic slices recording different high-pressure metamorphic conditions, and thus distinct subduction-exhumation paths at variable temperatures, highlights the western margin of the Voltri Massif as a structurally complex sector, potentially preserving a relict Alpine plate-interface zone.

Cortesogno L. et al. (1977) - Paragenesi in facies scisti blu in metabasiti scistose del settore occidentale del Gruppo di Voltri. Ofioliti, 2 (2/3), 207-216.

Malatesta C. et al. (2017) - Fluid-controlled deformation in blueschist-facies conditions: plastic vs brittle behaviour in a brecciated mylonite (Voltri Massif, Western Alps, Italy). Geological Magazine, 155(2), 335-355, https://doi.org/10.1017/S0016756816001163.

Scarsi M. et al. (2017) - Lawsonite-bearing eclogite from a tectonic mélange in the Ligurian Alps: new constraints for the subduction plate-interface evolution. Geological Magazine, 155(2), 280-297, https://doi.org/10.1017/S0016756817000395.

Tracking metamorphic overprints and xenolith-granite interactions during Alpine subduction

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Keywords: xenoliths, polymetamorphic basement, rheological behaviour.

Mountain belts are the ultimate expression of multiple geological processes operating through time. Reconstructing the sequence of metamorphic events is particularly challenging in polycyclic metamorphic basements where successive overprints may obscure earlier records. Here we present a detailed multi-analytical study on a suite of Variscan crustal xenoliths embedded within a Permian granite and subsequently involved in Alpine ultra-high pressure (UHP) metamorphism.

Most xenoliths display a high-Al pelitic composition, whereas others derive from felsic and marly protoliths. The sequence of assemblages related to (1) Variscan regional metamorphism, (2) Permian contact metamorphism, and (3) Alpine UHP metamorphism is broadly reconstructed through integrated microstructural observations and mineral-chemical data. Our results show that both the Permian contact event and the Alpine regional metamorphism developed under static conditions, producing pseudomorphic mineral assemblages in the absence of significant deformation. The interactions between the various xenolith types and the hosting granite during Alpine subduction are further explored, highlighting how bulk-rock composition may have controlled the contrasting rheological behaviour of the different xenolith types, potentially influencing fluid mobility at the xenolith-granite interface under largely H_2O-undersaturated conditions.

Succession of albite blooms during decompression in the Dora-Maira Massif: mechanism and timing

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Keywords: albite porphryroblast, oligoclase rim.

Albite porphyroblasts, frequently rimmed by oligoclase rims are commonly found in *HP/UHP* rocks from the Western Alps. While albite grew during decompression (i.e. exhumation) and cooling (i.e. retrograde metamorphism) in the presence of a fluid phase, it has been suggested that oligoclase formed during a late stage of heating, together with biotite and a second generation of garnet (e.g., Borghi et al,. 1996; Nerone et al., 2023). This late stage has been considered "Lepontine in age" and linked to the Lepontine metamorphism recorded in the Central Alps.

In order to explore the mechanism and timing of plagioclase growth, this study investigates retrogressed *HP* to *UHP* rocks from the Dora-Maira Massif, combining field and petrographic observations with thermodynamic modelling and U-Pb geochronology.

Albite porphyroblasts are commonly wrapped by the main matrix foliation suggesting that their growth occurred during ductile deformation. Textural relations (i.e. idioblastic garnet inclusions in albite porphyroblast) unambiguously indicate that garnet growth occurred prior to albite growth, and that chlorite replacement of matrix garnet has taken place during and/or after albite growth. Oligoclase rims are mostly found in pressure shadows, rarely surrounding the entire albite porphyroblast, indicating the last increment of the ductile deformation, before final cooling and transition to brittle behaviour.

Thermodynamic modelling shows that along a retrograde *P-T* path, which involves decompression and slight cooling, the growth of albite precedes the growth of oligoclase: a late stage of heating is thus not required to stabilize oligoclase. However, the whole-rock composition (i.e. the Na/Ca ratio) strongly controls (i) the stability field of both albite and oligoclase (ii) the *P* (i.e. depth) at which these minerals appear, and (iii) their modal abundances. In rocks with very low Na/Ca ratio, thermodynamic modelling does not predict the growth of albite, but only oligoclase is stable at very low *P*. This prediction is well aligned with petrographic observations: in these rocks, albite is absent and post-kinematic oligoclase porphyroblasts overgrow the main matrix foliation, suggesting that their growth occurred only during late cooling.

Finally, new U-Pb geochronological data are used to discuss the absolute timing of albite growth and the exhumation history of the Dora-Maira Massif.

Borghi A. et al. (1996) - Composite P-T paths in the internal Penninic massifs of the Western Alps: Petrological constraints to their thermo-mechanical evolution. Eclogae Geol. Helv., 89, 345-367, https://doi.org/10.5169/seals-167905.

Nerone S. et al. (2024) - Assessing the importance of H_2O content in the tectonometamorphic evolution of the shear zones: A case study from the Dora-Maira Massif (Western Alps). J. Metamorph. Geol., 42, 171-196, https://doi.org/10.1111/jmg.12750.

Apparent pressure inversion in the Western Alps: Insights from the Dora-Maira Massif

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Keywords: tectonic window, thrusting, pressure.

The metamorphic architecture of a mountain belt reveals how deep-crustal processes interact during continental subduction and mountain building. In the European Alps, lower-grade rocks crop out in windows below higher-grade ones as result of large-scale thrusting during exhumation. One of the best areas for exploring pressure (*P*) discontinuity along a tectonic contact is the northern Dora-Maira Massif, which exposes the largest sector of the Pinerolo Unit as a window below the coesite-eclogite Muret-Chasteiran Unit (Manzotti et al., 2025). Raman spectroscopy on carbonaceous material indicates that in the northern Dora-Maira Massif, there is no significant temperature (*T*) differences within and across units. Thermodynamic modelling indicates peak *P-T* conditions of ~1.8 GPa ~500 °C for the Pinerolo Unit (Manzotti et al., in press). These *P-T* values are similar to those previously estimated for the Pinerolo Unit in the southern Dora-Maira Massif (Groppo et al., 2019), as well as for the Money Unit in the Gran Paradiso Massif (Manzotti et al., 2015). Although the tectonic boundary between the Money and Gran Paradiso Units is undisputable, the *P* gap is less marked than in the northern Dora-Maira Massif. As a whole, it appears that the lower units (Pinerolo, Money) display lower-grade metamorphism than the overlying units.

These results confirm that the internal zones of the Western Alps display *P* gaps, with *UHP* units overthrusting *HP* units, resulting from the detachment of subducted crustal slices from the downgoing slab and their stacking during the ensuing continental collision.

Groppo C. et al. (2019) - What is in the sandwich? New *P-T* constraints for the (U)HP nappe stack of southern Dora-Maira Massif (Western Alps). Eur. J. Mineral., 31, 665-683, https://doi.org/10.1127/ejm/2019/0031-2860.

Manzotti P. et al. (2015) - Constraining *P-T* conditions during thrusting of a higher pressure unit over a lower pressure one (Gran Paradiso, Western Alps). J. Metamorph. Geol., 33, 981-1002, https://doi.org/10.1111/jmg.12156.

Manzotti et al. (2025) - Garnet growth across the quartz-coesite transition in metapelites: equilibrium vs. kinetics. Eur. J. Mineral., 37, 455-482, https://doi.org/10.5194/ejm-37-455-2025.

Manzotti P. et al. (in press) - Peak P-T conditions in the structurally deepest rocks from the Western Alps: The Pinerolo Unit (Dora-Maira Massif). Mineral. Petrol., 120.

Architecture of the Patrimonio Fault System and the Miocene post-orogenic extension in Alpine Corsica (France)

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Keywords: Alpine Corsica, back-arc extension, structural inheritance.

The exhumation of Alpine Corsica is the result of the Oligocene-Miocene lithospheric back-arc extension in the wake of the eastward migration of Apenninic subduction. Yet how post-orogenic extension evolved in the brittle regime leading to the final exhumation of Alpine Corsica remains poorly documented. Here we integrate structural observations with carbonate stable isotope ($\delta^{18}O$-$\delta^{13}C$) geochemistry and U-Pb geochronology of carbonate fault cements to constrain the spatial and temporal evolution of the W-dipping Patrimonio Fault System. The Patrimonio Fault juxtaposes the Low Pressure/Low Temperature Nebbio units and the syn-extensional Miocene sedimentary sequences of the Saint Florent basin onto the High Pressure/Low Temperature Schistes Lustrés. The Patrimonio Fault System initiated in the early Miocene (≥20 Ma), as documented by a ~1-km-thick top-to-W/WNW brittle-ductile zone with pervasive SCC' fabric and pseudotachylytes, which exploited inherited compressional-related fabrics on the western limb of the Castagniccia-Cap Corse antiform. Early distributed extension evolved into more localized sinistral transtension between 20 and 14 Ma, as recorded by lineated slickensides on the main fault zone, and by cockade-bearing splay faults in the footwall. We link the sinistral transtensional activity to the anticlockwise rotation of the Sardinia-Corsica block during the opening of the Ligurian-Provençal basin. A later (≤14 Ma) phase of mid- to late-Miocene extensional faulting, driven by Tyrrhenian-related tectonics, produced the mature Patrimonio Fault, characterized by multiple anastomosing strands of foliated gouges and phyllonites accommodating ~2-3 km of displacement.

Our results show that lithospheric back-arc extension in Alpine Corsica was accommodated by major conjugate E- and W-dipping extensional to transtensional semi-brittle and brittle fault systems during the Miocene. Our results also document how the architecture of the Alpine antiformal stacking controlled the geometry and partitioning of post-orogenic extension in Alpine Corsica, highlighting the key role of inherited structures in affecting lithospheric extension.

Subduction margin architecture, thermal structure and exhumation in the Central Andes of southern Peru

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Keywords: crustal budget, gravity modeling, thermal and thermochronological modeling.

The Peruvian Andes provide a unique setting to investigate the effects of ridge subduction superposed on a long-lived orogen. The recent (<5 Ma) arrival of the aseismic Nazca Ridge at the subduction interface offers a natural laboratory to examine how flat-slab dynamics interact with crustal structures inherited from Cretaceous to Miocene Andean evolution. Because slab geometry strongly influences magmatism, seismicity, crustal shortening, exhumation, and topography, understanding the relationship between the Nazca Ridge flat slab and the overriding plate is essential for reconstructing Andean geodynamics. We investigated the three-dimensional architecture and thermal structure of the Central Andes in southern Peru, highlighting the interplay between basement structure, Moho geometry, slab configuration, and thermal properties. Basement highs and lows acted as zones of weakness that localized deformation during Andean shortening. The subducting Nazca Plate shows strong along-strike variations in dip and continuity, influenced by plate kinematics and by the Nazca Ridge. These variations control mantle wedge development, arc magmatism, and deformation patterns in the overriding plate. Heat flow increases from northwest to southeast, reflecting a transition from flat-slab conditions to steep-slab subduction characterized by magmatism and elevated geothermal potential. The flat-slab configuration was investigated by an integrated two-dimensional geological and geophysical model extending ~1,000 km across the Peruvian Andes to depths of ~180 km. The model combines surface geology, structural reconstructions, stratigraphic constraints, and geophysical data with forward modeling of the Bouguer gravity anomaly. A density model based on petrological and pressure-temperature constraints was constructed to define the geometry and physical properties of the subduction system at depth. Sampling for low-temperature thermochronology provided constraints on rock exhumation along the studied transect. Increasing exhumation rates during the last 5 Ma coincide with the transition from steep to flat slab caused by Nazca Ridge subduction. Our results reveal a strong contrast between deep and shallow deformation. At depth, the subduction system is dominated by the gently dipping to nearly horizontal Nazca Ridge slab, whose flat geometry enhances coupling between the Nazca and South American plates, promoting inland migration of deformation and increased upper-plate shortening. In contrast, the upper plate architecture is largely controlled by inherited rheological heterogeneities and preexisting structures related to earlier Andean tectonic phases. Crustal budget calculations yield shortening estimates between 137 km (25%) and 275 km (40%), depending on assumptions about pre-orogenic crustal thickness. Despite uncerta inties, these values are consistent with paleomagnetic reconstructions showing a northward decrease in shortening away from the Bolivian Orocline.

Quartz as a chemical barrier: controlling flat garnet habit during Barrovian metamorphism

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Keywords: garnet microstructures, cathodoluminescence, thermodynamic modelling.

Oblate garnet habits are rarely reported at subsolidus Barrovian metamorphic conditions, and their origin remains debated. Post-growth deformation and coalescence have been invoked to explain garnet elongated habits (George & Gaidies, 2020), whereas pseudomorphic replacement of precursor phases by coupled dissolution-precipitation has recently been proposed in eclogite-facies shear zones (Petroccia et al., 2026), demonstrating that garnet shape can be the result of different processes. Here, we propose an alternative mechanism operating under typical "Barrovian" conditions, in which the flat habit reflects chemical barriers imposed by quartz crystallising as a reaction product synchronously with garnet growth.

We investigate a garnet-bearing quartz-rich micaschist from the upper Lesser Himalayan Sequence of eastern Nepal Himalaya, equilibrated at amphibolite-facies conditions. The sample shows a spaced banding of quartz-rich and muscovite-rich layers. Garnet porphyroblasts hosted within muscovite-rich layers show equant morphologies, whereas those at the interface with quartz-rich layers are systematically oblate parallel to foliation, as demonstrated by 3D reconstructions through X-ray μ-CT and 2D thin section analysis. EBSD maps confirm that garnets are internally undeformed and non-coalescent, excluding post-growth deformation and coalescence.

Hyperspectral cathodoluminescence (CL) zoning patterns of quartz in the matrix and included in garnet show increasing CL intensity from core to rim, whereas quartz in pressure shadows displays a systematically higher CL intensity comparable to quartz rims in the other microstructural positions. EBSD analysis of quartz reveals that internal misorientation is decoupled from the CL zoning pattern, indicating that CL zoning records primary growth stages. CL spectra comparison suggests that CL intensity reflects differences in the contribution of the ~450 nm peak, which has been associated with either Ti content or defect density (Holness & Watt, 2001; Leeman et al., 2012), with higher contributions related to higher CL intensity. Forward thermodynamic modelling investigates the garnet-producing reaction(s), evaluating whether quartz acts as a reactant or a product. We propose that quartz growing synchronously with garnet replaces the reactive phyllosilicate matrix above and below the growing porphyroblast, eliminating the nutrient source perpendicular to foliation while diffusion along phyllosilicate-rich layers remains active. This implies that oblate garnet morphology in quartz-bearing metapelites may record anisotropic nutrient availability during crystallisation, providing microstructural evidence for spatially heterogeneous reaction progress at the grain scale during Barrovian metamorphism.

George F.R. & Gaidies F. (2020) - Simultaneous operation of opposing reaction mechanisms: The influence of matrix heterogeneity on post-kinematic garnet crystallization in an inverted metamorphic sequence. J. Metamorph. Geol., 38, 743-769, https://doi.org/10.1111/jmg.12539

Holness M.B. & Watt G.R. (2001) - Quartz recrystallization and fluid flow during contact metamorphism: a cathodoluminescence study. Geofluids, 1, 215-228, https://doi.org/10.1046/j.1468-8123.2001.00015.x

Leeman W.P. et al. (2012) - A Study of Cathodoluminescence and Trace Element Compositional Zoning in Natural Quartz from Volcanic Rocks: Mapping Titanium Content in Quartz. Microsc. Microanal., 18, 1322-1341, https://doi.org/10.1017/S1431927612013426.

Petroccia A. et al. (2026) - Tracking Dehydration Reactions and Fossil Fluid Flux in Shear Zones Using Garnet Microstructures. J. Metamorph. Geol., 1-21, https://doi.org/10.1111/jmg.70042.

Deformation history and tectonic evolution of the Shillong Group of rocks, Meghalaya: Constraints from field, microstructural and phase equilibria modelling studies

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WITHDRAWN

Coupled or decoupled during subduction? The Alpine metamorphic record of the basement-cover pair from the northern Dora-Maira Massif, western Alps

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Keywords: basement-cover interfaces, ultra-high pressure, Dora-Maira Massif.

Recent studies on orogenic belts increasingly emphasize that the basement-cover interface plays a crucial role both at the onset of plates convergence, where they control the localization of basal décollements, and during "deep" subduction, where they facilitate tectonic underplating and nappe stacking.

In this study, we present a multidisciplinary investigation of basement-cover relationships and P-T-t evolution in the northernmost sector of the Dora-Maira Massif (DMM; Susa Valley). In this sector, despite the tectonic nature of the basement-cover contact (i.e., the Bussoleno Detachment Zone; Balestro et al., 2025), the Mesozoic cover remains closely associated with its Paleozoic basement. Determining whether these two units share a common metamorphic evolution is key in constraining the timing of detachment activation.

Forward thermodynamic modelling of a garnet-bearing micaschist from the Paleozoic basement and a phengite-bearing dolomitic marble from the Mesozoic cover reveals peak metamorphic conditions within the coesite stability field (T = 510-530°C, P = 2.7-3.0 GPa). The attainment of ultrahigh-pressure (UHP) conditions is further confirmed by the discovery of preserved coesite inclusions hosted within garnet in the micaschist. $^{40}Ar/^{39}Ar$ analyses of phengite from the dolomitic marble, performed using both the laser step-heating and the laser in-situ techniques, consistently suggest an early Eocene age for the time of peak metamorphism.

Taken together, results provide compelling evidence that in the northernmost sector of DMM, the Mesozoic cover was subducted synchronously with its Paleozoic basement, implying that decoupling occurred during exhumation rather than subduction. At the regional scale, the identification of coesite relicts and the inferred UHP peak conditions allows to extend norward the limit of UHP metamorphism within the DMM. The reconstructed P-T-t path for the basement-cover pair closely matches recent findings from more southern sectors (Manzotti et al., 2022, 2025), supporting the interpretation that at least the northern portion of the Dora-Maira Massif was buried and exhumed as a coherent tectonic block.

Balestro G. et al. (2025) - Tectonic relationships between the Paleozoic basement and the Mesozoic cover succession in the northern Dora-Maira Massif (Susa Valley, Western Alps), Journal of Maps, 21(1), 2451785, https://doi.org/10.1080/17445647.2025.2451785.

Manzotti P. et al. (2022) - A Journey Towards the Forbidden Zone: A New Cold UHP Unit in the Dora- Maira Massif (Western Alps). Contributions to Mineralogy and Petrology, 177, 59, https://doi.org/10.1007/s00410-022-01923-8.

Manzotti P. et al. (2025) - Garnet growth across the quartz-coesite transition in metapelites: equilibrium vs. kinetics. European Journal of Mineralogy, 37, 455-482, https://doi.org/10.5194/ejm-37-455-2025.

Inherited rift faults as Drivers of orogenic complexity: The case of the Amora Fault System, central Southern Alps (N Italy)

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Keywords: rift inheritance, fault reactivation, Southern Alps.

Understanding structural inversion is critical for reconstructing the evolution of fold-and-thrust belts and deciphering how inherited architectures dictate orogenic growth. This study investigates the tectonic evolution of the Amora Fault System (AFS) in the central Southern Alps—a Jurassic rift-related structure repeatedly reactivated during Alpine orogenesis. We reconstruct a multiphase history of faulting using an integrated approach combining detailed field structural analyses and mapping, paleostress reconstructions, and microstructural study of fracture-filled carbonates, integrated with analogue model comparisons.

The Amora Fault System initiated as a long-lived N-S-striking normal fault system during the Early-Middle Jurassic rifting, followed by renewed post-rift reactivation in the Late Jurassic-Early Cretaceous. Subsequent Alpine compression (Late Cretaceous-Eocene) led to the development of the S-verging Albino Thrust, strike-slip reactivation of Jurassic normal faults, and mid-Eocene magmatism accompanied by emplacement of E-W-trending andesitic dikes and associated faulting. Paleostress analyses reveal a distinct evolution of the stress field: from a Jurassic extensional regime (σ_1 vertical and E-W trending σ_3) to mid-Eocene magmatic extension (N-S trending σ_3), and finally to a compression with a horizontal, N-S-directed σ_1 during Alpine shortening. Our findings highlight how the interplay between structural inheritance, thermal weakening, and stress field reorientation controls thrust segmentation and deformation partitioning. More broadly, this study illustrates how inherited rift structures govern the architecture of orogenic belts, generating complex along-strike thrust geometries and multiphase deformation patterns. These results provide key insights into fault evolution across complete rift-orogen cycles and improve the understanding of the seismic activity localized along inherited structures.

Earth's youngest ultrahigh-pressure eclogite formed in an immature subduction zone

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Keywords: eclogites, coesite, subduction.

The subduction of crustal rocks to, and exhumation from, depths > 90 km in the stability field of the mineral coesite is known as ultrahigh-pressure metamorphism, widely regarded as evidence for cold subduction. This assumption stems from peak metamorphic conditions of ultrahigh-pressure rocks, which indicate subduction gradients 60 mm/yr in the vertical component. This is best explained by the formation in a young, immature subduction zone, which did not reach steady-state. We propose that deep subduction to ultrahigh-pressure conditions, and exhumation, may be more common in immature and warm, rather than mature and cold subduction zones.

Structural inheritance of an Anisian-Ladinian basin margin during alpine compression: The Focobon area in the Dolomites, northern Italy

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Keywords: alpine compression, structural inheritance, dolomites

Structural inheritance often shapes the architecture of fold and thrust belts. We present a new 1:10.000 geological map of the area around Focobon, in the northern part of the Pale di San Martino Group of the Dolomites. We document the reactivation of Anisian-Ladinian structures during the alpine orogeny.

The area is characterised by the classical western dolomites sequence, with the transition from an evaporitic basin and shallow coastal area (Bellerophon and Werfen Fms) to a carbonate platform and basin setting (Sciliar and Buchenstein Fms), before a Ladinian magmatic event.

The area is very poorly studied. Regional scale maps are limited to (Castiglioni, 1939) and (Sarti & Ardizzoni, 1984).

Two tectonic phases are documented. An Upper Anisian to Upper Ladinian extensional phase is recorded by the opening of a basin in the northeastern part of the area, identified by an increase in thickness of sedimentary units. In the NE, the typical Upper Anisian-Ladin basinal Fms of the western Dolomites (Moena and Buchenstein Fms) are present, whereas the southern part shows the carbonate platform units (Contrin and Sciliar Fms). Lateral contacts are abrupt and correspond to faults oriented about N-S and ENE-OSO.

In this complex basin-platform paleogeographic setting there was the onset of the Ladinian magmatic event: lava flows, pyroclastic deposits and intrusions filled the basin and a ENE-OSO oriented normal fault cut the slope of the platform and borders the volcanic basin.

During the Alpine compressional phase some of the ENE-OSO Anisian-Ladinian structures were reactivated as north-verging thrusts or transfer zones. The main thrust cut through the former Anisian-Ladinian basin and led to the local duplication of the volcanic and sedimentary cover.

Thrust structures are controlled by lithological heterogeneities: the basinal part shows a greater shortening with respect to the Sciliar platform which acted as a buttress.

Castiglioni B. (1939) - Il gruppo delle pale di San Martino e le valli limitrofe. Alpi dolomitiche. Memorie dell'Istituto geologico della R. Università di Padova, 13(4).

Sarti M. & Ardizzoni F. (1984) - Tettonica triassica nel gruppo di Cima Pape-Pale di Sanson (Dolomiti Bellunesi). Mem. di Scienze Geologiche, 36(15), 353-370.

Structural diagenesis drives the self-locking of regional décollements, example from the central Apennines

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Keywords: décollement, structural diagenesis, thrust.

The architecture of fold-and-thrust belts is fundamentally governed by mechanical weak zones that serve as regional décollements, commonly located in shales or evaporites. However, the Miocene synorogenic Calcari a Briozoi e Litotamni (CBL) in the Central Apennines presents a mechanical paradox: despite its current high competency, it hosted a pervasive regional shear zone, preferentially localizing strain over nominally weaker overlying marls and flysch. This study demonstrates that the CBL acted as a transient, "self-locking" décollement regulated by structural diagenesis. Through macro- and micro-structural analysis, we show that the CBL was activated while still a porous, unlithified carbonate sand. Layer-parallel shearing initially promoted the formation of compaction bands, which evolved into pressure-solution cleavage due to stress concentration at grain contacts. The dissolved calcite precipitated as syntectonic cement within the pore space and tectonic veins, triggering a strain-hardening feedback. This process transformed a weak granular horizon into a competent, lithified unit, ultimately locking the décollement and forcing deformation to re-localize into overlying units. U-Pb radiometric dating of cements reveals a ca. 5 Myr lag between deposition and tectonic activation, the time required for the unit to travel from the peripheral bulge, where it sedimented, to the thrust front, where it deformed, while remaining unlithified. Our results indicate that lithification state at the onset of thrusting is a primary control on strain localization, suggesting that structural diagenesis may systematically limit the lifespan of décollements in carbonate-rich foredeep sequences.

Landscape-Scale architecture of syn-rift gravitational gliding: The Bóixols carbonate rafting system (Southern Pyrenees)

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Keywords: raft tectonics, rifting, carbonate platform.

Gravitational gliding is a fundamental process in the evolution of rifted margins, where mechanically weak horizons facilitate the detachment and translation of overlying sedimentary successions. While these systems are frequently imaged in seismic reflection data, outcrop analogues exposing the complete structural architecture, from the proximal extensional domain to the distal contractional toe, are exceptionally rare. This study presents a high-resolution analysis of a shallow-seated gravitational gliding system in the Lower Cretaceous Organyà Basin (Southern Pyrenees), where a kilometer-scale carbonate platform developed and translated over a decollement exploiting deeper weak marls. By integrating traditional structural mapping with high-resolution Digital Surface Models (DSM) derived from LiDAR and orthophotographs, we reconstructed the 3D geometry and kinematics of the Bóixols sector. The analysis reveals an array of domino-style extensional faults within the platform, kinematically coupled with a low-angle thrust fault at its frontal domain, a diagnostic hallmark of gravitational rafting. The syn-sedimentary nature of these structures is evidenced by growth geometries preserved within the stratigraphic succession. Our results depict Bóixols outcrop as a unique analogue for interpreting carbonate rafting in subsurface settings, where the mechanical decoupling between deep basement tectonics and shallow gravity-driven sliding remains a major interpretative challenge. Furthermore, this work highlights how digital field geology, coupled with and tested through traditional field and stratigraphic analyses, can resolve complex gravity-driven processes that often remain ambiguous in regional geophysical datasets.

Revisiting the P-T evolution of the Mandanici Unit (Peloritani Mountains, Sicily): new constraints from quantitative compositional mapping and phase equilibrium modelling

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Keywords: metapelite, thermodynamic modelling, Peloritani Mountains.

The Mandanici Unit (MU) of the Peloritani Mountains (NE Sicily) represents a multistage Variscan greenshist facies tectono-metamorphic Unit, partly reworked during the late Oligocene, under sub- to lower-greenschist facies conditions. This last stage is associated with the initial juxtaposition of the present-day nappe-like edifice of the southern Calabrian Peloritani Orogen along deep-seated binaries. Locally, interference plicative structures evolved into a retrograde mylonitic stage before being involved in the emplacement of the thin-skinned thrust-sheet. This deformation is known as the Apennine stage of the Alpine orogeny (Cirrincione et al., 2015). As a result, MU is sandwiched between the high-grade metamorphic basement of the Aspromonte Unit (AU) and the anchimetamorphic Alì Sequence (AS), considered as the original sedimentary cover of the MU. Previous studies on metapelitic samples from the Savoca, Montagna di Vernà, and Briga sectors highlighted a clockwise Barrovian Pressure-Temperature (*P-T*) evolution characterized by burial, thermal relaxation, and retrograde shearing stages (Lo Po' et al., 2012).

In this contribution, we present results from a new image-assisted petrological, microstructural, and phase-equilibrium modelling study aimed at refining the metamorphic evolution of the MU. High-resolution compositional maps acquired at the University of Lausanne were processed through XMapTools and the Quantitative X-ray Map Analyser (Q-XRMA) software to investigate chemical zoning in garnet and associated mineral phases (Lanari et al., 2014; Ortolano et al., 2018).

The studied metapelites preserve Variscan deformation-blastesis relationships involving multiple foliations and syn-kinematic garnet growth episodes. Garnet porphyroblasts from the three investigated localities display distinct compositional zoning patterns, marked by progressive Fe enrichment and Mn depletion from core to rim, locally associated with texturally controlled resorption and re-equilibration features. These chemical variations, integrated with detailed microstructural observations, allowed reconstruction of revised *P-T* paths for the different tectono-metamorphic stages.

Phase equilibrium modelling performed using local bulk compositions highlights prograde burial conditions followed by thermal relaxation under lower amphibolite- to greenschist-facies conditions. Preliminary results suggest significant local differences in the retrograde evolution of the three sectors, likely related to heterogeneous strain partitioning during late Variscan exhumation and shearing. The new dataset provides tighter constraints on the tectono-metamorphic evolution of the MU, contributing to better constrain the late Paleozoic evolution of this southern European Variscan relic crust.

Cirrincione R. et al. (2015) - The Calabria-Peloritani Orogen, a composite terrane in Central Mediterranean; its overall architecture and geodynamic significance for a pre-Alpine scenario around the Tethyan basin. Periodico di Mineralogia, 84(3B), 701-749, https://doi.org/10.2451/2015PM0446.

Lo Pò D. et al. (2012) - PTd evolution of greenschist facies metapelites from the Variscan middle crust of the Peloritani Mountains (North Eastern Sicily). In: Length scales, time scales and relative contribution of Variscan orogenic events to formation of European crust, Proceedings of the French and Italian Geological Societies Meeting, Sassari (Italy), 23-26 May 2012. Géologie de la France, 1, 141-143.

Lanari P. et al. (2014) - XMapTools: A MATLAB©-based program for electron microprobe X-ray image processing and geothermobarometry. Computers & Geosciences, 62, 227-240, https://doi.org/10.1016/j.cageo.2013.08.010.

Ortolano G. et al. (2018) - Quantitative X-ray Map Analyser (Q-XRMA): a new GIS-based statistical approach for quantitative analysis of X-ray maps. Computers & Geosciences, 115, 56-65, https://doi.org/10.1016/j.cageo.2018.03.001.

S16.

Multiscalar structural analysis for understanding grain scale to plate margins processes. Session in memory of Guido Gosso

CONVENERS & CHAIRPERSONS:

Michele Zucali (Università degli Studi di Milano)

Manuel Roda (Università degli Studi di Milano)

Davide Zanoni (Università degli Studi di Milano)

Gisella Rebay (Università degli Studi di Pavia)

Polyphase Deformation and Metamorphic Evolution of High-Grade Variscan Rocks in Southeastern Corsica (France)

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Keywords: Fautea-Favone metamorphic complex, shear zones, variscan basement.

The Variscan basement of the Corsica-Sardinia block is one of the most extensively studied sectors of the Southern Variscan belt in the Mediterranean region. The rocks exposed in southern Corsica are traditionally interpreted as the northern continuation of the micaschists, gneisses and migmatites affected by amphibolite facies metamorphism (with granulites and eclogite relicts) observed in northern Sardinia (Rossi et al., 2009).

In south-east Corsica, the Fautea-Favone Metamorphic Complex (FFMC) is characterized by migmatites and by amphibole- and kyanite- garnet- bearing gneisses (Amabile et al., 2025 with references therein). These rocks record a complex polyphase tectono-metamorphic history with progressive deformation mainly related to two distinct shear events (referred as D2 and D3). The D2 shear event produced a km-thick N-S striking, pervasive S2 mylonitic foliation exhibiting both dextral and sinistral sense of shear, wrapping metre- to centimetre-scale lozenge-shaped folding domains. Chess board extinction in quartz and lobate and cuspate quartz-feldspar boundaries suggest deformation at high temperature in the presence of melt (Amabile et al., 2025).

Relicts of D2 mylonites, preserved as lozenge-shaped domains, are bound by a network of anastomosing, localized E-W striking dextral and sinistral shear zones (10-50 cm thick) (D3 event) that developed under ductile (melt-free) to brittle conditions (Giacomini et al., 2008; Amabile et al., 2025). Deformation mechanisms in quartz and feldspar constrain deformation temperature from c. 500-600°C to below 300°C.

The FFMC represents a segment of Variscan basement that records an initial crustal-scale diffuse shearing event (D2) developed under high-temperature conditions, characterized by a general shear flow regime (simple shear + pure shear). This was followed by a later, localized, anastomosing shearing event (D3), which evolved during progressive exhumation. The metamorphic assemblages indicate a retrograde clockwise P-T path from amphibole eclogite/HP granulite facies to greenschist facies conditions.

Amabile F. et al. (2025) - Deformation partitioning in the mid-to deep sheared crust of the Variscan Fautea-Favone metamorphic complex (southern Corsica, France). J. Maps, 21(1), 2498973, https://doi.org/10.1080/17445647.2025.2498973.

Giacomini F. et al. (2008) - Exhumation of a Variscan orogenic complex: Insights into the composite granulitic-amphibolitic metamorphic basement of south-east Corsica (France). J. Metamorph. Geol., 26, 403-436, https://doi.org/10.1111/j.1525-1314.2008.00768.x.

Rossi P. et al. (2009) - A restored section of the "southern Variscan realm" across the Corsica-Sardinia microcontinent. C. R. Geosci., 341(2-3), 224-238, https://doi.org/10.1016/j.crte.2008.12.005.

Unravelling the P-T-d history of a portion of the Schistes Lustrés (Beth-Ghinivert - Western Alps): From HP to exhumation

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Keywords: metamorphic evolution, Beth-Ghinivert, Western Alps.

The Schistes Lustrés of the Piedmont Zone (Pennidic domain) underwent a polyphasic metamorphic evolution during the Alpine orogenesis (Giacometti & Rebay, 2012). They consist of calcschists with scattered metre up to kilometre-sized blocks of ophiolites. In the Beth-Ghinivert mines area (Chisone Valley, Western Alps) irregular bodies of metabasites (meta-gabbro, glaucophanite and greenschists), associated with pyrite-rich mineralizations, occur in the calcschist. A detailed structural survey evidenced three deformation events in the calcschists and associated metabasites:

– D1 is characterized by isoclinal folding of pre-metamorphic surfaces and formation of a S1 axial-plane cleavage, preserved in small volumes;
– D2 produced closed to isoclinal folds and the associated S2 axial-plane foliation is the main schistosity of the area;
– D3 is characterized by open to close folds, locally associated with a S3 axial-plane crenulation cleavage.

Microstructural analisys coupled with mineral compositions determined by EMPA, allowed to determine the parageneses associated to each deformation event.

In glaucophanites and mafic schists the syn-D1 mineral assemblage consists of blue amphibole, white mica, chlorite, epidote, albite, quartz, minor titanite and sulphides (pyrite and subordinate chalcopyrite), the syn-D2 paragenesis is similar, with local enrichment in the calco-sodic molecule at amphibole crystal rims. Late chlorite, albite, epidote, white mica, ferro-actinolite and minor calcite, titanite and pyrite are associated to S3. In metapelite and quartz rich lithologies, syn-D1 mineral assemblage is chloritoid + phengitic white mica + quartz ± lawsonite ± allanite + rutile ± tourmaline; chlorite, epidote and paragonite are stable in S2, toghether with chloritoid and muscovite. Stilpnomelane is observed in quartz-rich enriched levels near the mineralization, and deerite has been described as well (Bouquet & Forette, 1973 and refs therein).

PT modelling of mafic rocks and metapelite indicates epidote-blueschist facies conditions for D1 and D2 events, with D2 being associated with a pressure decrease. Re-equilibration under greenschists facies conditions is recorded pervasively.

Bouquet, J. & Forette M.C. (1973) - Sur la deerite de l'ensemble des calchschistes pi_emontais _a Troncea (Italie), Bull. Soc. Fr. Mineral. Cristallogr., 96, 314-316.

Giacometti F. & Rebay G. (2012) - Deformation-metamorphism relationships in the metabasites at Beth-Ghinivert (Piedmont Schistes Lustrés Zone - Western Alps). Rend. online Soc. Geol. It., 22, 102-104.

Metamorphism and linked deformation at varied scales: Review and some perspectives

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Keywords: orogens, metamorphism, deformation.

Since the second half of the twentieth century there is a broad consensus that metamorphism is the dominant transformation mechanism in the lithosphere. The link between type of metamorphism and tectonic environment is widely recognized since seminal publication of Miyashiro (1961), and the temporal relationships between metamorphism and superposed deformation events has become a classic approach in orogens following the work of Zwart (1962). In the last three decades significant progress has been made on thermomechanical modelling of orogens, on thermodynamic modelling of metamorphic systems as well on petrochrology of metamorphic rocks.

The goal of this contribution is thus to review the state of knowledge on the links between metamorphic and deformation processes at different scales:

– Metamorphic patterns in large-scale geodynamic contexts.
– Multiple interactions between metamorphism and deformation at rock and outcrop scales. A particular attention will be paid on the one hand on deformation mechanisms that help overcoming kinetic barriers for metamorphic reactions, and on the other hand on deformation mechanisms that may preclude robust quantification of P-T conditions.

This presentation will be partly based on several of the works in which Guido Gosso participated, particularly in the Alpine belt.

Miyashiro A. (1961) - Evolution of metamorphic belts. J. Petrol., 2, 277-311.
Zwart H. J. (1962) - On the determination of polymetamorphic mineral associations and its application to the Bosost area (Central Pyrenees). Geol. Rdsch., 52, 38-65.

Glaucophane-winchite bearing pseudotachylytes in eclogites of the Sesia-Lanzo Zone (Italian Northwestern Alps): Evidence for palaeoseismic events under high-pressure conditions

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Keywords: eclogitic Western Alps, glaucophane and winchite-bearing veins, frictional melting.

Eclogites of the Sesia-Lanzo Zone, exposed in the Gressoney Valley within the Northwestern Alps of Italy, show thin and discontinuous glaucophane-winchite bearing veins. These veins are interpreted as former pseudotachylytes. The host eclogite is composed of omphacite, garnet, quartz, rutile and sulphides that equilibrated at approximately 570°C and 25 kbar. The veins exhibit a thickness ranging from millimetres to centimetres, with a length of up to 1-2 metres and are filled with fibrous blue glaucophane and winchite, which simulate a fluid-like texture. This texture is characterised by laminar and turbulent flow structures, which are commonly observed in pseudotachylyte veins. The interior of the veins contains clasts of omphacite, garnet, white mica, clinozoisite and titanite, suggesting that the pseudotachylytes initially developed as cataclasites due to the crushing of the host eclogite because of seismic rupture. This is evidenced also by the presence of fractured omphacite and garnet crystals along the contact with the host rock. Subsequent shear heating induced melting of the eclogite along the fractures. The amphiboles underwent crystallisation from the melt, as demonstrated by the fluidal texture preserved by the amphiboles within the veins. The supercooled melt underwent a crystallisation process, with the formation of Na-Ca-amphibole + albite occurring initially at the periphery of the vein, followed by the subsequent crystallisation of glaucophane at the core of the vein. The occurrence of these amphiboles in the veins indicates that the pseudotachylyte evolution was assisted by fluid circulation under blueschist-facies conditions, at approximately 8-16 kbar, during exhumation after the eclogite-facies peak reached by the host rock. Finally, the veins were cut across by late calcite, albite and actinolite veinlets formed under greenschist facies conditions during exhumation.

Martin S. et al. (2025) - Unusual glaucophane and winchite-bearing veins in mafic eclogites of the Sesia-Lanzo Zone (Italian Northwestern Alps): Are they due to hydrofracturing or a paleoseismic event? Lithos, 508-509, 108067, https://doi.org/10.1016/j.lithos.2025.108067.

Multi-scale structural analysis and geological conceptual model to derisk hydrocarbon exploration and exploitation activities in challenging thrust belt environments

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Keywords: fold-and-thrust belts, multi-scale structural analysis, exploration uncertainty reduction.

Multi-scale seismic interpretation and prospect definition in structurally complex continental fold-and-thrust belts are inherently challenging due to limitations in seismic acquisition and processing, which commonly result in poor subsurface imaging. In such settings, limited data quality prevents the full resolution of structural complexity, imposing intrinsic constraints on the reliability of seismic-based analyses.

AI-driven fault interpretation and sub-seismic fracture characterization are highly dependent on seismic quality and resolution. Structural restoration is widely used to constrain the timing of major tectonic events, including nappe emplacement, thrust and back-thrust development, sequence duplication, and salt tectonics, and provides key input for petroleum system modeling. However, when used in isolation, restoration approaches are often insufficient to capture structural variability and uncertainty at the prospect scale.

Seismic interpretation must therefore be supported by robust geological conceptual and structural models, integrating multiscale surface and subsurface data together with absolute timing constraints on burial, uplift, exhumation, erosion, folding, and faulting. Nevertheless, natural fold-and-thrust belts often deviate from idealized models, exhibiting significant lateral and longitudinal variations in their geometry, caused by the superposition of multiple tectonic phases and structural styles.

To effectively reduce uncertainty, a multi-scenario, multidisciplinary, and multiscale integrated workflow is required. Three main applications are presented: (1) 2D structural restoration to support regional-scale basin modeling; (2) critical re-evaluation of 3D vintage seismic interpretation, guided by geological conceptual models, to unlock new exploration opportunities; and (3) integrated analysis of seismic attributes and well data to investigate sub-seismic structural features and derisk drilling activities.

This integrated approach is essential for revitalizing hydrocarbon exploration and production in complex thrust belt settings, enhancing decision-making from prospect generation to field development, well planning, and operational optimization.

Unravelling the polycyclic evolution of basement units through multiscale and multidisciplinary analysis of pre-Alpine metamorphic remnants: Insights from the Tambo and Suretta nappes (Central Alps)

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Keywords: tectono-metamorphic evolution, pre-alpine metamorphic remnants, Central Alps.

Structural and metamorphic relics in crystalline basement units allow reconstruction of the tectono-metamorphic evolution of complex polycyclic basements. In the Central Alps, the Tambo and Suretta nappes (Briançonnais terrane, Middle Penninic Domain) experienced intense Alpine overprint, which extensively obliterated the record of the pre-Alpine evolution of this portion of the paleo-European crust.

Recent detailed fieldwork carried out in the framework of the Italian Geological Mapping Project (sheets 021-022 "Passo dello Spluga and Madesimo" and 037-038 "Bodengo and Chiavenna"; Tartarotti et al., 2026) has allowed a renewed and comprehensive field characterization of the central-southern portions of these nappes. Despite pervasive Alpine reworking, several sectors preserve domains in which pre-Alpine structural fabrics and/or metamorphic mineral assemblages are still recognizable. These include: 1) high-grade metapelites with garnet-kyanite-staurolite assemblages and locally preserved migmatite textures; 2) garnet-bearing amphibolites, with evidence of a pre-alpine, eclogite-facies event (Nussbaum et al., 1998); 3) meta-aplite and meta-pegmatite bodies, possibly associated to the widespread evidence of Carboniferous-Permian magmatism at the nappe scale and coherent with regional-scale evidence from the Central Alps (*e.g.*, Schaltegger, 1997). Such domains provide a valuable record of pre-Alpine tectono-metamorphic events and magmatic processes, potentially linked to different stages of the Variscan orogeny.

A multi-scale and multidisciplinary approach combining detailed fieldwork, petrographic and microstructural analyses, geochemistry and geochronology is applied to characterize these remnants and to disentangle Alpine from Pre-Alpine signatures. Preliminary results indicate that, even within strongly reworked basement sectors, older metamorphic and magmatic records are locally preserved and could be used to reconstruct meaningful P-T-t paths for the Variscan evolution of the Tambo and Suretta basement units. The geodynamic implications of the provided constraints are evaluated and discussed within the regional framework of the Central Alps.

Nussbaum C. et al. (1998) - Two subduction events in a polycyclic basement: Alpine and pre-Alpine high-pressure metamorphism in the Suretta nappe, Swiss eastern Alps. J. metamorphic Geol., 16, 591-605, https://doi.org/10.1111/j.1525-1314.1998.00154.x.

Schaltegger U. (1997) - Magma pulses in the Central Variscan Belt: episodic melt generation and emplacement during lithospheric thinning. Terra Nova, 9(5-6), 242-245, https://doi.org/10.1111/j.1365-3121.1997.tb00021.x.

Tartarotti P. et al. (2026) - Note illustrative della Carta Geologica d'Italia alla scala 1:50.000. Fogli 021-022 "Passo dello Spluga - Madesimo" e 037-038 "Bodengo - Chiavenna". ISPRA - Servizio Geologico d'Italia (in press).

Post-orogenic transtensional necking of the Variscan crust - insights from the Corsica-Sardinia Batholith

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Keywords: granite, shear heating, thermobarometry.

The Corsica-Sardinia Batholith is a huge magmatic system composed of plutons and sub-volcanic complexes emplaced over about 60 Myrs during post-collisional extension of the Variscan crust. This long lifetime and the incremental, episodic, nature of pluton emplacement reflects major changes of magmatic activity at the Carboniferous-Permian boundary, making the batholith an excellent tool to understand the post-orogenic tectonic re-organization of the Variscan crust. Carboniferous plutons (325-305 Ma) emplaced within deep trans-crustal E-W or NW-SE shear zones forming composite granodiorite to leuco-monzogranite intrusions. The geochemical fingerprint of these rocks is transitional between typical S-type and I-type granites being calc-alkaline, moderately to strongly peraluminous, radiogenic, and weakly fractionated. On the other hand, Permian magmatic complexes (295-270 Ma) are mostly sub-volcanic to shallow composite intrusions emplaced within NE-SW to N-S step-over or dilatational jogs connecting E-W faults. These complexes give way to a set of regularly spaced crustal boudins formed by remnants of Carboniferous plutons and metamorphic rocks. The composition of Permian complexes is extremely variable including calc-alkaline gabbro, quartz-diorite and sub-alkaline to alkaline granites, sometimes highly peraluminous and fractionated. AMS data and U-Pb geochronology constrain the magmatism shift and change of shear zones orientation to the Carboniferous-Permian boundary, providing observational evidence for large block rotations and displacement along an intra-Pangea lithospheric shear zone.

Sillimanite-gneiss tracks melt migration pathways across the continental crust: Meso- and microstructures from the Valpelline Series migmatites (Western Alps)

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Keywords: melt migration, melt-rock interaction, strain gradient.

Melt generated in the deep crust must segregate from its source and become focused into high-permeability ascent conduits to reach the upper crust and feed the roots of the plutons. However, evidence of such melt migration pathways in the middle and deep continental crust remains extremely elusive. We document the occurrence of anomalously sillimanite- and garnet-rich rocks (i.e., sillimanite-gneiss) along the axial planes of late-stage folds. The spatial distribution and extent of sillimanite-gneiss are controlled by the heterogeneity of deformation. Low strain domains, represented by cordierite-bearing migmatites, preserve melt production and segregation structures parallel to the regional foliation. In contrast, intermediate- and high-strain domains record late-stage folding, deforming the regional foliation and developing an axial plane foliation marked by crystallization of isoriented sillimanite. These high-strain zones display structures consistent with melt migration and extraction. We therefore propose that: (1) the open-system transformation of cordierite-biotite-garnet migmatitic gneisses into sillimanite gneiss resulted from melt-rock interaction, and (2) melt extraction and migration were deformation-driven. In high-strain domains, sillimanite-gneiss forms mappable horizons extending tens to hundreds of meters and can thus be interpreted as deformation-assisted melt migration zones within the deep continental crust.

The Rif belt in north Morocco: Paired metamorphic belts build in a context of ablative subduction?

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Keywords: Rif belt, paired metamorphic belts, ablative subduction.

The Betic-Rif Cordillera, located in the western Mediterranean, results of the convergence of the European and African tectonic plates and related subduction processes. This makes it an exceptional site for studying subduction dynamics.

A multidisciplinary approach was adopted in the Rif belt to investigate the tectonic significance and ages of metamorphic units, which remain a subject of debate.

The results of detailed structural and petrographic studies, as well as U/Th/Pb and 40Ar/39Ar dating, highlight the following evolution:

During the Upper Triassic, the Upper Sebtides, which are composed of Permo-Triassic metasediments overlaying Paleozoic basement, underwent high-temperature, low-pressure (HT-LP) metamorphism. This event is related to the exhumation of the mantle during the opening of the Tethys Ocean in a context of hyper-extension of the margin.

During the Oligocene, the Lower Sebtides were affected by a Barrovian to Abukuma metamorphic event (MP-HT). This phase occurred simultaneously with the intrusion of diorite sills bearing a calc-alkaline to high-K magmatic arc geochemical signature. This phase is contemporaneous with the HP-LT metamorphism observed in the crustal units of the Upper Sebtides. Synchronous HP-LT and LP-HT metamorphism with radically different thermal gradients are characteristic of "paired metamorphic belts".

(3) During the early Miocene, prograde HT-LP metamorphism affected the Lower Sebtides. These conditions reflect crustal heating, which is related to an extension phase, contributing to the final exhumation of the peridotites and the crustal metamorphic units. This event coincided with the opening of the Alboran Basin in a back-arc context.

(4) From the early to middle Miocene, collision occurred between the internal and external zones, associated with crustal shortening and the formation of a foreland basin.

(5) Prior to the Pliocene, the Betic-Rif arc underwent contractional processes related to late north-south shortening.

The opening of the Alboran basin as a back-arc basin during the Miocene implies that oceanic subduction was still active at this time. In this case, the Lower Sebtides, characterised by an HT-LP gradient and arc magmatism, correspond to the upper plate of the subduction system. By contrast, the Upper Sebtides correspond to the continental margin of the lower plate according to an ablative subduction model.

Tectonic map and structural architecture of the Briançonnais thrust sheets of the southern Western Alps

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Keywords: Briançonnais Zone, tectonic map, Western Alps.

In the southern Western Alps, tectonic units derived from the Briançonnais passive margin are exposed in two domains (Michard et al., 2022 and references therein): (i) the "Briançonnais Zone s.l.", dominated by Mesozoic sequences either overlying Permo-Carboniferous deposits or Variscan basement, described by the early French authors (e.g., Termier, 1903), and (ii) the pre-Mesozoic basement-dominated "Internal Crystalline Massifs" (ICM). We present a new tectonic map covering a large portion of the diverse units of the "Briançonnais Zone s.l." and immediately adjacent units. These comprise, from W to E: (1) Briançonnais, Subbriançonnais and Dauphinois units and far-travelled Ligurian Helminthoid units, structurally located in the footwall of the out-of-sequence Penninic Frontal Thrust (PFT), (2) a stack of Briançonnais s.str. units in the immediate hangingwall of the PFT, dominated by W-directed fore-thrusting (e.g., the classical "1.-4. écailles" of Termier, 1903), (3) a complex intermediate zone characterized by large-scale backfolds, leading to (4) a pile of backthrusted units, comprising units referred to as "Acceglio-type" and "Prepiemonte" units, and (5) units derived from the Piemont-Liguria Ocean. Units (4) and (5) tectonically overlie the ICM (Michard et al., 2022; Dana et al., 2023). We use existing geological maps and literature combined with own fieldwork data to construct a tectonic map and associated geological cross-sections of the above-mentioned units between the Maurienne Valley and the Argentera-Mercantour Massif. Our compilation aims at revealing the structural architecture of the "Briançonnais Zone s.l.", allowing for a classification of these units over longer distances along strike on the basis of structural and metamorphic criteria, avoiding as much as possible the traditional mixing of paleogeographic and tectonic interpretations, and preventing the use of multiple names for one and the same unit. These units record a polyphase structural evolution (D1 to D3) associated with Alpine metamorphic conditions ranging from greenschist to blueschist facies. In particular, we highlight the frequently underestimated importance of backfolding and backthrusting (D3) and its effect on structures associated with the earlier deformation phases linked to subduction and fore-thrusting (D1-D2). A comprehensive review of the "Briançonnais Zone s.l." tectonic units, in the form of a map and cross-sections, is essential for future detailed studies and for a better understanding of the highly non-cylindrical large-scale structure of the Western Alps arc and its transition into the E-W striking Central Alps.

Dana D. et al. (2023) - Structural and metamorphic evolution of a subducted passive margin: insights from the Briançonnais nappes of the Western Alps (Ubaye-Maira valleys, France-Italy). Swiss Journal of Geosciences, 116, 18.

Michard A. et al. (2022) - The Maira-Sampeyre and Val Grana Allochthons (south Western Alps): review and new data on the tectonometamorphic evolution of the Briançonnais distal margin. Swiss Journal of Geosciences, 115, 19, https://doi.org/10.1186/s00015-022-00419-8.

Termier P. (1903) - Les montagnes entre Briançon et Vallouise: (écailles briançonnaises, terrains cristallins de l'Eychauda, massif de Pierre-Eyrautz, etc.), 182, https://hal-insu.archives-ouvertes.fr/insu-00848081.

Polymetamorphic garnet tracks pre-Alpine HT-LP metamorphism in Pinerolo-Sanfront Unit, Dora Maira Massif, Western Alps

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Keywords: Dora-Maira, P-T-Path, structural evolution.

The Dora-Maira Massif (DMM) is one of the most significant tectonic domains in the Western Alps, characterised by extensive exposures of continental crystalline basement rocks. Stretching from the Maira Valley in the south to the Susa Valley in the north, the massif is bounded eastward by the Po Basin sediments and tectonically overlain westward by oceanic-derived Upper Penninic units. Following the discovery of ultra-high-pressure (UHP) metamorphism by Chopin (1984), the massif has become a key natural laboratory for investigating Alpine geodynamics. Numerous petrological and metamorphic studies have focused on reconstructing the evolution of the tectonic units within the Alpine nappe stack, particularly in the southern sector of the massif (Groppo et al., 2025 for a review).

Despite this extensive amount of works, the tectono-metamorphic evolution of the Pinerolo-Sanfront Unit (PSU), the structurally lowest unit of the DMM, remains comparatively poorly constrained, particularly in its north sector. Here, we present new metamorphic microstructural and geochronological data acquired as part of the CARG geological mapping project (Sheet 172 - Pinerolo), with a focus on the northern PSU. The PSU has traditionally been interpreted as a monometamorphic metasedimentary sequence that records exclusively Alpine blueschist-facies metamorphism (Groppo et al., 2019; Borghi et al., 1985). However, our multidisciplinary approach, integrating detailed microstructural investigations, thermodynamic modelling and $^{40}Ar/^{39}Ar$ white mica geochronology, revises this interpretation. Our results demonstrate that the PSU preserves evidence of a polymetamorphic history. An early generation of garnet records a pre-Alpine high-temperature/low-pressure (HT/LP) metamorphic event, likely linked to Permian contact metamorphism. This event was subsequently overprinted by high-pressure (HP) metamorphism during Alpine high-pressure (HP) metamorphism, marked by the growth of new garnet domains under blueschist-facies conditions. Finally, $^{40}Ar/^{39}Ar$ dating of white mica provides new constraints on the timing of the re-equilibriun in greenschist-facies, during the exhumation path.

Borghi A. (1985) - Metamorphism in the North part of the Dora Maira Massif (Cottian Alps). Boll. Mus. Regionale Sci. Nat. Torino, 3, 369-380.

Chopin C. (1984) - Coesite and pure pyrope in high-grade blueschists of the Western Alps: a first record and some consequences. Contrib. Mineral. and Petrol., 86(2), 107-118, https://doi.org/10.1007/BF00381838.

Groppo C. et al. (2019) - What's in the sandwich? New P-T constraints for the (U) HP nappe stack of southern Dora-Maira Massif (Western Alps). Eu. J. Mineral. 31(4), 665-683, https://doi.org/10.1127/ejm/2019/0031-2860.

Groppo C. et al. (2025) - A new UHP-HP tectono-metamorphic architecture for the southern Dora-Maira Massif Nappe Stack (Western Alps) based on petrological and microstructural evidence. J. Metamorph. Geol., 43(4), 359-383, https://doi.org/10.1111/jmg.12812.

Pre-alpine and alpine tectonic evolution of the II Zona Dioritico-Kinzigitica (IIDK) in the Gressoney Valley

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Keywords: Austroalpine domain, Adria plate basement, fabric evolution.

The II Zona Dioritico-Kinzigitica (II DK) represents a relict slice of pre-Alpine deep continental crust, exposed within the Austroalpine domain of the Western Alps (Sesia-Lanzo System; Dal Piaz et al., 1971). Lithologically, the unit mainly consists of a sequence of high-grade metapelites (kinzigites), marbles, and amphibolites, which preserve important evidence of the pre-alpine evolution (Gosso et al., 1979).

This study aims to characterize the II DK from a geological and structural perspective by analysing the evolution of different fabrics (coronitic, tectonitic, and mylonitic) and the degree of metamorphism. The goal is to reconstruct both the pre-alpine history, related to the Permian lithospheric thinning (Roda et al., 2019), and characterized by high-temperature metamorphism and partial melting, and the alpine evolution. Furthermore, data regarding the Permian evolution will be compared with the other two analogues of deep crust exposed in the Alps: the Ivrea-Verbano Zone (IVZ) and the Valpelline Series (VP). The ultimate aim is to reconstruct the litho-structural continuity of Adria during the lithospheric thinning process.

The workflow was developed upon an initial phase of field data acquisition and from preliminary studies in the Gressoney Valley. Based on the geological maps by Guido Gosso (1969) and Vincenzo Piovano (1974), a targeted geological-structural survey was conducted, coupled with sampling based on the evolutionary degree of fabric and metamorphism, followed by the processing of macro- and meso-scale structural data. Using the samples collected in the field we proceeded with a microstructural analysis to link the fabric evolution with the respective marker minerals. The microscope work was also preparatory to the Electron Microprobe Analysis (EMPA) and for the selection of minerals for the geochronology.

Based on the results of the multiscale structural analysis, an updated GIS-based geological map will be produced indicating the domains characterized by a variation in the degree of fabric and/or metamorphism. The results indicate that the Alpine metamorphism is characterised by tectonitic to mylonitic fabric mainly localized along the Pont Trenta shear zone. The shear zone developed under greenschist-facies conditions. In the Gressoney Valley, higher-pressure metamorphism is also observed, which is, however, associated with a coronitic fabric developed on pre-alpine minerals. The pre-alpine evolution is characterized by at least two deformation phases under granulite-facies conditions. The pre-alpine Pressure-Temperature-time evolution is compared with the P-T-t paths of the IVZ and VP present in the literature.

Dal Piaz G.V. et al. (1971) - La II Zona Diorito-kinzigitica tra la Valsesia e la Valle d'Ayas (Alpi occidentali). Memorie della Società Geologica Italiana,10,257-276.

Gosso G. et al. (1979) - High pressure emplacement of early Alpine nappes, post nappe deformation and structural levels (Internal Northwestern Alps). Inst. Geol. Mineral. Univ. Padova Mem., 32, 5-15

Roda M. et al. (2019) - What drives Alpine Tethys opening? Clues from the review of geological data and model predictions. Geological Journal, 54, 2646-2664, https://doi.org/10.1002/gj.3316.

Fluid-assisted brittle faulting and localized retrogression during exhumation of HP metabasalts (Calabrian Arc, Italy)

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Keywords: fault-vein network, fluid-rock interaction, subduction zone.

Along the subduction interface, interactions between fluids and fractures exert a fundamental control on fault strength and seismic behavior. Variations in slip mode reflect along-dip frictional and structural heterogeneities and fluid pressure fluctuations. Most constraints on these processes derive from geodetic, seismological, and experimental studies, whereas the geological record remains comparatively underexplored. Exhumed subduction complexes, and particularly fault-vein networks, provide direct records of P-T conditions, fluid-rock interaction, transient permeability, and deformation processes along the plate interface.

Here, we investigate a relict subduction environment in which an albite-epidote-calcite-bearing fault-fracture mesh is preserved within blueschist-facies metabasalts of the Diamante-Terranova oceanic unit and associated metasediments in the Calabrian Arc (southern Italy). We combine field observations, microstructural analyses, X-ray diffraction of fault rocks, and calcite fluid inclusion data to evaluate evidence for brittle faulting and fluid conditions during exhumation of these meta-ophiolitic units.

Field and microstructural observations show that HP fabrics are overprinted by brittle faulting and an associated network of fault-splay veins. These structures are filled by fine-grained albite-epidote-calcite phases and host-rock clasts, indicating brecciation and mobilization of fragmented material. Fluid inclusion data from calcite veins further constrain the P-T-fluid conditions during deformation.

These observations are consistent with episodic fluid overpressure driving multiple sealing and reactivation within the fault-vein network, and indicate fluid-assisted brittle deformation during exhumation along the subduction interface. The albite-epidote-calcite assemblages record localized retrogression focused along transient fluid pathways within otherwise blueschist-facies rocks. The Diamante fault-vein mesh may therefore represent a geological record of coseismic slip and fluid-assisted faulting during exhumation, offering insights into slip processes along the subduction interface.

Multiscale strain analysis of mylonitic rocks (Montalto Shear Zone - Calabria) and digital mapping for the geological survey CARG project (sheet n.602 Motta S. Giovanni)

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Keywords: shear zone, UAV, LiDAR.

The ongoing geological survey of sheet no. 602 (Motta S. Giovanni), located in southern Calabria, is aimed to produce a geological map at a scale of 1:50,000. Linked to the Italian National Cartography Project (CARG), this project enabled us to investigate deformation and crystallisation episodes affecting medium-to-high-grade metamorphic rocks of the Aspromonte Unit (Fazio et al., 2015; 2018; Ortolano et al., 2015) using various mapping techniques, both in person and remotely. In the field, we combined traditional structural-geological survey methods with the digital acquisition of rock exposures via UAV and LiDAR surveys to generate 3D virtual outcrop models at various scales. Microtomographic investigations on a selection of mylonitic schists produced by Alpine metamorphism of late-Variscan pegmatites have enabled us to achieve full 3D microscopic identification of minerals and to characterise rock fabrics. Preliminary results demonstrate that multiscale digital rock structural analysis improves our understanding of progressive strain in highly deformed rocks. These rocks, exhibiting outstanding tourmaline porphyroclasts in a strongly foliated fine-grained matrix (Fazio et al., 2019), could also be designated as a geosite of interest within the Aspromonte Geopark, potentially becoming part of the standard tour for visitors interested in geological heritage.

Fazio, E. (2019) - Chapter 10 - Recognition of Structures in Mid-crustal Shear Zones and How to Discern Between Them. In: Billi, A., Fagereng, Å. (Eds.), Problems and Solutions in Structural Geology and Tectonics, Developments in Structural Geology and Tectonics. Elsevier, 119-128, https://doi.org/10.1016/B978-0-12-814048-2.00010-7.

Fazio E. et al. (2018) - Strain localization and sheath fold development during progressive deformation in a ductile shear zone: A case study of macro-to micro-scale structures from the Aspromonte Massif, Calabria. Italian Journal of Geosciences ,137, 208-218, https://doi.org/10.3301/IJG.2018.09.

Fazio E. et al. (2015) - Tectono-metamorphic map of the south-western flank of the Aspromonte Massif (southern Calabria -Italy). Journal of Maps, 11, 85-100, https://doi.org/10.1080/17445647.2014.962634.

Ortolano G. et al. (2015) - Petro-structural geology of the Eastern Aspromonte Massif crystalline basement (southern Italy-Calabria): an example of interoperable geo-data management from thin section - to field scale. Journal of Maps, 11(1), 181-200, https://doi.org/10.1080/17445647.2014.948939.

Insights into deformation mechanisms of exhuming brittle-ductile shear zones (Oman Mountains)

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Keywords: shear zone, brittle - ductile deformation, exhumation.

Exhuming shear zones are key structures in the dynamic evolution of orogens. Such shear zones accommodate most of the shear-related exhumation within relatively small rock volumes. This is possible due to major strain partitioning occurring along weak levels, frequently represented by phyllosilicate-rich rocks. Thus, the study of such mylonites can provide fundamental insights into exhumation mechanisms responsible for the architecture of orogens.

The Hulw Shear Zone in the Saih Hatat Window of Oman is one of these exhuming shear zones juxtaposing two subducted continental tectonic units. This tectonic contact experienced sustained shearing, accommodating a delta pressure of circa 0.8 GPa between 1.2 and 0.4 GPa at a relatively constant temperature of circa 400°C between 77 and 74 Ma.

Micaschist belonging to the footwall displays a strain gradient moving toward the contact with the hanging wall. It corresponds to the development of a S-C-C' fabric and a modal enrichment in K-rich white mica and pyrophyllite matched by a progressive increase in their physical interconnectivity. Microstructural analysis suggests that interconnected C planes were formed due to an interplay of fracturing, precipitation of phyllosilicates, and preferential glide of the quartz-phyllosilicate grain boundaries.

Hyperspectral cathodoluminescence highlights different luminescence for the larger (several hundreds of μm) quartz grains, producing a bright signal and containing yielded cracks, and smaller equant quartz grains (less than 70 μm), darker in cathodoluminescence and devoid of cracks. Electron backscatter diffraction analyses suggest that large quartz grains experienced grain size reduction by subgrain rotation recrystallization to form smaller equant grains. Interconnected chains of small quartz grains are located in contact with the phyllosilicates, suggesting preferential recrystallization along these planes.

Transmission Electron Microscope analyses highlight pyrophyllite-muscovite intergrowths at the submicron scale as small as 300-500 nm, with truncated boundaries likely reflecting dissolution and precipitation mechanisms. Phyllosilicates are deformed, with kinking and fracturing.

Strain localization and weakening of this rock volume was achieved by an interplay of: I) diffuse microfracturing at high-angle and parallel to the shear planes, as evidenced by fluid inclusion bands and incipient shear plane analysis, and grain boundary sliding; II) synkinematic nucleation of retrograde mineral phases along discrete C and C' planes, forming an interconnected network of phyllosilicates; III) subgrain rotation recrystallization leading to a finer grain size of quartz, preferentially along the shear planes; IV) dissolution and precipitation processes of phyllosilicates. Concluding, this intimate and polyphase interplay between deformation and metamorphism is responsible for the formation and evolution of exhuming shear zones and the related structure of orogens.

Multi-scale structural analysis of the fracture network in carbonate rocks (CARG project, Marguareis area, Italy)

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Keywords: CARG, fractures, multi-scale structural analysis.

Fracture networks span multiple orders of magnitude, from micro-scale cracks to regional fault systems, and are fundamental to understanding crustal deformation, seismic and natural hazards, and subsurface fluid flow and fluid-rock interactions. Despite extensive research, characterizing the fracture networks remains challenging due to the inherent complexity of geological processes and geomechanical scaling.

This study investigates the scale-dependency of fracture network within the Meso-Cenozoic Briançonnais sequence of the Marguareis Natural Park (Don Barbera Hut area). Conducted within the frame of the new CARG Sheet 244-Ormea, this research leverages the exceptional exposure of faulted and fractured carbonate rocks to perform an in-depth structural analysis, from the outcrop-scale to the kilometer-scale.

A quantitative manual mapping and characterization of approximately 36,000 fractures has been made combining field-based investigations with airborne and unmanned aerial vehicles imagery, supporting the collection of a large multi-resolution dataset to assess small- and large-scale fracture intensity and rock mass heterogeneity.

Specifically, we investigated the scale-variant geometry and orientation of fault and fracture patterns, and the variation of both fracture density (P20) and intensity (P21), also in relation to the structural position with respect to the main faults and folds. Moreover, we analyzed how fracture parameters (e.g., minimum, maximum and mean trace length) and intersections (i.e., topology; X, Y and I nodes) vary with resolution.

While fracture orientation patterns remain relatively consistent across the scales, intensity parameters such as P20 and P21 are found to be strongly resolution-dependent. This implies that these metrics cannot be treated as intrinsic descriptors of a rock mass when estimated at a single scale. Consequently, robust fracture network analysis requires a multiscale approach, where the resolution is explicitly selected according to the specific geological processes or engineering objectives under investigation.

From a kinematic perspective, our data reveal the presence of a complex network of faults and fractures interpreted as a Riedel system embedded within a large-scale sinistral shear zone. These structures cut across and displace pre-existing folds through the Permian-Eocene succession, suggesting a post-Eocene activity.

Ultimately, this research allows us to improve our knowledge on how to treat the fracture network data to derive meaningful structural information and reconstruct the deformation evolution of the study area. In this view, the large structural dataset is compatible with an Oligo-Miocene evolution of the Marguareis area developed within a mega left-lateral shear zone.

Tectonic insights from new structural and petrographic data on the Mongolian Altai Range ophiolites (CAOB, Mongolia)

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Keywords: Altai, Mongolia, ophiolite.

The Mongolian Altai is a key sector of the Central Asian Orogenic Belt (CAOB), a region characterized by the progressive amalgamation of Precambrian to Paleozoic arc systems, accretionary wedges, and continental crustal blocks during the closure of the Paleo-Asian Ocean. Within the Altai Range, arc-type ophiolites and mantle wedge serpentinites, formed in a supra-subduction zone (SSZ) setting, are tectonically interleaved with continental basement rocks. Structural relationships between the various tectonic units, timing of emplacement and mechanisms of arc ophiolite and serpentinites emplacement remain poorly understood in critical sectors of the Mongolian Altai Range.

Here, we present new structural and petrographic data from two massifs exposed along the belt: the Naran massif to the NW and the Chandman serpentinite massif to the SE, which may originally have formed a continuous sequence of SSZ rocks, exposing shallow arc ophiolites to deep mantle serpentinites. Detailed geologic mapping was conducted, alongside systematic measurements of structural indicators (foliations, lineations, shear bands, fold axes, and fault planes with kinematic indicators) and selected samples were collected. Such extensive dataset enabled the reconstruction of new geological cross-sections based on traverses across the two massifs, as well as domain-by-domain stereoplot analysis. Additionally, structural data were coupled with petrographic constraints derived from optical and electron microscopy to further characterize the tectonometamorphic units.

In the north-western sector, the Naran massif exposes a mantle and gabbroic slice overlying amphibolites and metasedimentary rocks. To the north of the mantle slice, gneiss, micaschist, phyllite, and non-metamorphic carbonate-rich terrigenous sediments crop out, whereas to the south patchy outcrops of amphibolite-facies marbles are found. In the south-eastern sector, the Chandman massif is composed of a serpentinized mantle bordered by amphibolite-facies rocks and eclogites to the north, and by and association of low-grade carbonates and slates cut by volcanic dikes to the south.

Along-belt and across-belt structural data document the geometric relationships between arc and wedge serpentinites and their enclosing accretionary wedge, from mantle-level exposures to shallow crustal structures. At the mesoscale, shear fabrics recorded in both carbonates and metasedimentary lithologies are observed at the upper and lower contacts with serpentinites. Syn-kinematic mineral assemblages were identified along principal contacts. Pervasive fluid-rock interaction is documented by veining, hydrothermal alteration and reaction microstructures, attesting to the active role of fluids during tectonic emplacement. Strong, recent strike-slip reactivation is visible in both carbonate and serpentinite. Additionally, dike emplaced with similar orientations are present in the two massifs.

Our newly acquired dataset provides compelling constraints on the evolution of arc ophiolite and mantle wedge serpentinite emplacement in the Mongolian Altai Range, as well as on the kinematic evolution of Paleozoic accretionary systems in the Central Asian Orogenic Belt.

Duration of melt presence in the hot core of the European Variscan Orogen: Example from Bohemian Massif

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Keywords: hot orogeny, melt migration, Bohemian Massif.

Melting of the middle and lower crust is a fundamental feature of large hot orogens throughout Earth history, including both modern and ancient systems such as the Tibetan-Himalayan system, the Grenvillian orogen, and the European Variscides. The duration of melt-present conditions is critical because long-lived rheological weakening enables large crustal displacements and exhumation of subducted material. We studied migmatites of the high-grade Gföhl Unit from the Bohemian Massif in the core of the European Variscan orogen, which preserves evidence for a long-term sustained pervasive melt migration within a deforming partially molten middle crust. By combining monazite chemistry with bulk-grain and spatially resolved U-Pb geochronology, we constrain the duration of melt-present conditions here to ca.10 Myr. The structural and microstructural data suggest that the present melt weakened the whole system as predicted for the channel flow model. In addition, the petrological modelling shows that the temperature and pressure conditions continuously decreased from ca. 8 to 4 kbar and ca. 750 °C to 660°C along with equilibration of rock with percolating melt. This suggests that the partially molten material propagated upwards above the advancing basement promontory. Such geometry and time span of suprasolidus conditions of deformation are coherent with thermal and mechanical evolution predicted by numerical models of channel flow/hot fold nappe.

The presence of melt for 10 Myr and evidence for melt flow raise questions about how quickly and how far the melt moved. For maximum PT conditions recorded by the migmatites of the Gfohl Unit (10-12 kbar and 900-1000 °C), the melt viscosity is $\sim 10^4$ Pa s. During exhumation and cooling in the channel (or hot fold nappe), it increases to $\sim 10^5$ Pa s (at 4-8 kbar and 660-750 °C). Such a tenfold viscosity increase implies a comparable reduction in melt-flow velocity. We estimate that in the shallow cool portions of the channel, melt could have migrated at most several hundred meters during the 10 Myr period of partial melting. As a result, the melt remained trapped within the channel. Formation of wider and thus more efficient melt conduits is not observed in the rock record, and melt escape into the overlying sub-solidus material is not documented; such escape would require several-meters-wide conduits to prevent freezing. In the late stage, as the rocks approached the cold Earth surface, they crossed the solidus and the melt crystallized.

Mass-transport and chaotic deposits from spreading to subduction: Clues from the sedimentary cover of the Alpine, Corsican, and Apennine ophiolites

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Keywords: Ligurian-Piedmont Ocean, chaotic deposits.

Remnants of the Ligurian-Piedmont Ocean Basin (LPOB) are preserved within the ophiolite successions of the Western Alps, Northern Apennines, and Alpine Corsica. In all three belts, these successions are punctuated by chaotic deposits containing ophiolite-derived material.

While the sedimentological characteristics and lithostratigraphic position of these deposits in the Northern Apennines have been reconstructed in sufficient detail, and clearly placed within a tectonic framework, the formation processes and tectonic significance of the chaotic deposits preserved in the Western Alps and Alpine Corsica remain cryptic, due to pervasive tectonic deformation and high-pressure metamorphism.

In this contribution, we present the results of a comparative analysis of the chaotic deposits and their distribution within the ophiolite successions of the three mountain belts, integrating sedimentological, structural, and metamorphic data from selected ophiolite sequences.

We show how the characteristics of the sedimentary cover of the lower-grade ophiolite units of the Northern Apennines can be used to reconstruct the stratigraphy of the metamorphosed and highly deformed ocean-derived units of the Western Alps and Alpine Corsica, as well as the processes responsible for the formation of the chaotic deposits.

This comparison allows refinement of the stratigraphic architecture of the LPOB and reconstruction of its evolution from Middle Jurassic opening to Upper Cretaceous involvement in Alpine subduction and collision.

The proposed scenario depicts a remarkably uniform basin shaped by magmatic, tectonic, and sedimentological processes occurring synchronously in different sectors of the developing Jurassic oceanic basin. Synextensional, gravity-driven chaotic deposits occur both below and above the extrusive sequences within the ophiolite succession, recording different stages of seafloor spreading evolution. Subsequently, mass-transport deposits (MTDs) punctuate the turbiditic sequences overlying the ophiolites and can be interpreted as syncontractional submarine slides along the frontal slopes of the accretionary prism related to the Late Cretaceous-Paleocene closure of the LPOB.

... and the kyanite?

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Keywords: Massa Unit, Northern Apennines, P-T-t-D.

At the very beginning of our careers, we had the pleasure of meeting Guido, who served as referee for one of our first papers on the tectonic evolution of the Massa Unit in the Northern Apennines. At that time, the scientific community working on the Northern Apennines generally assumed that the metamorphism recorded by the different tectonic units was mainly due to lithostatic loading. The review was constructive and insightful and, although the paper focused on the Massa Unit cropping out in the Monti Pisani area, Guido planted a seed in our minds regarding the occurrence of kyanite in the Massa Unit on the western side of the Apuan Alps. From that moment on, we began trying to understand the tectono-metamorphic evolution of the continental units of the Northern Apennines from a different perspective.

Further research over the years highlighted that the Massa Unit s.l. is actually subdivided into several tectonic units (Carosi et al., 2004), affected by polyphase deformation and recording different metamorphic imprints, ranging from blueschist- to greenschist-facies conditions (Montomoli et al., 2024, and references therein).

Recently, we returned to study the innermost outcrops of the Massa Unit exposed in the Punta Bianca area (Montomoli et al., 2024).

Through detailed meso- and microstructural analyses aimed at unraveling the deformation history and the development of tectonic foliations, complemented by multi-equilibrium geothermobarometry based on high-resolution X-ray chemical maps of different generations of foliations, as well as by $^{40}Ar/^{39}Ar$ laser-probe dating of white mica, we reconstructed the P-T-t-D evolution of this area.

The Massa Unit cropping out in the Punta Bianca area did not reach high-pressure conditions comparable to those recorded in many other portions of the Unit, as it experienced peak metamorphic conditions of approximately 0.8 GPa and ~350 °C. This finding is consistent with the interpretation that, during convergence and underthrusting, the Massa Unit was subdivided into different tectonic slices (Carosi et al., 2004). Our data indicate that the Massa Unit exposed in the Punta Bianca area was not subducted as deeply as other portions of the Massa Unit; instead, it was deformed at relatively shallow structural levels under upper greenschist-facies conditions (according to the facies classification of Bousquet et al., 2008). In contrast, other portions of the same paleogeographic domain (i.e., the External Tuscan domain) reached blueschist-facies metamorphic conditions.

Carosi R. et al. (2004) - Late tectonic evolution of the Northern Apennines: The role of contractional tectonics in the exhumation of the Tuscan units. Geodin. Acta 17 (4), 253-273, https://doi.org/10.3166/ga.17.253-273.

Montomoli C. et al. (2024) - Deformation and pressure-temperature-time histody of the External Tuscan Units in the Northern Apennines (Italy): the case of the Punta Bianca Unit. J. of Geodinamics, 161, 102045.

Combined deformation processes and varied metal sources in generating large-scale elemental enrichments in mineral deposit systems: the Western Alpine Belt laboratory

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Keywords: Au deposits, Western Alps, Mineral System Concept.

According to the Mineral System Concept, the evolution of earth systems and geodynamics provide a wide range of contexts for ore formation by combining four factors: *whole lithosphere architecture, transient favorable geodynamics, fertility, and preservation of the primary depositional zone*. Large-scale ore deposits may be expected in relation to large, long-lived, deeply penetrating structures that juxtapose or interact with different basement domains. In Italy these features are well illustrated by the orogenic Au-rich veins system of the Western Alps. These polyphasic sulfide-bearing quartz-carbonate vein systems contain As, Sb, Au, Ag, Cu, Fe, Zn, Pb, Bi, Te, W, Co, Ni and Hg and occur in both Pennidic and Austroalpine nappes. Although distributed from the Ligurian Alps up to the Simplon area, the vein swarms tend to group in several *districts* close to the major Canavese and Insubric lineaments and their intersection, nappe limits and the SE margin of the Lepontine Dome, a wide domain of active crustal exhumation bordered by the transition from amphibolite- to greenschist facies metamorphism. These are ideal conditions for emplacing Au-rich *sismogenic* ore systems favoured by the ductile-to-fragile transition in wallrock rheology and by flash-induced metal supersaturation in metamorphic fluids after extreme pressure transients during slip events along fault arrays. Available radiometric ages from ≈30 to alpine-type fissures and which flooded the W Alpine belt eastwards to the Tauern Window. Ore mineral assemblages and textures as well as Au distribution and alloy compositions reflect polyphasicity of mineralization. Hosted in ortho- to paragneisses and in ophiolite domains, the vein districts also show distinct metal assemblages, e.g., Cu-Bi-Te-, Sb-Cu-, Fe-As-W-rich, Ni-Co-Ag-bearing, etc., likely related to local T°C conditions (meso- to epithermal) and/or sources. Serpentinites and metabasalt-hosted, metamorphosed submarine exhalative sulfide ores might be obvious and locally sustantial contributors of Cu, Zn and Ni-Co, although several metal assemblages suggest mixed metal sources with oceanic and continental crust affinity. The chemical signatures of hydrothermal rutiles also confirm the complexity of metal sources by variations in abundances of continental components as W, Sn, Nb, Zr, U, Th, LREE, not always readily correlating with the nature of the host rocks. Tungsten enrichments also occur as (REE-rich) scheelite notably in the vein systems hosted in the Austroalpine terranes. For these deposits a special source of metals might be the 320 Ma-old mesothermal Au-As-W-Bi-Te ores of the extensive vein system from Cannero to Swiss Malcantone, hosted in the South-Alpine basement bordering the northern limb of the Ivrea-Verbano-Zone.

Microstructures as dissipative records of coupled reaction-diffusion-deformation in deformed metamorphic rocks

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Keywords: dynamic systems, emergent features, nonlinear feedbacks.

Guido Gosso's work in the Western Italian Alps fundamentally shaped the way many of us think about metamorphic rocks: not as static mineral assemblages approaching equilibrium, but as dynamic systems in which deformation, reaction, and tectonic evolution are intimately intertwined. Through detailed studies of the Sesia-Lanzo Zone and related Alpine terranes, he demonstrated how microstructures preserve the memory of complex pressure-temperature-deformation histories, and how incomplete reactions, deformation partitioning, and overprinting relationships record the progressive evolution of subduction and exhumation processes. His work emphasized the importance of integrating structural geology, petrology, and microstructural analysis across scales, from thin section to orogen.

Inspired by this perspective, we revisit metamorphic microstructures as products of coupled nonequilibrium processes operating during deformation and metamorphism. Building on ideas implicit in Gosso's work, we propose that many metamorphic textures may be understood as emergent features of fully coupled reaction-diffusion-deformation systems, in which mineral reactions, chemical transport, strain localization, and dissipation evolve together through nonlinear feedbacks. In particular, deformation may accelerate reaction progress through enhanced transport and grain-size reduction, while reactions may weaken or strengthen rocks, redistribute fluids, and localize strain. Some reactions may even behave autocatalytically, amplifying microstructural heterogeneity and producing organized spatial patterns.

We suggest that the remarkable diversity of Alpine metamorphic microstructures documented by Gosso and colleagues, including reaction rims, compositional banding, shear-zone fabrics, corona textures, and incomplete eclogitisation, can be interpreted within a unified framework governed by competing characteristic timescales of reaction, diffusion, and deformation. These relationships may be expressed through dimensionless parameters such as the Damköhler number, Gruntfest number, Peclet number, and ratios of deformation rate to reaction rate, allowing microstructural regimes to be mapped within a common dynamical parameter space.

In this contribution we aim not only to develop a quantitative framework for metamorphic pattern formation, but also to honour Guido Gosso's enduring legacy: the recognition that microstructures are active geological records of coupled physical and chemical processes operating during the evolution of mountain belts.

GEO-METamoRphic-Information System (GEOMETRIS): An interoperable way for the digital transition of multiscale structural and petrological datasets of tectono-metamorphic units

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Keywords: multiscale geological data analysis, geomatics, WebGIS.

Orogenesis is often linked with the formation of dynamically evolving metamorphic rocks derived from different protoliths. Recent indications by ISPRA within the guidelines for the CARG project (e.g., Simonetti et al., 2024) indicate that the main practice to determine the origin and characterization of these orogenic-related metamorphic rocks is their grouping within tectono-metamorphic units (TMU), geological units composed of metamorphic rocks that underwent the same Pressure-Temperature-deformation (PTd) path (Spalla et al., 2005). This is because their petrogenesis is strictly related to the relationship between deformation vs. recovery processes, with the consequent development of tectonic-related structural features (e.g., foliations and lineations) linkable with local phase equilibria, useful, in turn, to constrain different PT stages encountered during orogenic evolution.

In this view, the quantification of multiscale petro-structural properties, from field surveys to microscopic scale analysis, is crucial to obtain the most reliable petrological and microstructural constraints, which are required for an efficient TMU PTd reconstruction. Recently, the integration of advanced digital tools combining optical and X-ray image analysis became essential for achieving a comprehensive characterization of the complex petrogenetic processes at the base of the TMU evolution (e.g., Ortolano et al., 2020). This contribution aims to present GEOMETRIS (GEO-METamoRphic-Information System), an innovative GIS-based Cyber-Infrastructure (CI) consisting of a suite of interactive multiscale geological and petro-structural databases. The system is structured according to current interoperability standards (e.g., OGC; GeoSCIML/INSPIRE) and equipped with original IT tools for efficient querying, access, processing, and acquisition of digitized geodata (e.g., Visalli et al., 2021).

GEOMETRIS enables the correlation of field- and laboratory-derived data from different rock specimens across multiple scales, linking information collected from outcrop-scale observations up to several types of microanalytical techniques, including SEM-EDS, EPMA, and thin-section analysis via optical devices. GEOMETRIS has been designed to enhance the intelligibility of the strict correlations between fabric-related features (i.e., the structural arrangement of mineral grains) and the development of local phase equilibria (e.g., effective bulk rock chemistry) at all scales of observation. Its interactive web-based interface facilitates the exploration of these relationships, with particular regard to the microdomain scale.

By integrating multiscale geological and petro-structural data with advanced analytical tools, GEOMETRIS will provide a groundbreaking framework for understanding rocks as active components of our planet's evolving processes, offering unprecedented insights into the complex interactions that drive Earth's geodynamics.

Ortolano G. et al. (2020) - Quantitative microstructural analysis of mylonites formed during Alpine tectonics in the western Mediterranean realm. Journal of Structural Geology, 131, 103956.

Simonetti M. et al. (2024) - A review of criteria, methods, and standards for mapping crystalline terrains: integrating field geology and analytical data, Italian Journal of Geosciences, 143(3), 426-454.

Spalla M.I. et al. (2005) - A critical assessment of the tectono-thermal memory of rocks and definition of tectono-metamorphic units: evidence from fabric and degree of metamorphic transformations. In: Grapis, D., Brun, J.P., Cobbold, P.R. (Eds.), Deformation mechanisms, rheology, and tectonics: from minerals to the lithosphere. Geol. Soc. Spec. Publ., 243, 227-247,

Visalli R. et al. (2021) - Micro-fabric analyzer (MFA): a new semiautomated ArcGIS-based edge detector for quantitative microstructural analysis of rock thin-sections. ISPRS Int. J. Geo-Inf.,10(2), 51.

Transfer of deformation and metamorphism to shallower lithospheric levels drives the exhumation of the subducted continental lithosphere in the Hulw Window (Sultanate of Oman)

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Keywords: Oman tectonics, shear zone, brittle-ductile deformation.

Exhumation of buried continental lithosphere is commonly ascribed to movement along high-strain zones, but how deformation and metamorphisms are localised and transferred to shallower lithosphere levels in space and time remains poorly constrained.

The Saih Hatat Window in Oman is a continental tectonic window structurally divided into the As Sifah and the Hulw windows, exposing continental rocks that underwent eclogite and blueschist facies metamorphism during the Cenozoic. Despite the presence of a significant change in peak-pressure across the contact between the Hulw Window (~0.7-1 GPa) and the As Sifah Window (~2-2.5 GPa), in the Hulw Window, the peak-pressure conditions appear similar in the lower and upper units divided by the Hulw Shear Zone. The reason for the absence of a pronounced peak-pressure gap is debated; whether this reflects an alternative exhumation mechanism or an incomplete reconstruction of the metamorphic structure of the Hulw window remains unresolved.

Our field observations reveal pronounced strain partitioning, whereby stiff mafic blocks (i.e., metabasite and mafic metasandstones) behave as low-strain domains, and the direct contact with the surrounding weaker matrix (i.e., mafic schists and metapelites) accommodates intense strain. Integrating structural analysis at different scales, with electron backscatter diffraction and forward thermodynamic modelling on both stiff and weak rocks, we document evidence for strain partitioning between competent mafic blocks and weaker mafic schist matrix domains. Strain localised along rheological boundaries occurring at peak metamorphic conditions of ~1.4-1.6 GPa at ~300-350°C, followed by progressive decompression during simple-shear-dominated deformation. The protracted localisation is sustained by fluid infiltration coupled with metamorphic reactions, highlighted by crack-and-seal veins, which record cyclic brittle-ductile behaviour associated with transient fluid overpressure during decompression.

Comparing our result with the existing data, we discussed the progressive transfer of ductile deformation and metamorphism from deeper to localised at shallower lithospheric levels. These results show that continental exhumation in the Saih Hatat Window did not occur along a single long-lived detachment, but through an interplay of non-coaxial shearing, reaction-assisted weakening, fluid overpressure and cyclic brittle-ductile deformation operating from blueschist to greenschist facies metamorphism. Continental exhumation thus emerges as a dynamic reorganization of a heterogeneous lithosphere, governed by feedback between deformation, metamorphic reactions, and preferential fluid circulation. The combination of these processes collectively governs the strain compartmentalisation and allows the exhumation of subducted continental lithosphere.

Multidisciplinary approach to investigate the structural and metamorphic evolution of the tectonic Alpine mélange in the Upper Soana Valley

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Keywords: Alpine subduction, tectonic mélange, transposition.

At boundary between the metaophiolites of the Piemonte Zone (PZ) and the Austroalpine continental crust, a tectonic mélange composed of thin slices of calcschists, quartzites, metabasites, serpentinites, and fine-grained gneisses crops out continuously along the western margin of the central and southern Sesia-Lanzo Zone (SLZ), from the Santanel Klippe to the Lanzo Massif (Spalla et al., 1983; Battiston et al., 1984). In the Upper Soana Valley, earlier studies described only qualitative greenschist-facies metamorphic assemblages within the metasedimentary units (e.g., Battiston et al., 1984). More recently, Modesti et al. (2025) documented garnet-chloritoid- and garnet-lawsonite-chloritoid-bearing micaschists preserving relic Alpine high-pressure assemblages, recording both prograde metamorphic evolution and decompression stages. Despite these advances, the tectono-metamorphic evolution of the continental-affinity units remains poorly constrained.

This contribution refines the geological and structural framework of the Santanel lake area, focusing on the tectonic boundary between the continental basement and the oceanic units. The study area records a complex polyphase deformation history that largely obliterated primary lithological relationships. Detailed structural analysis allowed the identification of three main deformation phases. The S1 foliation is preserved only as a relic fabric within eclogite boudins, whereas S2 constitutes the dominant foliation in both the gneisses and the oceanic metasedimentary units. The present-day structural architecture is mainly controlled by D3 deformation, which generated a pervasive regional foliation (S3) and extensively transposed earlier structures. The discontinuous distribution of lithologies is interpreted as the result of strong strain partitioning and pervasive boudinage during D3, which promoted the reworking and parallelization of pre-existing tectonic contacts. These results provide new constraints on the tectono-metamorphic evolution of the Sesia-Lanzo Zone-Piemonte Zone boundary and contribute to a better understanding of its still poorly constrained tectonic architecture.

Battiston P. et al. (1984) - Geologia di una traversa dal Gran Paradiso alla zona Sesia-Lanzo in alta Val Soana, Piemonte. Memorie della Società Geologica Italiana, 29, 209-232.

Modesti A. et al. (2025) - The Piedmont Zone From the Western Alps (Italy): New Insights From High-Pressure Ophiolitic Metasediments in the Soana Valley. Journal of Metamorphic Geology, 43(9), 909-937.

Spalla M.I. et al. (1983) - Deformazione e metamorfismo della Zona Sesia-Lanzo meridionale al contatto con la falda piemontese e con il massiccio di Lanzo, Alpi occidentali. Memorie della Società Geologica Italiana, 26, 499-514.

Linking petrostructural relics and subduction dynamics through numerical modelling

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Keywords: numerical models, metamorphism, deformation.

The reconstruction of tectono-metamorphic histories in orogenic belts depends on the preservation of petrostructural heterogeneities, which represent the memory of rocks through successive deformation and metamorphic events. This innovative approach (Spalla et al., 2000; Gosso et al., 2015) revolutionized such a perspective through the definition of Tectono-Metamorphic Units (TMUs), emphasizing gradients in fabric evolution, from coronitic to tectonitic and mylonitic domains, rather than relying exclusively on metamorphic field gradients. This framework enables objective correlations between deformation stages and mineral re-equilibration, demonstrating that deformation is intrinsically heterogeneous and that low-strain relict domains may survive within high-strain zones. This paradigm has been applied to several polymetamorphic basement units across the Alpine belt, where multiple tectono-metamorphic stages have been recognised through the integration of structural and metamorphic analysis. In many cases,

early fabrics are only locally preserved as relict domains within mafic bodies or other low-strain lithologies, whereas later stages are associated with tectonitics or mylonitisc domains.

To test the physical conditions for preserving such heterogeneities at the regional scale, we integrate field observations with 2D thermo-mechanical numerical modelling (FALCON, Regorda & Roda, 2024). By means of these models, we can track the Pressure-Temperature-deformation-time (P-T-d-t) evolution of markers, representing the numerical equivalent of rock memory. Incorporation of the TMU concept into the numerical framework allows evaluation of the deformation-metamorphism relationships throughout the subduction-collision system. The models could therefore constrain the conditions under which coronitic and tectonitic relics may survive within large-scale mylonitic shear zones. This integrated approach establishes a direct link between microstructural observations and lithospheric-scale geodynamic processes.

Gosso G. et al. (2015) - Taking advantage of petrostructural heterogeneities in subduction-collisional orogens, and effect on the scale of analysis. Periodico di Mineralogia, 84(3B), 779-825, https://doi.org/10.2451/2015PM0452.

Regorda A. & Roda M. (2024) - Thermo-mechanical effects of microcontinent collision on ocean-continent subduction system. Journal of Geophysical Research: Solid Earth, 129(12), e2024JB029908, https://doi.org/10.1029/2024JB029908.

Spalla M.I. et al. (2000) - The role of structural and metamorphic memory in the distinction of tectono-metamorphic units: the basement of the Como Lake in the southern alps. Journal of Geodynamics, 30(1), 191-204, https://doi.org/:10.1016/S0264-3707(99)00033-2.

Integrated field, microstructural, AMS and EBSD constraints on the architecture and construction mechanisms of late-orogenic batholiths: Insights from Southern Calabria

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Keywords: multi-scale fabric analysis, late Variscan granitoids, shear zones.

The architecture and building processes of the late Variscan Serre Batholith (southern Calabria, Italy) were investigated through an integrated multidisciplinary and multi-scale approach combining field mapping, microstructural analysis, anisotropy of magnetic susceptibility (AMS), and electron back-scattered diffraction (EBSD). Although characterized by a relatively limited areal extent (~1200 km²), the batholith represents a ~13 km-thick composite and zoned body continuously from floor to roof, making it an ideal case study for investigating batholith construction in post-collisional settings.

Field mapping and petrographic investigations constrained the relationships among five magmatic units, from older and deeper amphibole-biotite quartz diorites and tonalites to intermediate-seated K-feldspar-megacrystic and equigranular two-mica granodiorites and granites, and younger and shallower biotite ± amphibole granodiorites, emplaced sequentially through incremental overaccretion between ca. 297 and 292 Ma (Caggianelli et al., 2000; Fiannacca et al., 2017; and references therein).

Microstructural analysis revealed continuous deformation from submagmatic to low-temperature subsolidus conditions across all units, indicating persistent tectonic activity throughout the batholith's lifetime, though decreasing in intensity from the older and deeper to the younger and shallower magmatic units (Russo et al., 2023, 2025). AMS data identified internal fabrics even in apparently isotropic granitoids, with prevailing oblate ellipsoids reflecting flattening during emplacement. Magnetic foliations and lineations indicate an early extensional phase during emplacement of the deepest unit, followed by a dominant NW-SE compressional regime during construction of the overlying units. Quartz CPO data obtained by EBSD reveal deformation at medium-to-low temperatures, with dominant activation of basal , rhomb , and prism slip systems, and asymmetric patterns consistent with sub-simple shear deformation. The integrated dataset support a syn-tectonic, transpressional emplacement model in which successive magma pulses were accommodated along a progressively waning crustal-scale shear zone and sequentially sandwiched between the older granitoid units and the overlying and uplifting host rocks of the Mammola Paragneiss Complex. This study highlights the necessity of an integrated multiscale approach to address the complexity of mechanisms governing the architecture and incremental assembly of granitic batholiths within the orogenic crust.

Caggianelli A. et al. (2000) - Thermal history vs. fabric anisotropy in granitoids emplaced at different crustal levels: An example from Calabria, southern Italy, Terra Nova, 12, 109-116.

Fiannacca P. et al. (2017) - Timescales and mechanisms of batholith construction: Constraints from zircon oxygen isotopes and geochronology of the late Variscan Serre Batholith (Calabria, southern Italy), Lithos, 277, 302-314.

Russo D. et al. (2023) - From floor to roof of a batholith: Geology and petrography of the north-eastern Serre Batholith (Calabria, southern Italy). J. Maps, 19, 2149358.

Russo D. et al. (2025) - Geology and microstructural evolution of syn-to late-tectonic granitoids from Capo Vaticano Promontory (southern Calabria, Italy). Geological Magazine, 162, e8.

Multiphase tectonic evolution of the Maritime-Ligurian Alps transition zone (SW Alps)

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Keywords: orogen, tectonic evolution, Western Alps.

Unravelling the geodynamic evolution of collisional orogens requires the integration of multidisciplinary datasets from key tectonic sectors. In this study, we present a critical reappraisal of the geometry, kinematics, and metamorphic evolution of the tectonic units exposed at the junction between the Maritime and Ligurian Alps — a region of strategic importance for reconstructing the tectonic evolution of the Western Alps. Our re-evaluation builds upon the pioneering work of Guido Gosso, who first interpreted the geological evolution of this area in terms of a polyphase deformation history.

The analysis integrates and reassesses published stratigraphic, structural, geochronological, and metamorphic data to establish a coherent tectonic framework for this sector of the belt. The reviewed dataset underscores the fundamental role of fold-and-thrust tectonics in controlling the present-day architecture of the Maritime-Ligurian Alps junction. Structural relationships and tectono-metamorphic constraints indicate that the current configuration of the tectonic units primarily reflects polyphase crustal shortening and tectonic stacking processes, rather than simple metamorphic zonation patterns.

This new interpretation also provides the basis for a thorough reappraisal of the Penninic Front, the southwestern continuation of which is exposed along the Maritime-Ligurian Alps transition zone. Here, the Penninic Front is interpreted as a thrust-sheet zone characterized by the superposition of tectonic units with different tectono-metamorphic histories, regardless of their metamorphic grade. This challenges traditional models that are based on a direct correspondence between structural position and metamorphic evolution.

Hydration and petrologic changes of inner portions of the subducting oceanic lithosphere facilitated by intermediate-depth faulting

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Keywords: oceanic lithosphere, subduction, fault.

The subduction-zone rheology and seismic behaviour of hydrated oceanic slabs have been widely studied, while the unaltered, dry portions of the subducting lithosphere remain less understood despite their role in earthquake generation and slab pull through eclogitization. We present field-based evidence from the ophiolitic Lanzo Massif (Western Alps), a slice of mantle peridotite and gabbro that largely escaped hydration and Alpine metamorphism and behaved a mechanically rigid block in the subduction complex. At intermediate depths, this dry lithosphere locally developed pseudotachylyte-bearing faults (Moncuni locality) and widespread meso- to micro-faults (Mt. Arpone locality). At Mt. Arpone, faults offset the gabbroic dykes by several centimetres and contain sub-micrometric "annealed" ultracataclasite of mantle minerals, locally overgrown by chlorite and orthopyroxene. These features indicate faulting under dry conditions and production of tectonic porosity, followed by localized fluid infiltration.

This led to discontinuous hydration of peridotite and to the widespread transformation of cataclastic gabbroic plagioclase into zoisite-paragonite symplectites, suggesting blueschist-facies conditions for plagioclase breakdown during faulting. Recent studies show that this reaction is associated to volume reduction and the formation of reactive porosity, making plagioclase the most intensely eclogitized mineral in the studied samples.

Eclogitization of the Lanzo peridotite and gabbro only occurred where fluids were present, either from limited oceanic hydration, or from subduction-related fluid infiltration through faults, thus enhancing the metamorphic breakdown of gabbroic plagioclase.

The Arpone blueschist-facies ultracataclasites may represent seismic structures that did not evolve into frictional melting; they may be the precursors to the earthquake-generating faults that developed at Moncuni.

Deciphering collisional orogens through petrostructural heterogeneities: insights from the Baie Verte Margin, Newfoundland Appalachians

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Keywords: tectonics, eclogite, structural geology.

Polydeformed and polymetamorphic collisional orogens commonly preserve complex tectonometamorphic records in which early deformation and metamorphic stages are strongly obscured by younger overprinting events. Resolving these records requires the identification and integration of petrostructural heterogeneities and overprinting relationships across multiple scales. Approaches based on multiscale structural and metamorphic analysis, widely developed in Alpine geology, provide a powerful framework for deciphering similarly complex accretionary systems elsewhere.

The Baie Verte Peninsula, Newfoundland Appalachians, exposes one of the best-preserved segments of the Middle-Ordovician Taconic orogen and represents a key locality to investigate the subduction and exhumation of the Laurentian margin during closure of the Iapetus Ocean. However, the tectonic evolution of the area has long remained controversial due to extensive Silurian to Devonian structural and metamorphic overprinting associated with the Salinic and Acadian orogenic cycles.

Here we integrate regional mapping, meso- and microstructural analysis, metamorphic petrology, thermodynamic modelling, and petrochronology to reconstruct the tectonometamorphic evolution of the Baie Verte Margin. Mapping of petrostructural heterogeneities and multiscale overprinting relationships allowed the identification of distinct tectonometamorphic domains and the isolation of the Taconic record from younger overprints. These observations, combined with P-T estimates and accessory mineral geochronology, constrain the burial and exhumation history of eclogite-bearing rocks within the East Pond Metamorphic Suite and refine the architecture of the Baie Verte Margin. The results indicate deep subduction of Laurentian margin sequences to eclogite-facies conditions followed by progressive exhumation and retrogression during continued convergence and collision.

This study highlights how multiscale petrostructural analysis, integrated with petrology and geochronology, provides a robust framework for deciphering tectonic processes preserved within complex orogenic systems.

From outcrop to mineral dislocations: a journey across scales at UHP conditions

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Keywords: Dora Maira whiteschists, garnet microstructures.

The analysis of structures across multiple scales is fundamental for the study of complexly deformed metamorphic rocks. Structural analysis provides information on the overall geological context and guides future sampling. Moreover, crosscutting relationships from the outcrop to the mineral scale indicate the relative chronology of deformation events. This approach is especially effective in rocks that experienced a very wide range of pressure and/or temperature conditions over their history, such as the Dora Maira whiteschists from the Western Alps. Whiteschists represent one of the best-preserved examples of ultra-high-pressure (UHP) metamorphism and provide an exceptional opportunity to investigate deformation processes operating during burial and exhumation. In these rocks, garnet preserves a wide range of deformation-related microstructures developed under changing pressure-temperature conditions. To investigate the evolution of these structures from the outcrop to the grain scale, we combined field observations, optical microscopy, µ-CT, SEM-BSE and SEM-(HR)EBSD analyses.

The studied whiteschists are characterized by a pervasive foliation defined by the preferred orientation of phengite and garnet. Garnet grains show variable shapes, from rounded to elongated, and preserve multiple generations of fractures together with localized recrystallization textures. The earliest fracture system consists of parallel fractures developed at a high angle to the main schistosity and affecting garnet grains throughout the outcrop. Locally, these structures are associated with secondary fractures oriented at ca. 45°, together with micrometric rotating garnet domains, suggesting deformation under combined brittle and ductile conditions.

Microstructural relationships indicate that these early fractures were overprinted by localized recrystallization and by radial fractures surrounding coesite/palisade quartz inclusions. The latter formed during the coesite-to-quartz transition, reflecting the large volumetric change associated with this transformation during decompression.

Our results show that garnet can simultaneously preserve evidence of both brittle fracturing and ductile deformation during a single HP-UHP metamorphic cycle. This study highlights the importance of multiscale structural analyses for reconstructing the sequence of decompression events in UHP rocks.

From field structures to mineral isotopes: deciphering the tectono-magmatic evolution of the Finero Complex (Ivrea-Verbano Zone)

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Keywords: Finero Complex, Sr isotopes, trace elements.

The Finero Complex in the northern Ivrea-Verbano Zone represents one of the most enigmatic cross-sections through the mantle and lower continental crust. The mantle peridotite unit (Phlogopite Peridotite, PP) consists of pervasively metasomatized spinel-harzburgite enriched in phlogopite and amphibole, locally crosscut by Cr-diopside-bearing veins (Zanetti et al., 1999). The PP is structurally associated with a Permian lower crustal mafic sequence (Lu et al., 1997), subdivided into three units (Siena & Coltorti, 1989): i) the Layered Internal Zone (LIZ), including lherzolites, garnet-hornblendites, pyroxenites, anorthosites, and garnet-gabbros; ii) the Amphibole Peridotite (AP); and iii) the External Gabbro (EG), adjacent to the Kinzigite Formation.

Following a multi-scale approach, we integrated field observations, petrography, major- and trace-element mineral chemistry, and in-situ isotopic analyses of single mineral phases to investigate the relationships among the different lithological units and the processes responsible for their evolution.

Trace-element and isotopic heterogeneities reveal a complex history of melt infiltration and reaction affecting a pre-existing layered mafic-ultramafic system. The preservation of common unradiogenic signatures in lherzolites, pyroxenites, and wehrlites suggests that these lithologies represent the least-reacted portions of the system. Combined with the layered structural organization and the extremely depleted initial Sr-isotope compositions, these features point to affinities with ancient layered mafic-ultramafic complexes, possibly of Proterozoic age or older. Our results highlight how integrating structural observations from the field to the mineral scale with in-situ isotopic analyses can unravel the tectono-magmatic evolution of deep crustal sections preserved within fossil orogenic systems.

Lu M. et al. (1997) - The mafic-ultramafic complex near Finero (Ivrea-Verbano Zone). Chem. Geo., 140, 207-222.

Siena F. & Coltorti M. (1989) - The petrogenesis of a hydrated mafic-ultramafic complex and the role of amphibole fractionation at Finero (Italian Western Alps)." Neues Jahrbuch für Mineralogie Monatshefte, 6, 255-274.

Zanetti A. et al. (1999) - The Finero phlogopite-peridotite massif: an example of subduction-related metasomatism. Contributions to Mineralogy and Petrology, 134(2), 107-122.

Unravelling ancient orogenic systems: A multi-scale approach

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Keywords: ancient orogenic systems, multi-scale petro-structural analysis, crustal accretion and reworking.

Orogenic systems are fundamental components of Earth's convergent margins, where crust is formed, recycled, and stabilised over geological time. These dynamic environments record the processes governing lithospheric evolution and host major mineral resources. To resolve these complex histories, a multi-scale approach capable of linking large-scale tectonic architectures with mineral-scale processes is required (Gosso et al., 2015).

This approach was first applied to the Phanerozoic Variscan Orogen, in the Argentera-Mercantour Massif (Western Alps). Detailed mapping of mafic-ultramafic and calc-silicate boudins preserved in migmatitic rocks was integrated with microstructural analysis to determine the relative chronology of successive equilibrium mineral assemblages supporting mappable planar fabrics. The association of these rocks within the Variscan migmatites reflects remnant fragments of subducted oceanic lithosphere exhumed during continental collision and later overprinted during the Alpine cycle.

Building on this foundation, the approach was applied to older and more complex systems. In the Proterozoic Georgetown Inlier (NE Australia), structural, petrochronological, and thermodynamic data were integrated to investigate the role of NE Australia during the assembly of the supercontinent Nuna. Results define a two-stage tectono-metamorphic evolution: an early compressional phase (D1/M1, ca. 1600 Ma) associated with crustal thickening, followed by a post-collisional extensional phase (D2/M2, ca. 1550 Ma) marked by migmatization and melt-assisted deformation (Volante et al., 2020a,b). The coupling reveals a hybrid tectonic model where collisional processes transitioned into melt-assisted, extensional crustal reworking during post-collisional slab roll-back (Volante et al., 2022).

Finally, preliminary data from Archean SW Greenland demonstrate the strategy's potential to investigate early Earth dynamics by constraining the role of metasomatism during Neoarchean (3.0-2.5 Ga) terrane accretion and cratonisation. Multi-scale observations show that fluid-rock interaction is structurally controlled, forming decimetre- to decametre-scale pathways synchronous to large-scale folding and shearing. These pathways record a progressive transformation from amphibolite to aluminous gneiss, associated with major chemical reorganisation (Ca depletion and Al-K enrichment) and fluid-induced mineral replacement. These findings highlight metasomatism as a pervasive process during accretion, tightly coupled with deformation and mass transfer, playing a key role in crustal transformation, accretion and stabilisation during craton formation.

Together, these results demonstrate that a multi-scale approach is essential and successful for unravelling ancient orogenic complexities. Bridging mineral and regional scales reveals that processes analogous to modern orogenesis were active as early as the Archean, providing a powerful tool for reconstructing crustal evolution throughout Earth's history.

Gosso G. et al. (2015) - Taking advantage of petrostructural heterogeneities in subduction-collisional orogens, and effect on the scale of analysis. Periodico di Mineralogia, 84(3B), 779-825, https://hdl.handle.net/2434/372737.

Volante S. et al. (2020a) - Multiple P-T-d-t paths reveal the evolution of the final Nuna assembly in northeast Australia. Journal of Metamorphic Geology, 38(6), 593-627, https://doi.org/10.1111/jmg.12532.

Volante S. et al. (2020b) - Structural evolution of a 1.6 Ga orogeny related to the final assembly of the supercontinent Nuna: coupling of episodic and progressive deformation. Tectonics, 39(10), e2020TC006162, https://doi.org/10.1029/2020TC006162.

Volante S. et al. (2022) - Spatio-temporal evolution of Mesoproterozoic magmatism in NE Australia: A hybrid tectonic model for final Nuna assembly. Precambrian Research, 372, 106602, https://doi.org/10.1016/j.precamres.2022.106602.

Basin and Range extensional tectonics in the Uranium district of the Central Southern Alps

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Keywords: Early Permian, Southern Alps, extension.

Post-Variscan extension shaped the evolution of the Central Southern Alps, leading to the development of a complex network of Early Permian (Cisuralian) normal faults. Following the extensive studies performed in the recent past by Guido Gosso and his co-workers, detailed field investigations and multiscalar analyses in the Orobic Basin, one of the largest Permian extensional basins in the region, enabled the identification of both low-angle (LANF) and high-angle normal faults that controlled the formation of extensional depocentres hosting Lower Permian sedimentation. The principal structure, the Aga-Vedello LANF, defines the northern margin of the Orobic Basin and extends ENE-WSW for over 20 kilometres. Evidence of synsedimentary tectonic activity along this fault is provided by the significant increase in sediment thickness within its hanging wall.

Synsedimentary deformation structures observed within the Lower Permian successions occur at outcrop scale as intricate systems of Andersonian, domino-style, listric, and planar normal faults, commonly associated with pervasive soft-sediment deformation features indicative of unconsolidated conditions and seismic shaking.

Frictional processes, typical of the shallow upper crust, are consistently linked to hydrothermal fluid circulation of fluids enriched in Boron and metals as Uranium, especially along LANFs, which promoted the formation of tourmalinites accompanied along by uranium mineralization in the Vedello abandoned mine area. This structural framework supports models proposing that LANFs may develop under conditions of elevated pore-fluid pressure generated by syntectonic hydrothermal circulation, which lowers the effective normal stress acting on fault planes. These observations suggest that fluid-assisted weakening was a fundamental mechanism enabling sustained slip along LANFs.

Fracture analyses conducted on more than 500 synsedimentary faults aligned with the WNW-ESE orientation of the Early Permian fault system indicate a stress regime dominated by a vertical σ axis and a horizontal σ3 approximatively ranging between NW-SE and NNW-SSE, implying that the evolution of the Orobic Basin during the Early Permian was primarily controlled by extensional tectonics.

During subsequent N-S Alpine shortening, several of these normal faults, due to their favourable longitudinal orientation with respect to the belt, were inverted as thrust faults, accounting for the younger-on-older relationships often documented in the northern portion of the Central Southern Alps.

The puzzle of oceanic tectono-metamorphic units in the Zermatt-Saas Zone

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Keywords: Alpine subduction, HP/UHP metamorphic peak, Tethyan ophiolite.

Within the Alpine nappe stack of the Western European Alps, the Zermatt-Saas Zone (ZSZ) is a remnant of the Piedmont-Ligurian oceanic lithosphere (Middle-to-Late Jurassic) involved in the Alpine subduction system up to UHP-to-HP metamorphic conditions (Late Cretaceous to middle Eocene). Serpentinite, metabasite, and metasedimentary rocks record multiple stages of ductile deformation and metamorphic re-equilibration that developed during the Alpine subduction, collision, and exhumation. The inferred PTdt evolutions are contrasted and hectometre-sized domains preserve ultra-high pressure metamorphic peaks. These domains are generally wrapped by high pressure - intermediate temperature domains. Moreover, other domains record high pressure-low temperature climax conditions. The S2 dominant fabric at the regional scale is marked by HP mineral assemblages and wraps around UHP relic domains and rare eclogite facies continental slices. Relationships between domains recording HP/IT and HP/LT assemblages indicate that S2 is a long-living fabric responsible for the coupling of volumes recording these different tectono-metamorphic records. In addition, the deformation generating S2 (D2) is also responsible for the transposition of the ophiolitic sequence, which consists of three main rock types: serpentinite, metabasite and metasediments. The transposition determined a pervasive reorganization of the lithostratigraphy, with the formation of hectometre-sized meta-gabbro bodies and meter-sized rodingite lenses. These lithostratigraphic, structural, and metamorphic features are compatible with a tectonic mixing and therefore, the ZSZ can be regarded as a tectono-metamorphic mélange mainly shaped during HP pressure transposition in the subduction system.

The Scientific path of Guido Gosso (1946-2025)

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Keywords: metamorphic basement, mountain building processes, multiscale structural analysis.

Guido Gosso graduated in Geological Sciences from University of Turin in 1970, with a thesis on the Biellese-Monte Rosa-Matterhorn section. Between 1972 and 1975, he received advanced training at the Institute of Structural Geology in Leiden, where he had the opportunity to work with some of the leading structural geologists of the time, including H.J. Zwart, E. Den Tex, B.E. Hobbs, R.H. Vernon, G.S. Lister, P.F. Williams, and C.J.L. Wilson. He began his academic career at the University of Turin, where he was Assistant Professor of Geology (1972-1975), Petrology (1975-1979), and Structural Geology (1979-1983). In 1983, he was appointed Associate Professor at the University of Turin, teaching courses in Tectonics and Microstructural Geology. In 1986, he was appointed Full Professor of Structural Geology at the University of Palermo, and from 1990 onward he held the same chair at the Dipartimento di Science della Terra "A. Desio" of University of Milan. Guido made fundamental contributions to numerous scientific projects of both national and international significance, ranging from the ECORS-CROP-NFP20 program (1989-1993) to the major seismic exploration campaigns of the Alpine crust, including CroP and TransAlp (1988-2003). He also contributed to the Metamorphic Map of the Alps and to the UNESCO Metamorphic Map of the World for the Alpine sector. He took part in the first modern Italian scientific expedition to Antarctica, ITALIANTARTIDE-ENEA (1985), and in the Everest-K2-CNR Expedition (1988-1989) in the Shaksgam Valley, Karakoram. His research also involved northern Somalia, where he investigated the geological history of the Red Sea and the Gulf of Aden, as well as other regions such as the Copperbelt in Zambia, the Transantarctic Mountains, the Canadian Cordillera, and Xinjiang in China. At the same time, he collaborated with institutions and companies such as the BRGM, COGEMA, AGIP Mineraria, and Henraux, consistently demonstrating a strong commitment to applying structural geology across a wide range of scientific and industrial contexts. Guido was also among the founders and served as the first coordinator of the Italian Structural Geology Group (GIGS) of the Italian Geological Society, which remains a reference point for the Italian structural geology community. Guido also made a major contribution to the development of the international structural geology community, particularly through his involvement with the Deformation Rheology and Tectonics Group. Alongside his academic and research activities, he devoted considerable energy and passion to science communication to the general public. He published guidebooks for Alpine geological itineraries and organized public engagement events, including "Tra Cielo e Terra… con Scienza" in Cervinia (2002) and "Vedere la Scienza… Estate" in the Maritime Alps Natural Park (2003), organized in collaboration with the Institute for the History of Physics and the Geymonat Foundation. He mentored numerous students who later went on to hold professorships at Italian and international universities.

S17.

Deciphering the Alps-Apennines system: Integrating stratigraphy, geodynamics, and geological mapping for a sustainable future

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First evidence of MIS 5.5 deposits along Molise coasts as a tool for the uplift evaluation on Adriatic side of the Apennines (Italy)

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Keywords: Last Interglacial, Tyrrhenian deposits, shoreface-beach deposits, uplift.

Evidence of MIS 5.5 deposits along the Adriatic side of the central Apennines (Italy) is generally scarce (Stocchi et al., 2018). In particular, Tyrrhenian deposits have been documented mainly in the subsurface of the Romagna coastal plain (Amorosi et al., 2026 and references therein), whereas limited information are available for the southern Marche, Abruzzo, and Molise regions (Ferranti et al., 2006). Near the mouth of the Fortore River, along the Apulian coast, Bordoni & Valensise (1998) (and references therein) reported a marine terrace at ~25 m a.s.l. which is tentatively attributed to MIS 5.5 on the basis of morphostratigraphic analysis.

Recent investigations along the Molise coast have, for the first time, documented a sedimentary succession attributable to the Last Interglacial. The succession, exposed near the city centre of Termoli, is approximately 23 m thick and consists of yellow fine to coarse-grained sands. Sedimentary structures include ripple and longshore-current cross-stratification, as well as planar cross-bedding. Facies analysis indicates deposition in upper shoreface to foreshore environments. From a morphostratigraphic perspective, these deposits are associated with the Pleistocene foreland-basin succession of the Apennines. The succession presently occurs between 2 and 25 m a.s.l.

A sample collected at 14 m a.s.l. from the upper shoreface facies association was dated using quartz OSL techniques. The obtained age (127.8 ± 8.9 ka) is consistent with deposition during MIS 5.5.

The facies associations, their inferred palaeobathymetry, and the present elevation of the dated deposits indicate significant uplift of this sector of the Apennines during the last ~125 kyr. A mean uplift rate of approximately 0.2 mm/yr is inferred, in agreement with the regional tectonic framework proposed by Ferranti et al. (2006).

Amorosi A. et al. (2026) - Middle Pleistocene to Holocene glacio-eustatic sequences of the Po Basin (Italy): Towards improved geological mapping of the Quaternary period. Quateranry Science Review, 380, 1-19, https://doi.org/10.1016/j.quascirev.2026.109918.

Bordoni P. & Valensise G. (1998) - Deformation of the 125 ka marine terrace in Italy: tectonic implications. In: Stewart I.S., Vita-Finzi C. (Eds), Coastal Tectonics. Geological Society of London Special Publication 46, 71-110.

Ferranti L., et al. (2006) - Markers of the last interglacial sea-level high stand along the coast of Italy: tectonic implications. Quaternary International, 145-146, 30-54, https://doi.org/10.1016/j.quaint.2005.07.009.

Stocchi P. et al. (2018) - MIS 5e relative sea-level changes in the Mediterranean Sea: Contribution of isostatic disequilibrium. Quaternary Science Review, 185, 122-134, https://doi.org/10.1016/j.quascirev.2018.01.004.

Quaternary infilling of the intermontane basins of the Matese Mountains (southern Apennines): lithofacies, chronology, and sedimentation rates as constraints on regional uplift and extensional tectonics

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Keywords: Matese fault systems, CARG project, Quaternary chrono-stratigraphy.

The Matese Mountains, located in the axial sector of the central-southern Apennines, are bordered by a system of intermontane basins (Boiano, Carpino, Isernia, Venafro, and Alife) hosting alluvial plains drained by the Biferno, Volturno, Calore, and Tammaro river systems. These tectonic depressions are controlled by high-angle normal and transfer fault systems belonging to the Northern and Southern Matese Fault Systems (NMFS of Galli et al., 2017, and SMFS of Boncio et al., 2022), including seismogenic structures such as the Boiano Fault, Calore Fault, and Aquae Juliae Fault (Galli & Naso, 2009; Amato et al., 2025), which are responsible for historical earthquakes. As documented by field investigations and deep borehole data, mainly acquired during the preparation of the new 1:50,000 geological maps (Piedimonte Matese, Isernia, and Castel di Sangro sheets), the Quaternary infill of these basins consists of thick continental successions composed of alternating lacustrine, palustrine, marsh-fluvial, travertine, and alluvial deposits. Chronological constraints provided by tephrostratigraphic data, OSL analyses, and 40Ar/39Ar and radiocarbon dating allow reconstruction of the timing and sedimentation rates that characterized basin evolution. Lithofacies architecture and morphostratigraphic relationships indicate that sedimentation was controlled by the interaction between climatic variability and tectonic activity, with extensional tectonics exerting the primary control on accommodation-space development. Chronostratigraphic data reveal marked spatial and temporal variability in sedimentation rates, both among different basins and within individual basins, highlighting differential tectonic subsidence around the Matese structural high. Sedimentation rates are significantly higher during the Middle Pleistocene than during the Early and Late Pleistocene, suggesting a major phase of accelerated extensional tectonics and enhanced regional uplift between ca. 660 and 300 ka. During the Upper Pleistocene and Holocene, our data confirm the slip rates previously estimated for the NMFS and SMFS by earlier studies, except for the Aquae Juliae Fault, which appears to have undergone a significant decrease in activity rates. Furthermore, the data allow us to infer the activity of high-angle faults cross-cutting the basins, as observed in the Boiano and Venafro basins. The highest sedimentation rates are recorded in the northern Matese basins (Boiano and Carpino basins), whereas lower rates characterize the southern (Alife and Calore plains) and western sectors (Venafro and Isernia basins). These data support a model of asymmetric Quaternary tectonic activity in the Matese region, characterized by spatially variable uplift and subsidence patterns linked to the evolution of the Apennine extensional domain.

Amato V. et al. (2025) - Unveiling the hidden source of major historical earthquakes: A multi-scale, trans-disciplinary approach to the 1456 and 1688 Sannio earthquakes (Mw 7.0, southern Italian Apennines). Quaternary Science Reviews, 356, 109282, https://doi.org/10.1016/j.quascirev.2025.109282.

Boncio P. et al. (2022) - Late Quaternary faulting in the southern Matese (Italy): implications for earthquake potential and slip rate variability in the southern Apennines. Solid Earth, 13 (3), 553-582, https://doi.org/10.5194/se-13-553-2022.

Galli P.A.C. & Naso J.A. (2009) - Unmasking the 1349 earthquake source (southern Italy): paleoseismological and archaeoseismological indications from the Aquae Iuliae fault. Journal of Structural Geology, 31, 128-149, http://doi.org/10.1016/j.jsg.2008.09.007.

Galli P.A.C. et al. (2017) - Middle to Late Pleistocene activity of the northern Matese fault system. Tectonophysics, 699, 61-81, http://dx.doi.org/10.1016/j.tecto.2017.01.007.

Offshore geological mapping and shallow stratigraphic architecture of the Apennine-Calabrian transition: New insights from the northeastern Gulf of Taranto

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Keywords: active tectonic, seismo-stratigraphy, Southern Apennines.

The northeastern Gulf of Taranto is a key sector for reconstructing the offshore expression of the Southern Apennine front, where foredeep stratigraphy, inherited structural grain and present-day seafloor morphology converge within the broader Alps-Apennines geodynamic system. Building on the regional tectono-stratigraphic framework proposed for the offshore Southern Apennines and on recent evidence of ongoing shallow deformation in the Gulf of Taranto (Teofilo et al., 2018; Meo et al., 2026), this contribution highlights the value of integrated offshore geological mapping for reconstructing the late Quaternary evolution of the Apennine-Calabrian transition. An integrated dataset of high-resolution multibeam bathymetry, Sparker seismic profiles and well calibration data allows recognition of a fourfold shallow seismo-stratigraphic framework including the late Pleistocene-Holocene unit, the Santerno Formation, the Calcarenite di Gravina and the Cupello Limestones. Within this architecture, the upper late Quaternary interval records the highest internal variability and preserves acoustically disturbed bodies, fluid-escape acoustic anomalies and steep discontinuities affecting the shallow succession. These elements show that the recent stratigraphic record is not simply a sedimentary cover, but a sensitive archive of sediment remobilization, structural segmentation and vertical fluid pathways along the outer shelf-upper slope system. Morpho-bathymetric mapping further reveals persistent lineament families and preferred channel orientations, suggesting that the organization of the Taranto Canyon sector is strongly conditioned by structural inheritance. In this perspective, offshore geological mapping becomes a critical tool not only for refining regional stratigraphic models, but also for linking shallow deformation, sediment routing and slope instability within a tectonically active foredeep margin. The results provide new constraints on the shallow geological architecture of the southern Apennine front and highlight how integrated offshore geological mapping can link stratigraphic architecture, seafloor morphology and geodynamic processes, thereby refining regional geological models of the Apennine-Calabrian transition within the broader Alps-Apennines system.

Meo A. et al. (2026) - Ongoing Deformation at the Southern Apennine Front: Insights from the Gulf of Taranto (Italy). Geosciences, 16(4), 141, https://doi.org/10.3390/geosciences16040141.

Teofilo G. et al. (2018) - Neogene-Quaternary evolution of the offshore sector of the Southern Apennines accretionary wedge, Gulf of Taranto, Italy. Tectonophysics, 738, 16-32, https://doi.org/10.1016/j.tecto.2018.05.006.

Lateral variability of an exhumed erosive plate interface: new insights from the Vincigliata Unit (Tuscan Apennines) compared to the Sestola-Vidiciatico Unit (Emilia Apennines)

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Keywords: accretionary prism, plate interface, Northern Apennines.

New mapping in the Tuscan Apennines documents the Vincigliata Unit (VU), interpreted as a tectonic mélange representing the along-strike continuation of the Miocene erosive plate interface (in the Emilia Apennines as the Sestola-Vidiciatico Unit (SVU). An erosive plate boundary is a convergent margin where the downgoing plate removes and subducts upper-plate material, forming a tectonic mélange along a distributed shear zone. The VU is characterized by a block-in-matrix fabric, pervasive scaly cleavage, and widespread boudinage structures. New chronological constraints indicate that blocks span from Jurassic to Oligocene-early Miocene and are derived from Ligurian, Subligurian, and Epiligurian s.l. successions, consistent with an upper plate and forearc origin (Vannucchi et al., 2008). Laterally, the VU grades into kilometre-scale tectonic slices of the Canetolo Unit (Subligurian Units), reproducing the spatial relationships observed between the SVU and adjacent Subligurian units in the Emilia sector. In both areas, the internal architecture consists of stacked, lens-shaped tectonic slices derived from the upper plate, with deformation accommodated along multiple sub-parallel slip surfaces. This structural style reflects a "laminar" subduction channel, where deformation is distributed across coeval shear zones rather than localized along a single fault (Vannucchi et al., 2012). Variability within the interplate shear zone appears partly controlled by frontal prism composition and sediment flux. In the Emilia Apennines, abundant forearc mass-wasting deposits favoured development of a thick (ca. 250-500 m) map-scale mélange (SVU). In contrast, in Tuscany the VU is thinner (0-150 m) and locally discontinuous, reflecting more limited incorporation of such deposits. However, upper plate lithology alone cannot fully account for the pronounced differences observed across the Sillaro Line, a major transverse structure of the Northern Apennines. The Sillaro Line may represent a tear or transfer zone partitioning deformation and fluid flow along strike, without requiring changes in deeper slab geometry. Alternatively, along-strike variations in slab configuration (e.g., slab dip) could have influenced subduction channel geometry, with steeper segments producing narrower channels. This interpretation remains speculative owing to the lack of independent constraints (Nirta et al., 2007; Bettelli et al., 2012). Overall, the data indicate that the plate interface operated as a distributed, laminar subduction channel characterized by multiple coeval slip surfaces and progressive incorporation of upper plate material. Along-strike variability reflects the combined influence of sediment supply, upper plate heterogeneity, and structural segmentation across transverse lineaments such as the Sillaro Line. These results highlight the complexity of erosive convergent margins, where plate interface structure arises from multiple interacting controls.

Bettelli G. et al. (2012) - Revisiting the geology of the"Sillaro Line", Northern Apennines, Italy. Rendiconti Online della Società Geologica Italiana, 22, 14-17.

Nirta G. et al. (2007) - The Ligurian Units of Western Tuscany: insight on the influence of pre-existing weakness zones during ocean closure. Geodinamica Acta, 20(1-2), 71-97.

Vannucchi P. et al. (2008) - Geological record of fluid flow and seismogenesis along an erosive subducting plate boundary. Nature, 451, 699-703.

Vannucchi P. et al. (2012) - Lateral variability of the erosive plate boundary in the Northern Apennines, Italy. Ital. J. Geosci., 131, 215-227.

Stratigraphic architecture and depositional evolution of the Civita di Pietraroja area: A reference model for Southern Apennine Foreland-Foredeep successions

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Keywords: Pietraroja succession, foreland-foredeep successions, Southern Apennines.

The succession exposed in the Civita di Pietraroja area, in the Campanian sector of the southern Apennines, records sedimentary and tectonic evolution from the Early Cretaceous to the Miocene. The area belongs to the Matese Group and lies on a structural high of the Southern Apenninic Carbonate Platform, later incorporated into Neogene compression and reworked by Plio-Pleistocene extension. The ridge forms an east-dipping monocline bounded by normal faults, reflecting thrust-related deformation and later extension.

The Cretaceous succession begins with Aptian-Early Albian peritidal cyclic carbonates, arranged in shallowing-upward cycles including transgressive, subtidal, and intertidal-supratidal facies. These deposits are separated from the overlying ichthyolitic limestones by a marked erosional surface, representing a major stratigraphic hiatus (Boscaino, 2001). The ichthyolitic limestones, exposed along the eastern Civita slope, consist of thinly bedded, laminated limestones with chert nodules. They accumulated within a localized depression fed from the W-NNW, excluding continuity with the underlying carbonate units. Recent studies interpret these Plattenkalk horizons as deposits of a restricted lagoonal system, where cyclic salinity and oxygenation changes favoured exceptional preservation of plants, fishes, crocodylomorphs, and *Scipionyx samniticus* (Graziano et al., 2024).

The Miocene succession unconformably overlies the Mesozoic basement and records a marine transgression. It starts with the Cusano Formation, made up of rhodolith-bearing limestones with bryozoans, bivalves, echinoids, and benthic foraminifers, reflecting open-platform conditions. This is followed by the Longano Formation, consisting of marly limestones and clayey marls rich in planktonic foraminifers, indicating basin deepening and hemipelagic sedimentation. The succession ends with the Pietraroja Formation, composed of clays, clayey marls, and fine micaceous sandstones deposited in a deep-marine turbiditic setting, documenting carbonate-platform drowning.

The stratigraphic relationships observed along the eastern Civita slope and the SP89 road toward Bocca della Selva support an incised-valley model. In this framework, the Cretaceous carbonate basement underwent prolonged subaerial exposure and incision, locally associated with bauxite formation, before Miocene flooding filled depressions with onlapping deposits (Meo et al., 2024; Senatore & Meo, 2026). The vertical evolution from shallow-platform facies to hemipelagic deposits and siliciclastic turbidites represents a typical drowning succession, comparable with successions in the south-eastern Matese Mountains, the Taburno-Camposauro Group, and the Vitulano area. Overall, the Civita di Pietraroja succession provides a reference model for southern Apennine foreland-foredeep domains, where transgressive geometries, discontinuity surfaces, and marine deepening recur as common stratigraphic and structural features.

Boscaino M. (2001) - Lo scavo in località “Le Cavere” nel Parco Geopaleontologico di Pietraroja. Comune di Pietraroja e Soprintendenza Archeologica di Salerno, Avellino e Benevento. Rilevamento Geologico e Stratigrafia. Relazione.

Graziano R. et al. (2024) - New insights into the palaeoenvironmental-palaeoclimatic significance and sedimentary dynamics of carbonate Lagerstätten: The lower Albian of Pietraroja (Southern Italy). Sedimentology, 71(2), 619-686, https://doi.org/10.1111/sed.13146.

Meo A. et al. (2024) - Geological map of the San Giuliano Lake (Southern Italy): new stratigraphic and sedimentological data. It. J. Geosc., 143, 175-186, https://doi.org/10.3301/IJG.2024.12.

Senatore M.R. & Meo A. (2026) - Stratigraphy and Sedimentology: The site of Pietraroja from the Cretaceous to the Upper Miocene. The reference geological model. In: La Rocca R.A. & Amore F.O. (Eds), Le sfide di Insite, Progetto Prin 2022, Federico II University Press, January 2026, 63-70, https://doi.org/10.6093/978-88-6887-390-5.

Geological Mapping of the Flysch della Val Roveto in the 390-Frosinone Sheet (CARG Project): new biostratigraphic constraints

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Keywords: geological mapping, syn-orogenic deposits, CARG Project.

As part of the geological survey of the 390-Frosinone Sheet (CARG Project), we present the preliminary results of the mapping of the Upper Miocene terrigenous deposits extensively cropping out in the Val Roveto-Sora area, within the southern sector of the Latium-Abruzzi "turbidite complex". The mapped succession belongs to the foredeep deposits associated with the evolution of the central Apennine orogenic system during the Late Miocene.

In the Sora area, the pre-orogenic deposits include the Calcari a Briozoi e Litotamni (CBZ, Lower-Middle Miocene) and the Marne e Argille a Orbulina (UAM, Upper Miocene p.p.). The overlying syn-orogenic deposits include the Arenaceo-Pelitica Unit, also known as Flysch della Val Roveto (UAP, Upper Miocene p.p.), which is generally poorly exposed and laterally discontinuous. The Flysch della Val Roveto is composed of several lithofacies: pelitico-arenacea litofacies (UAPe) (dominant), consisting of yellowish fine- to medium-grained sandstones, dark-yellow siltstones, and pelites arranged in medium- to thick-bedded intervals; arenaceo-pelitica litofacies (UAPd) (secondary), consisting of yellow to brown fine- to medium-grained sandstones alternating with homogeneous pelites in thin- to thick-bedded intervals; a third lithofacies association is represented by thick-bedded coarse-grained sandstones (UAPb) (rare) locally containing coarse-grained particles coming from the local carbonate succession. Paleocurrent indicators point to a source area located to the W or NW of the Val Roveto (Ernici Mts). These deposits commonly display erosive basal contacts and include abundant intraformational mudstone clasts within the sandy intervals. The Flysch della Val Roveto was deposited in the early Messinian foredeep domain of the central Apennine orogenic system (Cipollari & Cosentino, 1995; 1999, and references therein). In the Broccostella area (SE of Sora), the Flysch della Val Roveto is unconformably overlain by coarse-grained clastic deposits referred to as the Conglomerati di Le Vicenne (VNN). These consist of polymictic conglomerates containing pebbles of Mesozoic limestones, coarse micaceous sandstones, cherty limestones, and characteristic greenish marly limestone clasts of the "Pietra paesina" type. In some places, the Conglomerati di Le Vicenne (VNN) are interlayered with lateritic clayey sands (VNNc).

Calcareous nannofossil biostratigraphic analyses performed on clay samples from the basal part of the Flysch della Val Roveto (Case Cantenne)revealed the occurrence of *Amaurolithus delicatus*. The First Occurrence (FO) of this marker species in the Mediterranean region is calibrated at 7.13 Ma and therefore provides a maximum age constraint for the deposition of the Flysch della Val Roveto. Cosentino et al. (1997) previously reported the occurrence of *Amaurolithus delicatus* from the uppermost part of the underlying Marne e Argille a Orbulina (UAM) in the Pietrasecca section, located further north in the same basin.

Cipollari P. & Cosentino, D. (1995) - Miocene unconformities in Central Apennines: geodynamic significance and sedimentary basin evolution. Tectonophysics, 252, 375-389.

Cipollari P. & Cosentino D. (1999) - Cronostratigrafia dei depositi neogenici del settore ernico-simbruino, appennino centrale. Boll. Soc. Geol. Ital., 118, 439-459.

Cosentino D. et al. (1997) - Integrated stratigraphy of the Tortonian/Messinian boundary: The Pietrasecca composite section (central Apennines, Italy). Eclogae geol. Helv., 90, 229-244.

Stratigraphic, paleontological, and paleoecological analyses of the Upper Miocene-Lower Pliocene wedge-top basin deposits in the Irpinia area (southern Apennines, Italy)

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Keywords: southern Apennines, lago-mare, turbidites.

We investigate a Mio-Pliocene clastic sedimentary succession spanning marine to continental environments that belongs to the Foreland Basin System of the southern Apennines and is well-exposed in the Irpinia area. Above a pre-evaporitic clay-dominated succession, marked by an angular unconformity with the overlying deposits, wedge-top basin sediments are exposed, highlighting further angular unconformity between them that separates a post-evaporitic succession comprising "lago-mare" sediments (latest Messinian to earliest Pliocene; Altavilla Group, Vitale & Ciarcia, 2018, and references therein), developed above evaporite deposits associated with the Messinian Salinity Crisis, from the overlying upper Zanclean strata of Baronia Fm (Ciarcia & Vitale, 2013). This last unconformity records a major orogenic phase in the southern Apennines, marked by out-of-sequence thrusting that affected the Mio-Pliocene wedge-top basin deposits.

Paleontological assemblages were examined to characterize the depositional settings and establish the biostratigraphic framework of the successions. Pre-evaporitic sediments yielded poorly preserved planktonic assemblages, indicating an age not older then Lower Miocene, whereas the overlying post-evaporitic layers were characterized by non-marine ostracods, including the species *Bullocypris robusta*, typical of upper Messinian lago-mare paleoenvironment. The relatively well-preserved planktonic and benthic assemblages of the uppermost sediments indicated a MPl4a/MNN14 zone (late Zanclean age), open shelf - upper bathyal paleoenvironment.

Ciarcia S. & Vitale S. (2013) - Sedimentology, stratigraphy and tectonics of evolving wedge-top depozone: Ariano Basin, southern Apennines, Italy. Sedimentary Geology, 290, 27-46, https://doi.org/10.1016/j.sedgeo.2013.02.015.

Vitale S. & Ciarcia S. (2018) - Tectono-stratigraphic setting of the Campania region (southern Italy). Journal of Maps, 14, 9-21, https://doi.org/10.1080/17445647.2018.1424655.

An overview of pre-orogenic platform-to-basin carbonate deposits across the Isernia and Castel di Sangro CARG sheets: The Meso-Cenozoic stratigraphic evolution of the chain segment at the intersection of the Campania, Molise, and Abruzzi regions

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Keywords: Cretaceous-Miocene, carbonate stratigraphy, Central-Southern Apennines.

The geological mapping of the Isernia and Castel di Sangro Sheets has allowed to characterise the tectono-stratigraphic evolution of a complex sector of the Apenninic chain, which represents the junction between the Campania-Molise and the Latium-Abruzzi. This regional overview shows selected outcrops coming from the backbone of main carbonate ridges, Mesozoic-Tertiary in age, mainly referred to the Matese-Frosolone, the Genzana-Arazzecca and Meta-Mainarde Tectonic Units. In the pre-thrusting scenario, these units have been attributed to palaeogeographic domains corresponding to carbonate platform (Matese and Latium-Abruzzi) as well as slope and basin depositional systems (Montagnola di Frosolone, Mainarde, Mt. Castelnuovo-Mt. della Rocchetta).

The regional survey has offered a complex and fragmented stratigraphy, which is still not totally understood due to lacking of well-exposed outcrops but also for poor fossil contents of the detrital intervals, fundamental for a good age attribution. In spite of these problems, the geometric organization of the tectonic units included in both the Sheets has been reconstructed as well as the chronology of the pre-thrusting extensional tectonics articulated in more events during the Mesozoic-Cenozoic. This tectonic activity dismantled the margin of the carbonate platform in different blocks, interrupting the continuity of the carbonate platform, which shows outcrops better exposed in the southern sector of the Isernia Sheet (Mt. Matese-M.te Cesima, Late Triassic-Cretaceous in age). The synsedimentary tectonics produced bio-lithoclastic bodies frequently recovered in the western sector of Matese Massif, in the Montagnola di Frosolone and Venafro Mt.

Margin and upper slope deposits are preferentially exposed along some carbonate ridges in the Castel di Sangro Sheet (Castelnuovo al Volturno and Castel San Vincenzo villages) testified by oolitic limestones, subordinate fenestral limestone/dolostone alternations and Ellipsactinia limestones for the Jurassic interval and by bioclastic calcarenites with Rudist and Orbitolina and detrital limestones with Rudists fragments and orbitoids for the Cretaceous time. On the other hand, the Mt. Marrone ridge, at the western boundary of the Castel di Sangro Sheet, appear to testify an intraplatform corridor hosting pelagic deposits in the Middle?-Late Triassic, composed of cherty dolostones and radiolarian cherts directly overlaid with Cretaceous detrital calcarenites and calcirudites.

These are just some examples of the very complex geology of the area analysed during the regional survey, at 1:50.000 scale, of the Isernia and Castel di Sangro sheets, within the CARG Project.

Geological map and palaeogeographic interpretation of the Monti Gemelli Meso-Cenozoic succession (Central Apennines, Italy)

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Keywords: olistoliths, pre-orogenic faults, Jurassic.

We present a new, detailed geological map of the Monti Gemelli Massif in the Central Apennines. The massif includes Montagna dei Fiori and Montagna di Campli, separated by the Salinello Valley, and is located along the eastern margin of the Laga Basin. The Monti Gemelli form a NNW-SSE-trending carbonate ridge composed of Meso-Cenozoic successions deformed during the Neogene Apennine orogeny. The present-day structure of the massif reflects a multiphase tectonic evolution, spanning from Early Jurassic Tethyan rifting through post-rift and pre-orogenic extensional stages to Neogene compressional deformation associated with the Apennine belt. During geological mapping, several key structural elements related to these tectonic phases were investigated, the most significant being the pre-orogenic Montagna dei Fiori Normal Fault and the Salinello Thrust. Particular attention was devoted to the interpretation of the Lower Jurassic stratigraphy, especially the scattered outcrops of the Calcare Massiccio, represented by five main exposures across the study area. The Monti Gemelli Massif has been the focus of numerous geological and structural studies over the past decades, particularly concerning the Lower Jurassic stratigraphy and the paleogeographic reconstruction of the basin in which the exposed sedimentary succession was deposited. Previous interpretations regarded the Calcare Massiccio outcrops either as fault-bounded structural highs (footwall blocks) related to Early Jurassic Tethyan rifting (Mattei, 1987; Storti et al., 2017) or as olistoliths emplaced within the pelagic basin during deposition of the Corniola (Di Francesco et al., 2010). To address this issue, multiple geological survey methods were integrated in order to achieve the most reliable interpretation of the Calcare Massiccio outcrops. The results of the new geological mapping support the interpretation of these bodies as olistoliths rather than as fault-bounded structural highs associated with Early Jurassic Tethyan rifting.

Di Francesco L. et al. (2010) - Contribution of different kinematic models and a complex Jurassic stratigraphy in the construction of a forward model for the Montagna dei Fiori fault-related fold (Central Apennines, Italy). Geological Journal, 45(5-6), 489-505, https://doi.org/10.1002/gj.1191.

Mattei M. (1987) - Analisi geologico-strutturale della montagna dei fiori (Ascoli Piceno, Italia centrale). Geologica Romana, 26, 327-347.

Storti F. et al. (2017) - Geological map of the partially dolomitized Jurassic succession exposed in the core of the Montagna dei Fiori Anticline, Central Apennines, Italy. Italian Journal of Geosciences, 136(1), 125-135, https://doi.org/10.3301/IJG.2016.05.

The arrangement of the Ernici Mts. shallow-water carbonate platform during the Maastrichtian-Paleocene interval: Insight from the geological mapping of the sheet 390 - Frosinone (CARG project)

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Keywords: K-Pg tectonic phase, Apennine carbonate platform, geological mapping.

The Cretaceous-Paleogene tectono-sedimentary evolution of the Latium-Abruzzi shallow-water carbonate platform (Apennine Platform) has been studied for decades by a plenty of authors, who have reported a substantial difference between the evolution of the inner carbonate platform environment and the platform edge environment. The former are typically characterized by a lack of sedimentation starting from the Santonian-Campanian (Paleogene hiatus) and a Miocene recovery in carbonate ramp facies, whereas the latter are represented by an Upper Cretaceous-Paleocene calciruditic facies followed by Eocene carbonate ramp and slope units. In this perspective, we present some "anomalies" observed during the geological mapping of Sheet 390 - Frosinone for the CARG project. One of the best exposed areas is in the San Casto hill, a small relief located at the southeastern margin of the Ernici Mts., in the city of Sora (FR). The base of the hill is characterised by a unit called "cyclothemic limestones with gastropods" (CCG - Berriasian *p.p*-lower Aptian *p.p.*), here the typical inner platform succession (Damiani et al., 1991a; Fabbi et al., 2023) belonging to this region is missing, instead an unconformable contact highlighted by an erosional surface separates CCG from the overlying unit "crystalline limestones" (CTN - Upper Cretaceous-Paleocene *p.p.*). The CTN litofacies reported in this area is made up of calciruditic limestone, often saccharoid, rich in sharp-edged lithoclasts of the Upper Cretaceous local succession, rudist and echinoids fragments, *Orbitoides* sp., *Siderolites* sp. and globorotaliids in reddish micritic pockets. This unit (CTN) belong to a platform edge environment and was never reported in unconformity on an inner platform unit (CCG). Upward CTN pass to "macroforaminifera calcarenites" (CFR) in particular to the member "nummulitids and discocyclinids calcarenites" (CFR1 - Paleocene *p.p.*-Eocene *p.p.*) through an erosional surface also characterised by the presence of neptunian dykes of CFR1 inside CTN. CFR1 has been found in other two localities of the sheet (Melfa gorges and Mt. Tartaro) overlying directly CCG. This particular geological setting could be possible only implying an Upper Cretaceous-Paleocene extensional tectonic phase (Vitale and Ciarcia, 2021), which allows the exhumation of Lower Cretaceous units and dismantles the carbonate platform and its edges during the Paleocene, in a drowning context witnessed by the presence of planktonic foraminifera (Tavani et al, 2015). The occurrence of CTN deposits in several Latium-Abruzzi carbonate platform areas, as well as to the south of the Latina Valley (Sgurgola, FR) and also given the presence of calciturbidites with *Orbitoides* sp. and *Siderolites* sp. in the "Tolfa Flysch" (FYT) can delineate a complex paleogeography driven by extensional tectonics occurred in the K-Pg interval.

Damiani A.V. et al. (1991a) - Elementi litostratigrafici per una sintesi delle facies carbonatiche meso-cenozoiche dell'Appennino centrale. Studi Geol. Camerti, vol spec. 1991/2, 187-214.

Fabbi S. et al. (2023) - Stratigraphy and tectonic evolution of a portion of the Simbruini-Ernici Mountains (Central Apennines-Italy). Review and new data from detailed geological mapping. Geol. F. Trips Maps, 15(2.3), 1-40, https://doi.org/10.3301/GFT.2023.08.

Tavani S. et al. (2015) - Transverse versus longitudinal extension in the foredeep-peripheral bulge system: Role of Cretaceous structural inheritances during early Miocene extensional faulting in inner central Apennines belt. Tectonics, 34(7), 1412-1430. https://doi.org/10.1002/2015TC003836.

Vitale S. & Ciarcia S. (2021) - The dismembering of the Adria platforms following the Late Cretaceous-Eocene abortive rift: A review of the tectono-stratigraphic record in the southern Apennines. International Geology Review, 64(20), 2866-2889, https://doi.org/10.1080/00206814.2021.2004559.

Towards a unified framework of the lithostratigraphy of the southern Apennines

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Keywords: lithostratigraphy, Southern Apennines, Italy.

The Southern Apennines represent one of the most complex and debated fold-and-thrust belts of the Mediterranean region. Despite about a century of geological investigations, studies and scientific publications, the lithostratigraphic framework of this orogenic system remains highly fragmented, with local and regional schemes often developed independently and based on heterogeneous criteria. In recent decades, a significant contribution to the attempt at terminological and conceptual homogenization of Italian stratigraphy has been provided by the CARG Project of the new Geological Map of Italy, which promoted shared criteria for the definition, revision, and correlation of lithostratigraphic units at the national scale, but difficulties related to geological complexity and long-standing regional research traditions are persisting. This lack of harmonization hampers large-scale correlations, tectonic reconstructions, and the integration of stratigraphic data into modern geological, geophysical, and geohazard-oriented studies.

This contribution aims to propose a unified lithostratigraphic framework for the Southern Apennines, integrating classical field geology with modern stratigraphic concepts and regional-scale synthesis. The proposed framework builds upon a critical revision of existing lithostratigraphic units, ranging from Mesozoic carbonate platform successions and basin deposits to Cenozoic foreland, foredeep, and wedge-top basin fills. Particular attention is paid to the hierarchical organization of lithostratigraphic units, the consistency of unit definitions across different tectonic domains, and the clear distinction between lithostratigraphic, biostratigraphic, and tectonostratigraphic criteria. The framework explicitly accounts for the complex superposition of allochthonous and para-autochthonous units, aiming to clarify long-standing ambiguities in the attribution and correlation of key formations.

The resulting unified scheme provides a coherent reference model that is scalable from outcrop to regional scale and adaptable to different applications, including tectonic modeling, basin analysis, seismic interpretation, and geo-environmental assessments. By promoting standardized terminology and correlation criteria, this approach contributes to improving communication within the scientific community and supports the integration of Southern Apennines lithostratigraphy into broader Mediterranean and circum-Mediterranean geodynamic models. Ultimately, the proposed framework represents a step toward a more robust and shared geological understanding of one of the most emblematic Southern Europe orogenic belts.

A preliminary methodological approach to evaluate slip rates from folding: A comparison with buried thrusts in the Po Plain (Italy)

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Keywords: Po Plain, strain analysis, slip rates.

In active fold-and-thrust belts, defining the slip rates of fault systems remains a major challenge in structural geology. While fault parameters such as fault dip, detachment depth, and overall structural architecture can be constrained along 2D seismic reflection data, the distribution of this information is often scattered. Conversely, the deformation recorded by shallow syn-tectonic strata (folding) can be easily imaged and is often provided as part of confidential data by oil & gas companies. In this contribution, we present preliminary results from a methodological approach developed to improve the likelihood of computing slip rates by using regional-scale horizons derived from geological modeling. Using kinematic modeling algorithms, we tested a variety of synthetic 3D models, recording the deformation associated with progressive slip increments of faults with variable dip and tip position. By unfolding the deformed stratigraphic horizons, we recorded the strain distribution for each model at each slip step. The goal is to assess the consistency of this relationship using as test cases some already-studied buried anticlines of the Po Plain (Northern Italy), where a thick Plio-Quaternary foredeep succession recorded the activity of underlying faults. Once tested and validated, this quantitative workflow may serve as a useful tool for application at a regional scale in the Po Plain and the Adriatic offshore, and in other similar tectonic settings worldwide.

Neogene to Quaternary evolution of the Segmented Hellenic foredeep between Corfu and Paxos (offshore Western Greece)

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Keywords: Hellenic foredeep, Adria plate, Ionian thrust.

This study is devoted to investigating the tectono-stratigraphic evolution of the Hellenic Foredeep in the northern Ionian Sea, focusing on the offshore sector between Corfu and Paxos islands. Based on the interpretation of vintage 2D seismic reflection profiles integrated with bathymetric data, we reconstruct the basin-infill history from the Oligocene to the Holocene, inferring the existence of a marked along-strike segmentation between the two areas. The stratigraphic architecture reveals that the foredeep developed over a complex Mesozoic-Eocene carbonate substrate characterized by inherited paleogeographic and structural heterogeneities. In the Corfu sector, the foredeep successions from the Oligocene-Miocene to the Holocene show a persistent syn-flexural geometry. These sequences form wedges that pinch out eastwards against a long-lived Mesozoic structural high which has been also affected by a Neogene SW-verging Hellenic blind thrust. This configuration is in agreement with previous regional structural studies in this sector (Chizzini et al., 2022, Soto et al., 2024; Rossetti et al., 2025). We interpret that this paleorelief effectively segmented the basin, acting as a structural barrier that conditioned sediment progradation toward the northeast and maintaining a flexure-dominated subsidence regime throughout the Neogene. In contrast, the Oligocene to Pliocene sequences in the Paxos sector were deposited above the Apulian Mesozoic carbonate platform, which experienced syncronous flexural subsidence. Here, from the Oligocene to the Pliocene, foredeep sequences were deposited over the Apulian carbonate platform during synchronous flexural subsidence. This tectonic setting changed during the Pleistocene-Holocene, when basin evolution was dominated by the continuous growth of a large anticline detached above Triassic evaporites. Isopach maps reveal that while depocenters maintained a general NW-SE trend, their magnitude and location shifted significantly through time, particularly in the Paxos sector. Following a Pliocene reduction in sediment thickness, the subsequent Pleistocene subsidence was driven by the uplift of the external Hellenic front. This process, linked to the salt-cored folding, led to a marked segmentation of the foredeep, where Pleistocene-Holocene deposits now form a syn-orogenic wedge, pinching-out toward the evolving fold. Our preliminary reconstruction of the evolution of the Hellenic Foredeep in both sectors suggests that the distribution of foredeep sedimentation was controlled by the interplay between inherited Mesozoic structures in the Apulian platform, differential flexural of this thick and rigid lower plate in response to the westward advance of the Hellenides orogen. We inferred that the Neogene segmentation of the Hellenic foredeep is controlled by two processes; namely, a N-S varying orogenic load and the local existence of thick accumulations of Triassic evaporites.

Chizzini N. et al. (2022) - Tectono-stratigraphic evolution of the offshore Apulian Swell, a continental sliver between two converging orogens (Northern Ionian Sea, Central Mediterranean). Tectonophysics, 839, 229544, https://doi.org/10.1016/j.tecto.2022.229544.

Rossetti F. et al. (2024) - Building the Albanides by Deep Underplating. Tectonics, 43, e2024TC008506, https://doi.org/10.1029/2024TC008506.

Soto J.I. et al. (2024) - Contrasting Styles of Salt-Tectonic Processes in the Ionian Zone (Greece and Albania): Integrating Surface Geology, Subsurface Data, and Experimental Models. Tectonics, 43(6), e2023TC008104, https://doi.org/10.1029/2023TC008104.

Depositional model of the slope to basin deposits in the external sector of the southern Apennines

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Keywords: abortive rift, preorogenic stratigraphy, sedimentary paleoenvironments.

We present a 3D model that shows the transition from emerged areas to slope and deep-basin sectors prior to Miocene orogenic shortening in the Apennine Platform-Lagonegro-Molise Basin system (Ciarcia & Vitale, 2025). It attempts to reconstruct a complete Late Cretaceous-Eocene geological framework that accounts for the tectono-stratigraphic and sedimentological evolution of the platform-slope-to-basin system in the external sectors (Vitale & Ciarcia, 2022). Starting from Maastrichtian time, the Apennine and Apulian platforms were affected by a critical extensional event that dismembered the shallow-water domain. This process resulted in the sinking of large parts of the platforms and the formation of calciclastic, marly, and clayey deposits. We illustrate the main features of these deposits and the sedimentary paleoenvironments. We reconstructed five main lithofacies: (i) shallow-water shelf deposits; (ii) debris- and grain-dominated apron deposits; (iii) calciclastic deposits dominated by slope resedimentation; (iv) slope-to-basin Scaglia-type deposits; (v) slope-to-basin varicolored clay sediments.

Vitale S. & Ciarcia S. (2022) - The dismembering of the Adria platforms following the Late Cretaceous-Eocene abortive rift: A review of the tectono-stratigraphic record in the southern Apennines. Int. Geol. Rev., 64(20), 2866-2889, https://doi.org/10.1080/00206814.2021.2004559.

Ciarcia S. & Vitale S. (2025) - Orogenic evolution of the northern Calabria-southern Apennines system in the framework of the Alpine chains in the central-western Mediterranean area. GSA Bull., 137(3-4), 1143-1176, https://doi.org/10.1130/B37474.1.

Integrated surface-subsurface mapping and geochemical data into a 3D Geological model of the SE termination of the Salsomaggiore structure (Northern Apennines foothills, Italy): Tectono-stratigraphic evolution and occurrence of unconventional Critical Raw Materials (CRMs)

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Keywords: Northern Appennines, mountain foothills, Critical Raw Materials.

In the context of the global energy transition and in compliance with recent directives on the sustainable management of georesources (DL n. 84/2024), high-resolution characterization of subsurface structural and stratigraphic architecture has become a strategic priority for each national territory.

This study analyzes the Salsomaggiore Structure (Northern Apennines foothills, Italy), to investigate the interaction between polyphase tectonic evolution and the circulation of mineralized fluids within mountain frontal ranges of foreland basin systems.

A multidisciplinary approach was adopted, integrating literature data (Di Dio et al., 2005), new surface geological mapping, interpretation of seismic reflection profiles, and geochemical analyses (e.g., Mezzadri, 1990). This integration allowed for the reconstruction of the deep architecture of the structure and the development of a 3D geological model focused on the south-eastern termination of the structure.

The reconstruction demonstrates that the current geochemical characters and distribution of the brine waters are strictly dependent on the polyphase tectonic and erosive evolution undergone by the Salsomaggiore Structure from the Messinian to the Present. Although the entire area shared a common depositional and structural setting, since the latest Messinian, after the emplacement of the Intra-Messinian Chaotic Complex which favored the trapping of fossil brines. The growing anticline generated differential uplift and erosion inducing marked sectoral differentiation. In the north-western sector (Salsomaggiore Terme), the preservation of an impermeable seal (Lugagnano Clay - Lower Pliocene) ensured the isolation of Miocene units, protecting the original brines from external contamination. Conversely, in the central (Tabiano and Contignaco) and south-eastern (Sant'Andrea Bagni) sectors, higher uplift rates, erosion, and increased fracture density compromised the integrity of the geological seals. This triggered mixing processes between fossil waters, meteoric recharge, and resedimented evaporitic units, leading to the formation of variably sulfurous and diluted saline-iodine fluids.

This study links the evolution of the Salsomaggiore anticline to the distribution of waters enriched in Critical Raw Materials (CRMs; e.g., B, Li, and Sr; Cioce et al., 2025) and demonstrates that the geometry of geological bodies and the timing of tectonic-erosional exhumation are primary controls on the accumulation and preservation of unconventional CRM deposits, providing a predictive model for analogous settings along the Apennine Front and in fold-and-thrust belts worldwide. Furthermore, it shows that integration of basic geological methodologies is needed for the sustainable exploration of critical mineral resources and natural resources in general.

Cioce S. et al. (2025) - Understanding the Geology of Mountain Foothills Through Hydrogeochemistry: Evaluating Critical Raw Materials' Potential for the Energy Transition in the Salsomaggiore Structure (Northwestern Apennines, Italy). Minerals, 15(9), 936, https://doi.org/10.3390/min15090936.

Di Dio G. et al. (2005) - Note Illustrative della Carta Geologica d'Italia Scala 1: 50.000, F. 199 Parma Sud. S.EL.CA. Firenze.

DL n. 84/2024: Programma Nazionale di Esplorazione Mineraria, Approvato 01.07.2025, Art. 10, DL n. 84/2024. Available online: https://www. isprambiente.gov.it/files2025/attivita/pne_finale.pdf.

Mezzadri P. (1990) - Le Acque Minerali della Provincia di Parma; Roberto De Nicola editore: Napoli, Italy.

Jurassic submarine labyrinths: Tethyan rift architecture and calciturbidite dispersal in the Sibillini Mountains (Central Apennines)

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Keywords: Jurassic Rift, calciturbidites, geological mapping.

The Mesozoic evolution of the Central-Northern Apennines is fundamentally tied to the complex interplay between extensional tectonics and pelagic sedimentation. Deciphering this system is essential for integrating stratigraphy and geodynamics into modern geological mapping, offering critical insights into the long-term evolution of Tethyan margins and providing analogues for subsurface resource management in a sustainable future. This study investigates how the rugged palaeotectonic architecture inherited from the Early Jurassic rift governed the dispersal of shallow water-derived calciturbidites in the Sibillini Mts.

This study aims at reconstructing the Jurassic paleotectonics and palaeogeography of the Sibillini sector and demonstrate how submarine topography forced the pathways of resedimented neritic material for over 40 million years (see also Cosentino et al., 1982; Galluzzo & Santantonio, 2002; Santantonio et al., 2017; Cipriani et al., 2020). Methodology integrates high-resolution geothematic field mapping (1:10,000 scale) with bed-by-bed stratigraphic and sedimentological analyses of the Mesozoic succession.

The study reveals that the complex pattern of intrabasinal highs (Pelagic Carbonate Platforms—PCPs) and intervening basins acted as a primary filter. A clear "shelter effect" is documented where basins lying downflow of PCPs remained resediment-free, while marginal palaeoescarpments formed obstacles that deflected flows or triggered sediment discharge at their toes. Some calciturbidites also exhibit sedimentary structures with double kinematics (downflow and upflow), suggesting reflection. Conversely, some flows were vigorous enough to climb these escarpments, leaving overbank deposits on the PCP tops. The Lazio-Abruzzo Carbonate Platform is considered the primary source for these calciturbidites, but shedding from carbonate platforms currently buried under the Adriatic Sea must also be considered for the northern Sibillini sector.

These findings demonstrate that submarine rift morphology is a long-lasting feature in pelagic environments, significantly outliving the active rifting stage. The analysis of resedimented carbonates allows reconstructing the Mesozoic palaeogeography also for sectors where syn- and post orogenic tectonics deformed or partly obliterated the original Jurassic depositional architecture. By focusing on the Sibillini Mts, this work refines the palaeogeographic models of the Central Mediterranean and provides a robust outcrop analogue for characterizing buried hydrocarbon reservoirs.

Cipriani A. et al. (2020) - Geological mapping reveals the role of Early Jurassic rift architecture in the dispersal of calciturbidites: New insights from the Central and Northern Apennines. Basin Research, 32(6), 1485-1509.

Cosentino D. et al. (1982) - Megabrecce, flussotorbiditi e serie ridotte di Forca Canapine (F. 132 Norcia). Rendiconti della Società Geologica Italiana, 5(1), 45-50.

Galluzzo F. & Santantonio M. (2002) - The Sabina Plateau: a new element in the Mesozoic palaeogeography of Central Apennines. Bollettino della Società Geologica Italiana, 1(2), 561-588.

Santantonio M. et al. (2017) - Discussion on «Geological map of the partially dolomitized Jurassic succession exposed in the central sector of the Montagna dei Fiori Anticline, Central Apennines, Italy» by G. Storti, F. Balsamo & A. Koopman (2017). Italian Journal of Geosciences, 136(2), 312-316, https://doi.org/10.3301/IJG.2017.09.

Tectono-stratigraphic evolution of a sector of the eastern Monferrato (Northern Apennines): new insights from the Sheet 158 “Casale Monferrato” (CARG Project)

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Keywords: CARG, geological mapping, Northern Apennines evolution.

The tectono-stratigraphic evolution of the northwestern sector of the eastern Monferrato, Northern Apennines, is characterized by the interaction between sedimentation and polyphases tectonic deformation from the Late Cretaceous to the Pliocene. New geological mapping carried out within the CARG Project on Sheet 158 “Casale Monferrato” provides updated insights into the structural-stratigraphic architecture and evolution of this area.

The stratigraphic succession consists of upper Eocene-Miocene Epiligurian deposits unconformably overlying the External Ligurian Units, which represent the remnants of the Alpine accretionary wedge. The Ligurian Units commonly consist of stratally disrupted successions with a block-in-matrix fabric (i.e., broken formations). Such an arrangement reflects intense deformation during the evolution of the orogenic wedge and testifies to the complex structural reorganization that affected the Ligurian Domain prior to the deposition of the Epiligurian succession. The Ligurian Units generally crop out in the cores of fault-bounded anticlines, suggesting that tectonic uplift and compressional reactivation played a key role in their present-day exposure and structural configuration.

The Epiligurian succession has been subdivided into four major Unconformity-Bounded Stratigraphic Units (UBSUs), separated by regionally significant erosional and angular unconformities recording prominent tectono/sedimentary evolutionary steps. The oldest unit is represented by upper Eocene hemipelagic marls of the Monte Piano Formation. These sediments are unconformably overlain by the Rupelian-Aquitanian Cardona and Antognola formations, strongly deformed by WNW-oriented transpressive faults, which were active during the Oligocene-Early Miocene. Above an angular unconformity, the Burdigalian-Serravallian Pietra da Cantoni Formation records the evolution of a shallow water carbonate ramp. A further tectonic phase is marked by the angular unconformity at the base of the Tortonian-lower Messinian hemipelagic sediments of the Sant’Agata Fossili Marls Formation. These are overlain by the evaporitic deposits of the Vena del Gesso Formation. Late Messinian post-evaporitic deposits and the Zanclean marine Argille Azzurre Formation are observed at the top of the successions.

The cross-cutting relationships between tectonic structures and stratigraphic unconformities suggest a complex polyphase evolution from the Late Cretaceous-early Eocene to the early Pliocene, controlling the accommodation space and the stratigraphic pattern, ultimately shaping the present-day geological framework of the study area. Ongoing fieldwork and seismic interpretation will provide new constraints on the geodynamic evolution of this sector of the eastern Monferrato, further improving the reconstruction of its tectono-sedimentary evolution.

The Arpino 1 borehole: new data on the lower Messinian deposits of the 390-Frosinone sheet (CARG project)

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Keywords: Central Apennines, early Messinian, borehole stratigraphy.

Near Arpino (FR), Cacciamali (1892) and Carrara & Conato (1990) documented the presence of marine marls and clays, which were exploited for brick production until the 1990s. However, these deposits were not presented in the Sheet 160 Cassino (Servizio Geologico d'Italia, 1966), and the previously described outcrops are no longer accessible. For this reason, whithin the CARG 390-Frosinone project, a stratigraphic borehole was drilled (Arpino 1) at "*Le fornaci"* site to recover a continuous sediment core from the Arpino clays.

The borehole consists of a 31.50-meter-long sediment core, predominantly composed of dark gray clays from the bottom up to - 8.70 m below ground level (b.g.l.) At this depth, a distinct color transition to beige is observed. Between 5.70 m up and 2.40 m b.g.l., well-rounded carbonate pebbles appear within the clay. The uppermost interval contains angular carbonate clasts and brick fragments.

Samples were collected for micropaleontological analysis of ostracods and foraminifera (80) and calcareous nannofossil (54). The benthic foraminifera assemblages range from relatively diversified to poorly diversified or oligotypic, and are dominated by *Cribroelphidium translucens*, *Ammonia beccarii*, *Elphidium granosum*, and *Ammonia parkinsoniana*. The planktonic foraminifera are scarce and include *Globorotalia suterae*, *Globorotalia miotumida,Globorotalia nicolae,* and*Turborotalita multiloba*. The planktonic-to-benthic (P/P+B) ratio is consistently very low (0-7%), indicating deposition in infralittoral environment, with a further decrease toward the top of the core. Ostracod assemblages show low biodiversity and include *Cytheridea arca*, *Aurila albicans*,*Keijella lucida, Callistocythere* spp.*, Leptocythere* sp.*,* and *Graptocythere* sp.*,* suggesting restricted and environmentally stressed marine conditions. Evidence of ecological stress, likely linked to increasing salinity, is also provided by the dominance, in the middle of the sediment core, of *Cribroelphidium translucens*(78.8% of the benthic foraminifera) and the abundance of opportunistic taxa such as *Braarudosphaera bigelowii*.

The occurrence of *G. nicolae* points to the early Messinian (MMi 13b; Lirer et al., 2019), and the presence of *T. multiloba*indicates an age not older than 6.42 Ma (FCO *T. multiloba*; Lirer et al., 2019). The influx events of *Helicosphaera sellii*(6.48-6.30 Ma) and *Braarudosphaera bigelowii* (6.168 Ma) further tie the age of the sediment core to the early Messinian. These chronostratigraphic indications are consistent with the findings, up to the top of the core, of *Cytheridea arca* and *Aurila albicans*, which occur from the Tortonian to the early Messinian. Notably, in the Legnagnone section (northern Apennines) the last occurrence of *Aurila albicans* occurs at ca. 6.12 Ma, just before the onset of the Messinian salinity crisis.

Cacciamali G.B. (1892) - Geologia arpinate. Boll. Soc. Geol. It., 11, 293-333.

Carrara C. & Conato V. (1990) - Nuovi dati sul Miocene superiore dell'area laziale-abruzzese meridionale: affioramenti di Arpino e Monte S. Giovanni Campano (Frosinone, Italia centrale). Mem. Descr. Carta Geol. d'It., 38, 77-84.

Servizio Geologico d'Italia (1966) - Carta Geologica d'Italia alla scala 1:100.000, Foglio 160-Cassino. Litografia Artistica Cartografica, Firenze.

Lirer F. et al. (2019) - Mediterranean Neogene planktonic foraminifer biozonation and biochronology. Earth-Science Reviews, 196, 102869.

Rejuvenating the Tethyan passive margin: integrating Early Cretaceous syn-sedimentary tectonics into the Alps-Apennines geodynamic evolution

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Keywords: mass-transport deposits, geodynamics, geological mapping.

The geodynamic evolution of the Adria plate, a cornerstone for understanding the Alps-Apennines system, has long been framed by the Early Jurassic rifting phase. While subsequent Mesozoic periods were traditionally viewed as tectonically quiescent, emerging evidence reveals that the late Early Cretaceous was a time of significant supra-regional tectonic activity. Understanding these events is not only crucial for refining regional geodynamic models but also for defining the subsurface architecture necessary for a sustainable future in terms of resource management and territorial planning. This study aims to characterize the sedimentological and stratigraphic markers of Early Cretaceous extensional tectonics within the Umbria-Marche-Sabina domain, highlighting how these processes remodeled the Tethyan passive margin. The methodology employs an integrated approach combining high-resolution geological mapping with detailed litho-biostratigraphy. Several stratigraphic sections across the Central and Northern Apennines were analyzed, utilizing planktonic and benthic foraminifera, calcareous algae, and nannofossil assemblages to provide precise chronological constraints for tectonic events. The results identify a significant clustering of mass-transport deposits, including slumps, rock-falls, and debris flows, primarily concentrated within the Barremian-early Aptian interval. Key findings include the occurrence of coarse-grained detrital bodies (e.g., Mt. Primo, Montagna dei Fiori and Narni-Amelia Ridge), locally containing lithoclasts derived from both Lower Jurassic/Cretaceous shallow-water platforms and exhumed Jurassic pelagic carbonate platforms (PCPs). The presence of neptunian dykes, mineralized veins, and abrupt thickness variations in the Barremian Maiolica formation further supports a model of fault-driven rejuvenation of inherited Jurassic structures. This research refines the transition from Tethyan extension to the inception of Alpine compression, demonstrating that the Early Cretaceous was a period of active crustal remodeling. Such high-resolution stratigraphic and structural insights are fundamental for accurate subsurface modeling, which is essential for the sustainable management of geo-resources, such as groundwater and energy targets, in complex fold-and-thrust belts.

First record of the Cenomanian-Turonian "Filament Event" in the Umbria-Marche-Sabina Basin (Central Italy)

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Keywords: filament Event, Cenomanian-Turonian boundary, Umbria-Marche-Sabina Basin

The occurrence of thin-shelled pelagic bivalves, commonly referred to as "filaments" or "Posidonia", is well known from Jurassic pelagic successions of the Tethyan domain (Conti & Monari, 1992). Within the Umbria-Marche-Sabina Basin (UMSB), these fossils are particularly common in the Rosso Ammonitico and Calcari e Marne a Posidonia formations, whereas similar occurrences have never been reported so far from younger pelagic deposits.

The so-called "Filament Event" has been described in the literature (i.a. Negra et al., 2011; Kędzierski et al., 2012; Mülayim et al., 2021) as a global-scale phenomenon characterized by the widespread occurrence of thin-shelled pelagic bivalves of uncertain taxonomic affinity across the Cenomanian-Turonian boundary interval, especially within the *Whiteinella archaeocretacea* and *Helvetoglobotruncana helvetica* planktonic foraminiferal biozones.

In this work, we present the first evidence of "Filament Event" within the Upper Cretaceous Scaglia Bianca and Scaglia Rossa formations of the UMSB. To investigate the occurrence and possible areal distribution of the Cenomanian-Turonian "Filament Event" several stratigraphic sections located in different sectors of the UMSB were studied in detail: Cava del Furlo (Marchean Ridge), La Roccaccia (Mt. Petrano, Umbria-Marche Ridge), Fiastra Lake and Borgiano (Sibillini Mts.), and Salinello Gorge (Montagna dei Fiori). Each section is approximately 20 m thick and includes the Bonarelli Level (OAE2), with nearly 10 m of stratigraphy both below and above the level, providing continuous and well-exposed intervals suitable for detailed investigation.

Additional occurrences of thin-shelled bivalves have been identified in several localities of the UMSB, including Mt. Moria, Sabini Mts. and Narnese-Amerina Ridge. Although these localities were not investigated with the same level of stratigraphic detail as the three selected sections, they are reported here to highlight the wider distribution of the event within the UMSB.

Conti M.A. & Monari S. (1992) - Thin-shelled bivalves from the Jurassic Rosso Ammonitico and Calcari a Posidonia Formations of the Umbrian-Marchean Apennine (Central Italy). Paleopelagos, 2, 193-213.

Kędzierski M. et al. (2012) - Bio-events, foraminiferal and nannofossil biostratigraphy of the Cenomanian/Turonian boundary interval in the Subsilesian Nappe, Rybie section, Polish Carpathians. Cretaceous Research, 35, 181-198.

Mülayim O. et al. (2021) - 'Filament' marker beds in the Karababa-a member (Turonian) of the Arabian platform, SE Turkey: palaeo-environmental significance, stratigraphy and correlation potential. Proceedings of the Geologists' Association, 132, 188-198.

Negra M.H. et al. (2011) - The filament event near the Cenomanian-Turonian boundary in Tunisia: filament origin and environmental signification. Bulletin de la Société géologique de France 182(6), 507-519.

Mapping the unmappable: mélanges and their significance in the tectono-stratigraphic and geodynamic evolution of the Alps-Apennines system

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Keywords: mélanges, geological mapping, orogenic belts.

Mélanges and chaotic rock units are a fundamental yet intrinsically complex component of the Alps-Apennines system and of exhumed subduction complexes in both ancient to modern settings worldwide. They form through diverse processes (tectonic, sedimentary and diapiric), producing chaotic rock units characterized by a diagnostic block-in-matrix fabric, whose composition and internal organization reflect their geodynamic setting of formation. However, during the multistage evolution of convergent margins, these processes commonly alternate and interact, progressively overprinting and reworking primary fabrics and leading to the development of polygenetic mélanges. Although such processes may be intimately interlinked, tectonic deformation typically represents the latest and most pervasive overprint, imparting a block-in-matrix architecture that may be indistinguishable from that of primary tectonic mélanges. This convergence in structural appearance underlies a long-standing debate on the origin of chaotic rock units, namely whether they derive from tectonic mixing at different structural levels or from the tectonic reworking of primary mass-transport deposits, and significantly hampers their recognition and mapping, thereby limiting our understanding of the tectono-stratigraphic and geodynamic evolution of orogenic belts and exhumed subduction complexes.

Here we present a synthesis of several years of field-based structural and stratigraphic investigations, and geological mapping, carried out across a range of geological settings, aimed at constraining the origin and significance of mélanges in the Alps-Apennines system. Our results highlight a systematic relationship between distinct types of chaotic units and specific formative processes (tectonic, sedimentary, diapiric and polygenetic), operating throughout the evolution of the system, from Mesozoic rifting to late Cenozoic collisional and post-collisional stages. This relationship demonstrates that mélanges and chaotic rock units are not anomalous and "unmappable" features, but rather key markers of tectono-stratigraphic and geodynamic events. Their temporal recurrence and spatial distribution provide valuable constraints on the frequency, timing and style of deformation and sedimentation during convergent margin evolution. Therefore, discriminating among mélange-forming processes and defining their structural position are essential steps for reconstructing the architecture and evolution of orogenic belts and exhumed subduction complexes, as well as for improving the reliability of geological mapping (e.g., within national programs such as the CARG project), with important scientific, societal, and environmental implications.

Maso-Cenozoic sedimentary evolution of a tectonically vontrolled slope in South-Western Sicily (Italy)

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Keywords: tectonically controlled slope, meso-cenozoic, paleogeographic evolution.

The study area is located North of the town of Sciacca (AG), in the SW sector of Sicily, and includes two inactive quarries, separated by a few meters, where the analyzed succession is particularly well exposed. The sector lies in the outermost portion of the Sicilian fold-and-thrust belt, a geologically complex structure characterized by phases of compressive and extensional deformation spanning from the Mesozoic to the Cenozoic (Catalano et al., 2000). The regional geological setting is characterized by a complex stacking of tectonic units, including Jurassic platform carbonates, Mesozoic pelagites, and Cenozoic terrigenous deposits (Sulli et al., 2024). The main objective of this study is therefore to reconstruct the tectono-sedimentary evolution of the sector, with particular emphasis on defining depositional processes and paleoenvironmental changes through geological time. To this aim, intensive sampling was carried out, followed by laboratory analysis, along with the collection of structural data on bedding orientations and kinematic indicators present on discontinuity surfaces. The outcrops in the quarries provide the opportunity to directly observe sedimentary relationships and deformational structures over a limited spatial interval (approximately 30 m, from the quarry floor to road level), allowing detailed stratigraphic correlations between them. This study specifically highlights the presence of pelagic sedimentation from the Jurassic to the Upper Cretaceous, where extensional tectonics led to the formation of tectonically controlled escarpments active throughout this period. Following the deposition of shallow-marine units during the Late Oligocene-Early Miocene, these scarps were reactivated under compressive stress, leading to the deposition of more recent units (Pliocene) with divergent geometries. In particular, the exposure of the quarry faces reveals a discordant stratigraphic contact between the carbonate platform unit and a depositional environment unit attributable to a pelagic carbonate platform or pelagic plateau. Laterally, an erosional surface is present, upon which the pelagic lithologies—from the Lower Jurassic to the Upper Cretaceous—rest at high inclinations, all displaying brecciated textures. The surfaces observed between the various units have been interpreted as depositional paleoscarps controlled by tectonics, now tilted during compressive deformation events that developed after the Upper Oligocene-Lower Miocene. These events were responsible for the syn-tectonic deposition of the most recent (Pliocene) units of the succession. The presence of shallow-marine deposits from the Upper Oligocene-Lower Miocene, in near concordance and with inclinations and dips similar to those of the underlying pelagic environment unit dated to the Upper Cretaceous, indicates that scarp sedimentation remained active until the Lower Miocene, with repeated reactivations from the Upper Jurassic to the Upper Cretaceous.

Catalano R. et al. (2000a) - Central western Sicily structural setting interpreted from seismic reflection profiles. Mem. Soc. Geol. It., 55, 5-16.

Sulli A. et al. (2024) - Note Illustrative della Carta Geologica d'Italia alla scala 1:50.000, F. 628 Sciacca. 307 pp.

Unraveling shallow active fault geometry in the Southern Apennine fold-and-thrust belt: the Postiglione fault system

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Keywords: active tectonics, Southern Apennine, GPR.

The Calore River Valley represents a key sector of the Southern Apennine fold-and-thrust belt, where the superimposition of Late Cretaceous to Quaternary tectonic phases produces a complex stratigraphic and structural architecture. The valley is underlain by Mesozoic Apennine Carbonate Platform limestones and dolostones, overlain by Cenozoic pelagic sediments of the Lagonegro-Molise Basin, wedge-top basin deposits, and Pleistocene-Holocene fluvial and slope deposits. Five terrace orders record alternating phases of tectonic uplift, volcanic activity (notably the Campanian Ignimbrite at 39 ka), and alluvial aggradation, with recent geochronological constraints indicating that the youngest deposits (

Di Bucci D. et al. (2006) - Relay Ramps in Active Normal Fault Zones: A Clue to the Identification of Seismogenic Sources (1688 Sannio Earthquake, Italy). GSA Bull., 118, 430-448, https://doi.org/10.1130/B25783.1.

Famiglietti N.A. et al. (2025) - Low-Frequency Ground Penetrating Radar for Active Fault Characterization: Insights from the Southern Apennines (Italy). Remote Sensing, 17(21), 3631, https://doi.org/10.3390/rs17213631.

Imaging the shallow architecture of the Ufita River Valley (Southern Apennines, Italy): Low-frequency GPR constraints on tectonics of an intra-montane basin

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Keywords: Ground Penetrating Radar, Ufita Fault System, seismic hazard.

The Campania sector of the Southern Apennines represents one of the most geologically complex and seismically hazardous domains in the Mediterranean, where the superposition of Late Cretaceous-Neogene tectonic phases and Pleistocene extensional tectonics produces a deeply heterogeneous crustal architecture. Active normal faulting within this orogenic belt was responsible for catastrophic historical earthquakes, including the 1857 Basilicata (Mw 7.0) and 1980 Irpinia (Mw 6.9) events, yet many seismogenic sources remain poorly constrained at shallow depths where Quaternary deposits mask bedrock structures. The Ufita Valley stratigraphy consists of pre-Pliocene flysch units overlain by Pliocene wedge-top basin deposits. Pleistocene alluvial and slope deposits are followed by late Pleistocene fluvio-lacustrine sediments. Fluvial terraces from the late Pleistocene to Holocene record alternating aggradation and incision phases driven by climate and ongoing tectonic uplift. Triangular facets, flat-iron ridges, and structural-controlled slopes, can be interpreted as clues of activity of the Ufita Fault System. In this context, GPR represents a non-invasive, high-resolution tool ideally suited for imaging shallow subsurface structures in areas covered by thick heterogeneous deposits. Its capability to detect stratigraphic and structural discontinuities, such as fault planes, fracture zones, and horizons offset, has proven effective in similar geological settings, where low-frequency GPR successfully resolved active faults within carbonate and sedimentary sequences, refining the regional seismotectonic framework (Ercoli et al., 2021; Famiglietti et al., 2025). This study applies low-frequency Ground Penetrating Radar (GPR) to image the shallow architecture of the Ufita Valley. Ten GPR profiles totaling ∼1900 m were acquired using different survey geometries, achieving penetration depths from ∼5 m to ∼50 m through a heterogeneous sedimentary succession. A rigorous processing workflow enabled centimeter-accurate subsurface mapping. Novel biostratigraphical data aid in constraining the interpretation of geological units cropping out across the Ufita River. Radargrams reveal steeply dipping ENE-WSW to E-W truncations of pre-Quaternary and Quaternary reflectors. These GPR-derived features define a tectonic architecture with distributed deformation that was previously unrecognized from meso-scale observations and local paleoseismological surveys, revealing the recent tectonics of the Ufita Valley. GPR imaging combined with regional geology reveals shallow evidence of recent tectonics, linking buried faults to historical seismicity and improving seismic hazard assessment in the Campania sector of the Southern Apennines.

Ercoli M. et al. (2021) - Ground-Penetrating Radar Signature of Quaternary Faulting: A Study from the Mt. Pollino Region, Southern Apennines, Italy. Solid Earth, 12, 2573-2596, https://doi.org/10.5194/se-12-2573-2021.

Famiglietti N.A. et al. (2025) - Low-Frequency Ground Penetrating Radar for Active Fault Characterization: Insights from the Southern Apennines (Italy). Remote Sensing, 17(21), 3631, https://doi.org/10.3390/rs17213631.

Sea-Level change and vertical land motion in foredeep settings: Late Pleistocene-Holocene evidence from the Metaponto coastal plain (Southern Italy)

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Keywords: tectonics/sea-level changes, foredeep settings, Southern Apennines.

This study reconstructs the Late Quaternary evolution of the Metaponto coastal plain (southern Italy), located in the Southern Apennines foredeep, where stratigraphy reflects the interaction between glacio-eustatic sea-level changes and vertical land motion (uplift, subsidence, and compaction). A multi-proxy approach is applied to a 22 m sediment core (Meta 1), integrating stratigraphy, sedimentology, grain-size analysis, and limited radiocarbon dating.

Four depositional units (DU1-DU4) document a transition from offshore to continental environments. DU1 (~16.6-10.5 kyr BP) records transitional-offshore settings with fine sand and silty deposits, abundant marine macrofossils, and poor sorting, indicating suspension-dominated sedimentation during post-glacial transgression. Grain-size distributions show long fine tails, consistent with low-energy marine conditions (Folk & Ward, 1957).

Above an erosional surface, DU2 marks a shift to higher-energy coastal environments, including shoreface, foreshore, and aeolian dunes. Improved sorting and sand-dominated textures reflect tractional processes and shoreline progradation. DU3 records alternating lagoonal and aeolian/beach facies, indicating shoreline oscillations and repeated back-barrier infill. DU4 consists of lagoonal and pedogenized deposits, marking final emergence of the coastal plain.

Grain-size analysis, supported by principal component analysis (PCA) and k-means clustering, identifies two main end-members: sand-dominated (tractional) and mud-enriched (suspension-influenced) facies. These broadly correspond to coastal versus offshore/lagoonal environments, although overlaps occur where different settings share similar textures (Visher, 1969).

Correlation with the nearby MSB borehole provides a late Holocene constraint (~3.7 kyr BP) for beach-dune development landward of the present coastline (Corrado et al., 2022). Comparison with global sea-level curves indicates significant uplift during the Late Glacial-early Holocene (up to a few mm/yr), followed by relative stability and late Holocene subsidence (~1 mm/yr), likely influenced by sediment compaction (Caputo et al., 2010).

Overall, the Meta 1 succession records a three-phase evolution: (i) transgressive offshore sedimentation, (ii) development of coastal and aeolian systems, and (iii) lagoonal infill and coastal progradation. The study highlights the combined role of eustasy and tectonics in shaping coastal stratigraphy, while noting that sparse chronological control limits precise quantification of vertical land motion.

Caputo R. et al. (2010) - Ionian marine terraces of southern Italy: Insights for the quaternary geodynamic evolution of the area. Tectonics, 29, TC4005, https://doi.org/10.1029/2009TC002625.

Corrado G. et al. (2022) - Late Quaternary evolution of the Metaponto coastal plain, southern Italy, inferred from geomorphological and borehole data. Quaternary International, 638-639, 84-110, https://doi.org/10.1016/j.quaint.2022.01.008.

Folk R.L. & Ward W.C. (1957) - A Study in the Significance of Grain-Size Parameters. Journal of Sedimentary Petrology, 27, 3-26, https://doi.org/10.1306/74D70646-2B21-11D7-8648000102C1865D.

Visher G.S. (1969) - Grain-Size Distribution and Depositional Processes. Journal of Sedimentary Petrology, 39, 1074-1106.

Tectono-stratigraphic architecture and depocenter evolution of the Miocene Marnoso-arenacea foredeep (Umbria, Italy), data from the new CARG projects

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Keywords: Umbria Apennines, foreland basin systems, Marnoso-arenacea foredeep.

The Marnoso-arenacea Basin (MaB) represents a Miocene foredeep turbidite system, whose interpretation is fundamental for reconstructing the geodynamic evolution of the Northern Apennines. In this study, we synthesize a large amount of data, derived from integrated multiple analytical approaches, in order to investigate the stratigraphic successions outcropping in key areas of the Umbria pre-Apennines, with the aim of highlighting the main depositional and deformational events and the mutual relationships between tectonics and sedimentation in the Miocene MaB.

The research integrates detailed geological mapping, physical stratigraphy (26 sections), biostratigraphic analyses of calcareous nannofossils assemblages (over 450 samples), petrographic characterization of sandstones, and interpretation of subsurface data, including a set of commercial seismic sections and borehole information.

The results of our analyses demonstrate that MaB succession is organized into several tectono-stratigraphic units (Afra-Mt. Verde, Pietralunga- Gubbio-Valtopina, and Mt. Vicino), characterized by significant lateral variations in thickness, facies associations, and sandstone composition. These variations reflect the influence of active tectonics on basin physiography, controlling sediment dispersal, depocenter migration, and accommodation space.

Integration of surface and subsurface data reveals a complex foredeep evolution marked by progressive foreland-ward migration of depocenters, the occurrence of intra-basin structural highs, and by a significant role of syn-sedimentary tectonics. In addition, new stratigraphic and structural information, highlight the strong longitudinal variability of the basin physiography. The timing of basin development and deformation phases has been refined, highlighting the diachronous onset of foredeep conditions across the different tectonic units and the progressive deactivation of western sectors linked to thrust emplacement.

These results provide new constraints on the tectono-stratigraphic framework of the Umbria-Romagna foreland basin and confirm the Northern Apennines as a natural laboratory for understanding the interplay between sedimentation and tectonics in collisional orogenic systems.

Inherited rift architecture, thrusting, and active normal faulting in the Umbria-Marche Apennines, Italy: New insights from 3D structural modelling within the framework of the CARG Project

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Keywords: 3D structural modelling, thrust and normal fault linkage, Umbria-Marche Apennines.

The Umbria-Marche sector of the Northern Apennines is a natural laboratory for investigating how inherited rift architecture, mechanical stratigraphy, and crustal rheology control deformation during contractional and extensional stages. It records Neogene shortening of the Adria passive-margin succession followed by Quaternary post-orogenic extension and active normal faulting. We integrate field structural data, borehole-calibrated seismic interpretation, balanced and restored cross-sections, gravity modelling, and 3D structural modelling to reconstruct crustal architecture and fault-system organization.

The contractional architecture is best explained by a ramp-dominated structural style, rather than by displacement along a regionally continuous shallow décollement (Butler & Mazzoli, 2006). Shortening was mainly accommodated by thrust ramps cutting the sedimentary succession and linking downward into the upper crustal basement. Deformation was partitioned among thrust slip, folding, and distributed strain within a heterogeneous carbonate-siliciclastic multilayer. Along-strike variations in ramp geometry, displacement gradients, fold architecture, and linkage patterns indicate that thrust segmentation was controlled by inherited Mesozoic extensional faults, stratigraphic thickness variations, and competence contrasts (Tavarnelli et al., 2019).

The later extensional overprint is expressed by NW-SE to NNW-SSE striking, high-angle normal-fault systems that dissect the inherited fold-and-thrust stack. Throw profiles and displacement-length scaling from the 3D model indicate progressive fault growth by segment interaction and linkage. The Monte Vettore-Monte Bove, Monte Fema, and Norcia-Preci systems show different degrees of maturity, from integrated fault corridors to asymmetric and segmented arrays.

Cross-cutting relationships indicate that active normal faults mostly cut across older thrusts instead of systematically reactivating them through negative inversion (Porreca et al., 2020). Their distribution nevertheless suggests that post-orogenic extension was influenced by deeper crustal inheritance related to the Mesozoic rift template. Gravity-constrained sections and earthquake hypocenter distributions show that active deformation is mainly confined to the brittle upper crust, with seismicity concentrated between about 3 and 12 km depth and controlled by contrasts involving the Anidriti di Burano Formation, the Verrucano Group, and the crystalline basement.

Overall, the Umbria-Marche Apennines record polyphase reworking of an inherited passive-margin crust, where pre-orogenic architecture governed thrust localization during Neogene shortening and later influenced normal-fault segmentation, linkage, and seismogenesis.

Butler R.W.H. & Mazzoli S. (2006) - Styles of continental contraction: A review and introduction. In Styles of Continental Contraction, Geological Society of America Special Paper 414, https://doi.org/10.1130/2006.2414(01).

Tavarnelli E. et al. (2019) - The role of structural inheritance in the evolution of fold-and-thrust belts: Insights from the Umbria-Marche Apennines, Italy. In Koeberl, C., and Bice, D. M., eds., *250* Million Years of Earth History in Central Italy. Geological Society of America Special Paper 542, 191-211, https://doi.org/10.1130/2019.2542(10).

Porreca M. et al. (2020) - 3D geological reconstruction of the M. Vettore seismogenic fault system, Central Apennines, Italy: Cross-cutting relationship with the M. Sibillini thrust. Journal of Structural Geology, 131, 103938, https://doi.org/10.1016/j.jsg.2019.103938.

Integrated stratigraphy and depositional architecture of Jurassic condensed successions from the Saccense Domain (SW Sicily, Western Tethys)

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Keywords: ammonite biostratigraphy, Jurassic, Western Tethys.

The Jurassic successions exposed at Contrada Diesi (Mt Maggiaro) and Contrada Nadorello (Rocca Nadore Ridge, southwestern Sicily) provide an exceptional record of the tectono-sedimentary evolution of the Saccense Domain along the southern margin of the Western Tethys. Both successions developed during the Jurassic on structural highs affected by reduced sedimentation, synsedimentary tectonics and prolonged pelagic condensation following the drowning of the Lower Jurassic carbonate platform and are now located in the southwestern sector of the Sicilian Fold and Thrust Belt. This study presents a comparative analysis based on integrated ammonite biostratigraphy, facies and microfacies analyses, and taphonomic observations aimed at reconstructing the depositional architecture and palaeogeographic evolution of these condensed successions.

The Contrada Diesi succession consists of a relatively continuous Bathonian-Kimmeridgian pelagic record characterised by *Bositra*-rich limestones, calcisiltitic intervals, stromatolitic surfaces and ammonite-rich condensed levels. Ammonite assemblages indicate significant Mediterranean affinities, locally associated with Submediterranean influences during the Oxfordian. The succession preserves several discontinuity surfaces and reworked ammonite assemblages, recording repeated phases of exhumation, erosion and sediment starvation (Marino et al., 2004; D'Arpa & Melendez, 2006).

In contrast, the Contrada Nadorello succession displays strong lateral variations in thickness and facies distribution, with local thinning and omission of stratigraphic intervals. The occurrence of multiple Fe-Mn crusts, erosional surfaces, stromatolitic textures and condensed ammonite-bearing horizons suggests persistent bottom-current activity and differential sediment redistribution across adjacent structural highs.

Comparison between the two successions highlights the strong internal heterogeneity of the Saccense Domain during the Middle-Late Jurassic, reflecting the interaction between inherited palaeotopography, extensional tectonics, bottom-current dynamics and variable sedimentation rates. Ammonite biostratigraphy further allows reliable correlations with other Mediterranean and Submediterranean successions of the Western Tethys, including the Iberian Range, Southern Alps and Subbetic Domain. These successions represent key archives for reconstructing the tectono-sedimentary evolution and palaeogeographic fragmentation of the southern Tethyan carbonate platform system during the Jurassic.

D'Arpa C. & Meléndez G. (2006) - Oxfordian ammonites from Contrada Diesi (Sciacca, Sicily), a historical locality studied by Gemmellaro. Quaderni del Museo Geologico Gemmellaro, 9, 63-74.

Marino M.C. et al. (2004) - Middle Jurassic-Early Cretaceous integrated biostratigraphy (ammonites, calcareous nannofossils and calpionellids) of the Contrada Diesi section (South-Western Sicily, Italy). Riv. It. Pal. Strat., 110(1), 357-372, https://doi.org/10.13130/2039-4942/6311.

The story of a subduction-exhumation channel at the Alps-Apennine junction: New insights from the geological mapping of the Voltri Massif

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Keywords: geological mapping, tectonic melange, Alps-Apennine System.

Exhumation channels are key structures in convergent margins, enabling the return of high-pressure (HP) and ultra-high-pressure (UHP) rocks from subduction depths through tectonic mixing and strain localization. In the Alpine belt, these structures are commonly preserved as block-in-matrix mélanges recording strongly heterogeneous pressure-temperature histories within limited tectonic domains. Well-exposed examples occur also in the Ligurian Alps within the Voltri Massif metaophiolite (e.g.; Federico et al., 2007 and Malatesta et al., 2012).

We present here a structural-geological map of the Varenna Valley (Genoa, NW Italy), located at the boundary between the Voltri Massif and the Sestri-Voltaggio Zone. Previous petrological studies documented the occurrence of markedly contrasting peak metamorphic conditions in metagabbroic rocks of the area, ranging from blueschist-facies to eclogite-facies peaks, followed by greenschist-facies retrogression (e.g.; Capponi & Crispini, 2002, Malatesta et al., 2012).

The structural-geological map is based on 1:10,000 field mapping and associated with comprehensive structural analyses including foliations, folds and stretching lineations, geological cross-sections, and foliation-trajectory map.

The map shows the presence of meter to kilometer-scale, N-S elongated bodies and slices of metamorphic oceanic lithologies (e.g.; metagabbro, metabasite, peridotite and metasediment) embedded within a serpentinitic matrix in a tectonic mélange. The mechanically competent blocks are wrapped by a regional (blueschist to greenschist-facies) composite foliation related to superposed ductile deformation phases and cut by shear zones and faults. The foliation trajectories map outlines how the regional fabric deviates systematically around the blocks, defining a flow-like pattern. In contrast, several blocks preserve internal relics textures and foliations related to pristine tectono-metamorphic evolution.

Our results contribute to refine the structural characterisation of the long story of subduction-related mélanges and their role in accommodating deformation and material transfer at the Alps-Apennines junction.

Capponi G. & Crispini L. (2002) - Structural and metamorphic signature of Alpine tectonics in the Voltri Massif (Ligurian Alps, north-western Italy). Eclogae Geologicae Helvetiae, 95, 31-42.

Federico L. et al. (2007) - Different PT paths recorded in a tectonic mélange (Voltri Massif, NW Italy): implications for the exhumation of HP rocks. Geodinamica Acta, 20(1-2), 3-19, https://doi.org/10.3166/ga.20.3-19.

Malatesta C. et al. (2012) - The exhumation of high-pressure ophiolites (Voltri Massif, Western Alps): Insights from structural and petrologic data on metagabbro bodies. Tectonophysics, 568, 102-123, https://doi.org/10.1016/j.tecto.2011.08.024.

Where oceans die and mountains rise: Plate convergence and paleo-seismicity revealed by marine sediments in the Calabrian Arc

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Keywords: Calabrian Arc, subduction system, submarine paleoseismology.

The Calabrian Arc is one of the most enigmatic subduction systems on Earth. It lies on the oldest in situ oceanic crust and, despite its narrow geometry, displays a structural and geodynamic complexity that remains poorly understood (Polonia et al., 2016). Surface deformation is spatially fragmented, suggesting a highly heterogeneous system in which the degree of mechanical coupling between the subduction interface, accretionary wedge, and upper plate remains unclear (Sgroi et al., 2021, 2025). Despite low convergence rates, the Calabrian Arc hosts seismogenic faults capable of generating earthquakes exceeding magnitude 7. However, instrumental and historical records are shorter than the recurrence intervals of large earthquakes, while onshore paleoseismology is often limited by discontinuous sedimentation. In this context, the submarine environment offers more continuous archives of high-energy sedimentary events potentially linked to seismic activity.

This abstract reports on the structure and tectonic evolution of the Calabrian Arc subduction system through an integrated analysis of multi-channel and single-channel seismic reflection data. Crustal deformation is strongly controlled by plate convergence, slab tearing, and margin segmentation inherited from pre-existing Mesozoic structures. Multi-proxy studies of marine sediments show that turbidites represent valuable sedimentary archives of past earthquakes, recording the feedbacks between seismic shaking and sedimentation and extending earthquake records far beyond historical catalogues. Integrating submarine paleoseismology with onshore studies allows to the: (i) reconstruction of high-resolution, long-term spatiotemporal earthquake histories along the convergent margin; (ii) identification of megathrust earthquake signals in marine event-stratigraphic sequences; and (iii) characterization of paleo-seismicity over multiple seismic cycles, improving seismic and tsunami hazard assessment.

Integrated analyses of sediment cores and geophysical data was targeted to reconstruct resedimented deposits over the last 30-50 ka. Very thick deposits (megaturbidites) are interpreted as the result of Hellenic Arc earthquakes that generated trans-Mediterranean tsunamis (CE365, 14 ka, 40-50 ka). Thin seismo-turbidites record activity of crustal faults within the Calabrian Arc, including onshore structures. Thick turbidites are instead interpreted as evidence of subduction earthquakes recurring every 2-3 ka. Since the most recent deposit dates to ~2.9 ka, careful reassessment of present seismic hazard is required (Polonia et al., 2023). Resolving the relationship between deep geodynamics and surface deformation will fundamentally improve our understanding of how subduction systems evolve, lock, and release strain in complex continental margins.

Polonia A. et al. (2016) - The Ionian and Alfeo-Etna fault zones: new segments of an evolving plate boundary in the central Mediterranean Sea? Tectonophysics, 675, 69-90, https://doi.org/10.1016/j.tecto.2016.03.016.

Polonia A. et al. (2023) - Large earthquakes along slow converging plate margins: Calabrian Arc paleoseismicity based on the submarine turbidite record. Geoscience Frontiers, 14, 101612, https://doi.org/10.1016/j.gsf.2023.101612.

Sgroi T. et al. (2021) - New seismological data from the Calabrian arc reveal arc-orthogonal extension across the subduction zone. Scientific Reports, 11(1), 473, https://doi.org/10.1038/s41598-020-79719-8.

Sgroi T. et al. (2025) - Structural development and seismogenesis in the Messina Straits revealed by stress/strain pattern above the edge of the Calabrian slab (Central Mediterranean). Tectonophysics, 915(26), https://doi.org/10.1016/j.tecto.2025.230920.

Integrated geophysical and heat-flow constraints on crustal structure and magmatism in the Sicily Channel, Central Mediterranean

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Keywords: Sicily channel, Pantelleria graben, gravity anomaly.

The Sicily Channel is a foreland-foredeep system in the Central Mediterranean where crustal extension, magmatism, and foreland-orogenic interactions coexist within a complex geodynamic setting (Corti, 2006; Lodolo et al., 2012; Civile et al., 2021). This study integrates 2D multichannel and time-to-depth converted seismic reflection profiles, satellite-derived gravity anomalies, magnetic anomalies, and heat-flow measurements to investigate crustal architecture and tectonic evolution across the Pantelleria Graben and the adjacent Adventure Bank; the latter containing the external thrust front of late Miocene Maghrebian-Apenninic orogenic system partly cross-cut by extensional faults. Seismic interpretation reveals that the Pantelleria Graben is covered by a thin veneer of Plio-Quaternary sediments and flanked by normal faults. The structural analysis also identifies local inversion of pre-existing normal faults in the southern Pantelleria Graben and in the Adventure Bank suggesting a transition from early Pliocene extension to later localized transpressional reactivation. Then, the Pantellaria Graben and its adjacent parts also feature magmatic intrusions including a distinct magmatic body beneath its southern rim as shown by the gravity and magnetic anomalies. Surface heat flow data further provides the evidence of the shallow magmatic bodies along the rift axis, thus indicating localised magmatic emplacement along normal fault zones. Gravity modeling along two seismic reflection profiles suggests pronounced crustal thinning beneath the Pantelleria Graben (Moho depths ~16.7-20 km), accompanied by high positive Bouguer gravity and magnetic anomalies and low Free-Air gravity values; while the Adventure Bank shows crustal thickening (Moho > 30 km) and a marked decrease in gravity, magnetic, and surface heat flow values. These features agree with a crustal structure at the transition from the foreland to the thicker orogenic wedge. However, the integrated analysis revealed that the Sicily Channel shows dynamically active crustal transition, where local magmatism and rifting are associated to local inversion tectonics affecting different geological domains from the foreland to the orogen.

Civile D. et al. (2021) - Morphostructural setting and tectonic evolution of the central part of the Sicilian Channel (central Mediterranean). Lithosphere, 2021(1), 7866771, https://doi.org/10.2113/2021/7866771.

Corti G. et al. (2006) - Coexisting geodynamic processes in the Sicily Channel. Geol. Soc. Am., 409, 83-96, https://doi.org/10.1130/2006.2409(05).

Lodolo E. et al. (2012) - Magnetic signature of the Sicily Channel volcanism. Mar. Geophys. Res., 33(1), 33-44, https://doi.org/10.1007/s11001-011-9144-y.

New constraints on the Quaternary tectonic phases of the central Apennines from integrated deposition and incision histories of intermontane basins

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Keywords: intramontane basins, Quaternary, morphostratigraphy.

Continental synthems represent a natural database recording the recent geological history of the Earth's surface. Their sedimentological characterization and chronostratigraphical position can provide multiple insights into sedimentary and erosional processes, the climatic and biological evolution of environments, and the tectonic processes driving the formation of the related basins. Particularly, the Plio-Quaternary continental deposits are a powerful database to investigate and understand the tectonic and climatic processes shaping the landscape in tectonically active areas. In the central Apennines, the geological history stored in continental synthems has provided important insights into the regional tectonic phases involving the mountain belt during the Plio-Quaternary (e.g., Cosentino et al., 2017; Nocentini et al., 2017; 2018; Mondati et al., 2026). In this study, we present an updated synthesis of the Plio-Quaternary evolution of intermontane basins by integrating literature data with new findings from the Middle Liri Valley, derived from field work and U-Th datings for the realization of the Sheet 390-Frosinone (CARG project). We compare the morphostratigraphic history of the Middle Liri Valley with those of the Aterno, Tirino, Tiberino, and Rieti basins, focusing on depositional stages, incision stages and rates. Our results support a synchronous onset of regional uplift between 1.5 and 2 Ma, marked by the abandonment of previous paleosurfaces and the onset of a prolonged incision phase, followed by a second phase of accelerated incision during the Middle Pleistocene, coeval with increased activity of the normal faults bounding the main Apennine intermontane basins. These findings support the hypothesis of a regional and coeval uplift and fault acceleration across the central Apennine chain, connected to changes in mantle dynamics that occurred during the Early Pleistocene.

Cosentino D. et al. (2017) - New insights into the onset and evolution of the central Apennine extensional intermontane basins based on the tectonically active L'Aquila Basin (central Italy). Geological Society of America Bulletin, 129, 1314-1336, https://doi.org/10.1130/B31679.1.

Mondati G. et al. (2026) - Constraining the early stage of the post-orogenic extensional tectonics in central Italy: New evidence from a long sediment core from the tectonically active L'Aquila Basin. Geological Society of America Bulletin, 138(3-4), 1179-1207, https://doi.org/10.1130/B37760.1.

Nocentini M. et al. (2017) - Plio-Quaternary geology of L'Aquila-Scoppito Basin (central Italy). Journal of Maps, 13, 563-574, https://doi.org/10.1080/17445647.2017.1340910.

Nocentini, M. et al. (2018) - Plio-Quaternary geology of the Paganica-San Demetrio-Castelnuovo Basin (Central Italy). Journal of Maps, 14, 411-420, https://doi.org/10.1080/17445647.2018.1481774.

Palynology as a game changer in metamorphic stratigraphy: Evidence from Elba Island and the Alpine Domain

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Keywords: palynology, metamorphic rocks, Palaeozoic.

Palynology is increasingly demonstrating its potential as a robust stratigraphic and palaeogeographic tool even within metamorphosed sedimentary successions, where its applicability has long been underestimated due to thermal and deformational overprinting. Recent advances show that organic-walled microfossils can survive a wide range of metamorphic conditions, preserving biostratigraphically significant information that can be used to constrain depositional ages and reconstruct the evolution of deeply reworked crustal domains. In this contribution, we explore the role of palynological analysis as a primary approach to unravel the stratigraphic architecture and palaeogeographic evolution of the Paleozoic-Mesozoic successions of central-northern Italy. By integrating new and published datasets, we demonstrate how palynology provides critical constraints in settings where traditional palaeontological and stratigraphic markers are scarce or obliterated. Key examples are drawn from the high-grade polymetamorphic basement of eastern Elba Island and from selected Alpine successions. In eastern Elba, the identification of Palaeozoic palynomorph assemblages in metasedimentary rocks allows the determination of minimum depositional ages for their protoliths and provides a unique window into the early evolution of the Adriatic domain. Similarly, palynological investigations in Alpine metamorphic units reveal previously unrecognized stratigraphic signals that contribute to refining correlations and reconstructing sedimentary histories across tectonically dismembered units. These results, also framed within recent high-impact studies, highlight how palynology can overcome the limitations imposed by metamorphism and tectonic reworking, offering a unifying framework to integrate geological, palaeontological, and geochronological data. Ultimately, this approach enables more robust palaeogeographic reconstructions of Adria from the Cambrian to the Mesozoic and underscores the broader potential of palynology to resolve long-standing uncertainties in complex orogenic systems.

From geological reconstruction to resource management: Late Neogene to Quaternary evolution of Southwestern Sicily and offshore Sciacca

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Keywords: 3D modelling, geological resource, Sicily.

During the Neogene-Quaternary, the geological evolution of SW Sicily and its offshore sector was controlled by the interaction of three main geodynamic processes: (1) the forelandward migration of the Sicilian Fold and Thrust Belt; (2) the opening of deep grabens within the Strait of Sicily; and (3) lithospheric-scale deformation associated with high-angle N-S-trending structures extending for more than 250 km across the Strait of Sicily to the offshore Sciacca area. These processes developed within the regional geodynamic framework of convergence between the European and African plates, along an NNW-SSE direction.

Within this tectonic framework lies the area investigated in the CARG geological sheets 618 "Castelvetrano" and 628 "Sciacca". Multidisciplinary investigations were carried out to reconstruct the former setting of the rifted palaeomargin and the tectono-sedimentary evolution of the foreland basin system. The activities included biostratigraphic and sedimentological analyses, mesostructural surveys, and interpretation of reflection seismic profiles. In addition, paleomagnetic analyses and OSL and ESR dating allowed a detailed definition of the Middle-Late Pleistocene chronostratigraphy.

The results enabled the reconstruction of a multistage tectonic evolution from the Late Neogene to the Quaternary: 1) a Messinian-Early Pliocene compressional event, responsible for the development of SE-vergent folds, locally associated with décollement levels at different stratigraphic intervals; 2) a Late Pliocene-Early Pleistocene compressional event, characterized by the activation of high-angle thrusts that led to the exhumation of the main carbonate reliefs and to the development of the forward thrust system of the Gela Thrust Wedge; 3) a post-Early Pleistocene compressional-transpressional event, which activated major NNE-SSW-trending left-lateral transpressive faults.

The understanding of this framework was further refined through the construction of a 3D geological model, which allowed the correlation between onshore and offshore structures, clarifying the continuity on land of crustal-scale shear structures previously recognized offshore in the Sciacca-Capo San Marco sector.

The detailed reconstruction of structural setting and geological evolution represents a fundamental tool for sustainable land and resource management. The integration of seismic-stratigraphic and structural data provided new insights into the relationships between deep aquifer systems hosted within fractured Mesozoic carbonates and offshore fluid escape structures, linking the Sciacca geothermal field to offshore thermal anomalies. Furthermore, the mapping of fluid seepages and current-related sedimentary structures in submerged areas contributes to a better understanding and protection of marine benthic habitats, while offshore seismostratigraphic investigations provide estimates of sand deposits potentially available for beach nourishment along retreating coastlines.

Geological and thermophysical characterization of the Alps-Apennines junction wedge top basin in northwest Italy for the evaluation of the geothermal resources

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Keywords: geothermal energy, geological model, Alps-Apennines junction.

Foreland wedge top basins are usually characterized by complex slope depocenters, bounded by several basin-scale unconformities, and affected by coeval deformation. In consequence, deciphering the interplay of different geological processes (e.g., active tectonic backgrounds, dynamic erosion and subsidence rates, and ongoing shortening in adjacent fold-thrust belts), governing the structural and sedimentary patterns of these basins is required for the characterization of multi-purpose reservoirs.

The Eocene-Miocene depositional systems formed in the Alps-Apennines junction wedge-top basin include areas with important geothermal activity, characterized by several hot springs up to 70°C (e.g., Acqui Terme) and moderately high surface heat flux, between 62 and 84 mW m^{-2} (Pasquale et al., 2014), evidencing their potential as a new geothermal resource. The location of the hot springs, north to the metamorphic basement outcrops, identify the last one as the recharge area of the meteoric water. Furthermore, the presence of a thin crust (30-35 km), revealed by recent seismic tomography studies (e.g., Nouibat et al., 2023), enhances the role of the deep structures in the formation of the geothermal reservoir.

We explored the relationship between tectonics and basin evolution through the analysis of subsurface and surface data, including seismic reflection profiles, well data, field observations, and facies analysis of the outcropping successions, in order to implement a 3D geologic model. The last one provides thickness and lateral facies variations, as well as the architecture of these systems. In particular, five major units were identified within the basin, which are representative of key stages in its tectonic evolution.

The 3D geological model is the basis for a quantitative characterization of the relationship between tectonic subsidence and sediment accumulation, useful to understand the complex evolution of this and analogue sedimentary basins. In addition, petrophysical measurements were performed on several samples of the metamorphic basement, in order to constrain the values of its thermophysical parameters (e.g., seismic velocity, density, thermal conductivity). All the obtained results are used to reconstruct the thermal conditions of the basin through the kinematic restoration and forward modelling of two perpendicular cross-sections, using the OpenFlow Suite™.

Nouibat A. et al. (2023) - Ambient-noise wave-equation tomography of the Alps and Ligurian-Provence basin. J. of Geophys. Res.: Solid Earth, 128, e2023JB026776, https://doi.org/10.1029/2023JB026776.

Pasquale V. et al. (2014) - Heat flow and geothermal resources in northern Italy. Renewable and Sustainable Energy Reviews, 36, 277-285, https://doi.org/10.1016/j.rser.2014.04.075.

Slow fluid leakage along faults: A multidisciplinary study on the mud volcanoes in the southern Apennines (Italy)

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Keywords: mud volcanoes, southern Apennines, multidisciplinary surveys.

This study presents a multidisciplinary investigation of the Bolle della Malvizza mud volcanoes, located in the southern Apennines fold-and-thrust belt (Italy), aimed at characterizing these structures and constraining processes and sources of mud and gas leakage. Twelve main vents are present, continuously and slowly ejecting mud, saltwater, and gases, including CH4 and CO2. We carried out different investigations, including (i) stratigraphic and structural surveys, (ii) topographic and morphometric evaluations using a Digital Elevation Model obtained by drone photogrammetry, (iii) geochemical measurements of CO2 flux, radioactivity, and soil pH, and (iv) geo-physical surveys including Electrical Resistivity Tomography, Induced Polarization, and Self-Potential (Vitale et al., 2023, 2025). Nine main groups of mud volcanoes are present in the area, varying in size (from a few centimeters to 13 meters) and height (from ~3 to 15 cm). These mud eruptive vents are aligned along the ENE-WSW- and N-S-directed normal faults. The geogenic CO2 flux is low when compared to other non-volcanic emissions in the southern Apennines. The electrical resistivity tomography reveals conductive volumes interpreted as clay-rich layers alternating with resistive bodies of clay-marly rocks, and conductive layers corresponding to shallow and deep aquifers. The induced polarization data highlights high-chargeability zones linked to clay-rich bodies and a narrow vertical conduit connecting deeper conductive zones to shallow levels. Self-Potential data show a pronounced negative anomaly aligned with the main vents, spatially matching the high-chargeability conduit and a resistivity inflection in the electrical section. Ground deformation modeling and Monte Carlo simulation suggest a source at ~110 m depth, with a negative volume change of $\sim 5 \times 10^5$ m³. We propose a conceptual model in which deep fluids slowly ascend along damage zones of two major faults, interacting with the surficial aquifer and the clayey host rock, and accumulate in a shallow reservoir that gradually releases muddy fluids to the surface, forming mud volcanoes that are continuously eroded during rainfall events.

Vitale et al. (2023) - Insights on the active Southern Matese Fault system through geological, geochemical, and geophysical investigations of the CO_2 gas vent in the Solopaca area (southern Apennines, Italy). Tectonophysics, 846, 229657, https://doi.org/10.1016/j.tecto.2022.229657.

Vitale et al. (2025) - Geophysical, geochemical, and structural investigations of natural non-volcanic degassing in Oliveto Citra area (southern Apennines): Understandings of structural controls on CO_2 leakage. Mar. Petrol. Geol., 173, 107264, https://doi.org/10.1016/j.marpetgeo.2024.107264.

S18.

Vertebrates in Deep Time: paleoecology, paleoenvironments and evolutionary dynamics

Conveners & Chairpersons:

Jacopo Amalfitano (Università di Padova)

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New insights into the Late Cretaceous vertebrate fauna of the "Castellavazzo Stone" (Belluno, northeastern Italy)

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Keywords: Mesozoic, fossil, fishes.

The 'Castellavazzo Stone' (Belluno Province, Venetian Prealps, northeastern Italy) represents a condensed stratigraphic interval of the Soccher Formation deposited during the Late Cretaceous in the Belluno Basin (northwestern Tethys). This distinctive lithofacies, formerly assigned to the Scaglia Rossa l.s., crops out near Longarone and consists of 6-7 m of dark red to grey-greenish hard limestones with dark red argillitic interlayers and a characteristic nodular fabric. Despite its peculiar fossil content, the Castellavazzo vertebrate assemblage has been largely neglected since Bassani's works (1886, 1888), with only sporadic reassessments in the intervening decades (e.g., Larocca Conte et al., 2019). The chondrichthyan fauna from this locality is taxonomically diverse, encompassing several lamniform taxa, including large apex predators such as *Cretoxyrhina mantelli* and *Scapanorhynchus subulatus*, alongside several species of the durophagous shark *Ptychodus*. Actinopterygian fishes are also represented, including '*Lepidotes*' sp. and ?*Protosphyraena ferox*. Notably, the specimens appear to derive from distinct stratigraphic horizons, adding further complexity to the interpretation of this understudied fossil record. The Castellavazzo assemblage shows close similarities with the '*lastame*' fauna of the Lessini Mountains (Calzoni et al., 2025), a nodular condensed interval of the Scaglia Rossa deposited atop the Trento Plateau during the mid-Turonian-early Coniacian. Both localities share comparable chondrichthyan taxa yet differ in faunal composition; most notably, marine reptiles are exclusive to the '*lastame*' record. The precise stratigraphic relationships between the two condensed intervals remain to be fully resolved, making their faunal comparison particularly valuable for regional paleobiogeographic reconstructions. Here we present a comprehensive reappraisal of the Castellavazzo assemblage through systematic revision of all available historical specimens, many neglected for over a century, and reinterpretation of the stratigraphic setting of the fossiliferous intervals. In addition to reassessing the taxonomic composition and diversity of this assemblage, our results shed new light into Late Cretaceous chondrichthyan diversity and biogeographic dynamics across the Tethyan domain.

Bassani F. (1886) - Sull'età degli strati a pesci di Castellavazzo nel Bellunese. Bollettino della Società Geologica Italiana, 4, 143-148.

Bassani F. (1888) - Colonna vertebrale di Oxyrhina Mantelli, Agassiz, scoperta nel calcare senoniano di Castellavazzo, nel Bellunese. Memorie di Matematica e di Fisica della Società Italiana delle Scienze, 7(Serie 3), 1-5.

Larocca Conte G. et al. (2019) - Reassessment of a large lamniform shark from the Upper Cretaceous (Santonian) of Italy. Cretaceous Research, 99, 156-168, https://doi.org/10.1016/j.cretres.2019.02.011.

Calzoni P. et al. (2025) - How excavation activity is both a blessing and a curse for the palaeontological heritage: The case study of the fossils from the "Lastame" in the Verona Province (Northern Italy). Geoheritage, 17, 141, https://doi.org/10.1007/s12371-025-01184-4.

Ichnological review of the theropod tracks from Mattinata (Apulia, southern Italy)

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Keywords: dinosaur footprints, Gargano promontory, Apulia Carbonate Platform.

In 2001, three dinosaur track-bearing blocks were reported from the pier of Mattinata, in the Gargano promontory (Apulia, southern Italy). The limestone blocks (MPA, MPB and MPC), strongly dolomitised, were referred to the peritidal carbonates of the Sannicandro Formation, deposited in the shallow-water environment of the Apulia Carbonate Platform. A Kimmeridgian-Tithonian age was inferred on the basis of the lithological features. The dinosaur footprints, currently housed in the Museo Civico di Mattinata, are preserved both as concave epireliefs (in blocks MPA and MPC) and convex hyporeliefs (in block MPB). They were originally assigned to three distinct morphotypes, attributed to theropod dinosaurs (Conti et al., 2005). In this work, the theropod tracks were re-examined through high-resolution digital photogrammetry. The results of the ichnological review led to recognise the presence of numerous anatomical details, such as the impression of clear phalangeal pads, sharp claw traces and, in some specimens, metatarsal impression. The occurrence of different morphotypes is likely related with variations in the trackmaker's posture. The Mattinata ichnoassemblage includes: i) highly digitigrade specimens, in which the proximal pads of digits II and IV are not impressed; ii) semi-plantigrade tracks, in which digits II and IV are totally impressed, along with the metatarsal-phalangeal portion of the autopod; iii) plantigrade specimens, in which the autopod impression is completely recorded, also showing the metatarsal trace. The latter two morphotypes clearly show the hallux impression, distinctly separated from the rest of the footprint in the semi-plantigrade specimens. These new interpretations reveal several affinities with the theropod tracks from Borgo Celano, also located in the Gargano Promontory within the Calcare di Bari Fm. (upper Hauterivian-lower Barremian, Petti et al., 2008), despite having previously been considered distinct from them. Additionally, the presence of digit I allows comparison with other still debated tetradactyl tracks from the Late Jurassic-Early Cretaceous of Europe attributed to theropods, such as *Theroplantigrada*, *Eutynichnium* and *Bueckeburgichnus*. Further qualitative and quantitative analyses will allow phenetic and statistical comparisons with the pedal anatomy of theropods known from the coeval osteological record, in order to determine whether the impression of digit I reflects the substrate conditions (e.g., penetrative tracks) or the anatomy of the trackmaker (e.g., non-reduced digit I, that remained partially functional during locomotion).

Conti M.A. et al. (2005) - Jurassic dinosaur footprints from Southern Italy: footprints as indicators of constraints in paleogeographic interpretation. Palaios, 20, 534-550.

Petti F.M. et al. (2008) - A theropod dominated ichnocoenosis from late Hauterivian-early Barremian of Borgo Celano. Rivista Italiana di Paleontologia e Stratigrafia, 114, 3-17.

New geological and ichnological data from Sezze (Latium, central Italy)

Antonelli M.[1], Fagioli G.*[2], Rossi G.[2], Angeli A.[2], Petti F.M.[3], Fabbi S.[2], Sacco E.[1], De Sario F.[4], Raponi D.[5], Pignatti J.[2] & Romano M.[2]

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Keywords: dinosaur tracks, geological mapping, CARG Project.

The Sezze dinosaur tracksite represents one of the most significant ichnosites within the Italian palaeontological record, dating to the early-middle Cenomanian. The site, approximately 70 km southeast of Rome, is located within Sheet 401 "Sezze" of the Geological Map of Italy at the 1:50,000 scale, for which geological mapping is currently in progress as part of the CARG Project. The Sezze area belongs to the Lepini Mountains sector, which is characterised by a shallow-water carbonate platform succession pertaining to the Apennine Carbonate Platform or Latium-Abruzzi-Campania Carbonate Platform. This carbonate system developed from the Triassic along the southern margin of the Neo-Tethys Ocean and persisted until the end of the Cretaceous. The exposed successions are predominantly composed of limestones and dolomitic limestones deposited in neritic to intertidal environments, which were subsequently deformed during the compressional phase linked to the development of the Apennine belt and subsequently affected by post-orogenic extensional tectonics. More than two hundred dinosaur footprints, attributed to sauropod and theropod dinosaurs, are preserved on three distinct stratigraphic layers within a disused quarry (formerly known as Cava Petrianni) near the town of Sezze. A sauropod trackway characterised by a wide-gauge configuration supports its attribution to titanosaurs (Nicosia et al., 2007). Qualitative and quantitative analysis of the elongated theropod tracks, which in some cases preserve hallux and metatarsal impressions, suggests oviraptorosaurs as the most suitable trackmakers (Antonelli et al., 2023). A new ichnological survey was recently performed on the SCP I track-bearing surface, where the sauropod trackway occurs. The investigation was supported by drone-based photogrammetry, which enabled the creation of high-resolution orthophotos and digital elevation models (DEMs) of both the entire surface and individual *manus-pes* sets. The newly acquired data reveal numerous anatomical details in the best-preserved sauropod tracks, including distinct digit impressions with sharp claw marks in the *pes* tracks and a crescent-shaped *manus*. These anatomical features permit a more robust comparison with both sauropod ichnotaxa and the osteological record, thereby providing new insights into the palaeobiogeographic origin of the quadrupedal trackmaker. Numerous small-sized theropod footprints are also preserved on the SCP I surface, most of them occurring along the expulsion rims of the sauropod tracks. Additionally, not far from SCP I, another exposed surface reveals the occurrence of additional small- to medium-sized tridactyl footprints, which are reported here for the first time.

Antonelli M. et al. (2023) - Inferred oviraptorosaur footprints in the Apenninic Carbonate Platform: New tools for the identification of trackmakers from the Sezze ichnosite (lower-middle Cenomanian; central Italy). Cretaceous Research, 141, 105362.

Nicosia U. et al. (2007) - Dinosaur tracks as paleogeographic constraints: new scenarios for the Cretaceous geography of the Periadriatic region. Ichnos, 14(1-2), 69-90.

Taphonomy, palaeoecology and palaeobiological significance of the Cisterna quarry fossil site (Upper Miocene, southeastern Italy)

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Keywords: Mediterranean Sea, Pietra leccese, Tortonian.

During the Late Miocene, the marine fauna of the Mediterranean Sea underwent remarkable modifications driven by global cooling and regional oceanographic changes that climaxed with the Messinian Salinity Crisis. We provide a comprehensive synopsis of the outstanding marine vertebrate assemblage from the Tortonian strata of the Pietra leccese limestone exposed at the Cisterna quarry, ca. 2 km southeast of Lecce (southern Italy). This thoroughly monitored locality has yielded an impressive vertebrate fauna, including cetaceans (both odontocetes and mysticetes, among which are the holotypes of the macroraptorial sperm whale *Zygophyseter varolai*, the stem beaked whale *Messapicetus longirostris* and the archaic grey whale *Archaeschrichtius ruggieroi*), sea cows (*Metaxytherium medium*), hard-shelled sea turtles, bony fishes (including the holotypes of *Makaira adensa*, *Makaira cyclovata*, *Pizzikoskerma salentina* and *Sicophasma macrocanalata* among other istiophorid billfishes) and elasmobranchs. Taphonomic evidence, including bone modifications consistent with the activity of offshore bioeroders such as *Osedax*, provides new insights into the preservation and palaeoenvironmental context of these remains. The Cisterna fauna records a warm-water, nutrient-rich, offshore setting and illuminates a key phase in the evolutionary history of toothed whales. Its quasi-hyperlongirostrine ziphiids and macroraptorial sperm whales reflect predator ecomorphs that were soon to decline globally, while the close affinities between *M. longirostris* and the Peruvian *Messapicetus gregarius* point to faunal exchange between the southeastern Pacific and the Atlanto-Mediterranean realm through the then-open Central American Seaway. Taken together, the Cisterna quarry preserves a uniquely well-resolved marine vertebrate assemblage that serves as an unparalleled testament to the Late Miocene marine biodiversity of the Mediterranean Sea.

Lost and found: The Chiavon Creek Lagerstätte (Vicenza, NE Italy) and its tropical ichthyofauna

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Keywords: Teleostei, Lagerstätte, Paleogene.

The fossil record of northeastern Italy represents one of the most significant archives for understanding the Paleogene radiation of marine biota in the Tethys. Key localities include the renowned shallow-water Bolca sites (Verona and Vicenza provinces), worldwide known as benchmarks for the study of Eocene tropical marine ecosystems, the Ypresian bathyal sites of Solteri (Trento) and Monte Solane (Verona province), and the Rupelian coral-reef assemblages of Perarolo (Vicenza province), all contributing significantly to reconstruct Paleogene marine paleodiversities in the western Tethys and documenting the post-K/Pg radiation of teleost fishes. Despite this rich scientific heritage, numerous fossiliferous localities remain either uninvestigated or are in need of modern revision. Among these, Chiavon Creek (Vicenza province) represents a historically important yet still understudied *Lagerstätte*. First reported in the mid-19th century, this site yielded a diverse ichthyofauna, in some respects similar to that of Bolca, associated with abundant marine and terrestrial plants and scattered invertebrates. Several taxa were described in earlier studies (e.g., Heckel, 1853; Bassani, 1889), but a comprehensive revision of the assemblage is still lacking. The original material recovered from the site in the 19th and 20th centuries is dispersed across several museums of the Veneto region and in the Naturhistorisches Museum in Vienna. The last revision of this fossil material dates to Bassani (1889) and even earlier for the Austrian collection (Kner & Steindachner, 1863). Additional specimens are known but never were studied in detail, with many of them never being figured. Since these collections have been neglected for over a century (except for sporadic or sparse studies), a reappraisal of the Chiavon Creek site is more than urgent, as it can unravel a lost Paleogene ecosystem and help resolve evolutionary and radiation trends of teleost during the early Cenozoic. The ongoing taxonomic revision has revealed an assemblage dominated by clupeiforms, gonorynchiforms, and percomorphs (e.g., Carangidae, Sparidae). Furthermore, the historically debated stratigraphic age of the fossil site by Bassani (1889) was resolved during the 20th century by Fabiani (1915), who assigned it to an early Oligocene age, which, however, remains poorly constrained. It is, in fact, unsupported by solid paleontological evidence and needs high-resolution stratigraphic and micropaleontological investigations to assess the significance of its ichthyofauna within the broader evolutionary history of Paleogene Tethyan fish communities, especially in a critical time span such as the Eocene/Oligocene transition.

Bassani F. (1889) - Ricerche sui pesci fossili di Chiavòn (Strati di Sotzka - Miocene Inferiore). Atti r. Accad. Sci. fis. mat. Napoli, ser. 2, 3(6), 1-102.

Fabiani R. (1915) - Il Paleogene del Veneto. Mem. Istit. Geol. R. Univ. Padova, 3, 1-336.

Heckel J.J. (1853) - Bericht überdie von H.R.A. de Zigno hier angelangte Sammlung fossiler Fische. Sitzungsber. Kaiserl. Akad. Wiss., 11, 122-138.

Kner R. & Steindachner F. (1863) - Neue Beitrage Kenntniss der Fossilien Fische Oesttereichs. Denkschr. Kaiserl. Akad. Wiss., Math. Naturwiss. Kl., 21(1), 17-36.

A new marine otophysan fish (Teleostei: Ostariophysi) from the Eocene of Bolca, Italy

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Keywords: Teleostei, Ypresian, Pesciara site.

With more than 260 currently recognized species-level taxa, the Eocene (Ypresian) fish fauna of Bolca (Pesciara site) represents one of the most diverse vertebrate assemblages in the fossil record. It comprises elasmobranchs (sharks and batoids), some of the last pycnodontiforms, and a remarkable number of teleosts. The teleost assemblage includes more than 240 species, the vast majority of which pertains to the Acanthomorpha, the spiny-rayed teleosts. Non-acanthomorph teleosts are represented by less than 30 taxa, including a single putative pachyrhizodontid, three osteoglossiforms, 16 elopomorphs, five clupeomorphs, a single aulopiform, two possible gonorynchiforms, and the basal otophysan *Chanoides macropoma*. Otophysans currently represent about 68% of the living freshwater fish species, being represented in the marine biosphere only by the members of the catfish families Ariidae and Plotosidae. Two partially complete articulated skeletons pertaining to a new marine Eocene otophysan fish from Bolca were recently discovered in the collection of the Carnegie Museum, Pittsburgh. This new otophysan exhibits a suite of peculiar features, including the fusion of hypurals 1 and 2, ventral expansion of the os suspensorium, and presence of peripheral ctenoid scales. The scales are characterized by a distinctive single marginal row of cteni that are well separated from the main body of the scale, very similar to those of the extant African citharinoid family Distichodontidae (Vari, 1979).

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Vari R.P. (1979) - Anatomy, relationships ande classification of the families Citharinidae and Distichodontidae (Pisces, Characoidea). Bulletin of the British Museum (Natural History) Zoology series, 36, 261-344.

First confirmed record of the weasel shark genus *Paragaleus* in the Mediterranean Pliocene

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Keywords: palaeobiogeography, palaeoecology, palaeoichthyology.

The weasel shark genus *Paragaleus* (Carcharhiniformes: Hemigaleidae) includes four living species that inhabit the tropical waters of the Atlantic and Indo-west Pacific oceans. The ascertained range of the Atlantic weasel shark, *Paragaleus pectoralis*, reaches latitude ~21°N, such that *Paragaleus* is currently absent from the Euro-Mediterranean region. However, during most of the Miocene epoch, the genus was widespread in the Mediterranean Sea and nearby European waters (including the Paratethys as well as the North Sea). Here, we provide the first unambiguous record of *Paragaleus* from the Mediterranean Pliocene based on abundant fossil teeth collected from the Zanclean (5.1-4.5 million years ago) locality of Arcille (Tuscany, central Italy). These dental remains demonstrate the regional persistence of a species of *Paragaleus* phenetically close to *P. pectoralis* after the Messinian Salinity Crisis. Moreover, they further indicate tropical conditions for the Early Pliocene Mediterranean Sea. The eventual extirpation of *Paragaleus* and other weasel shark genera (namely, the once widespread *Chaenogaleus* and *Hemipristis*) from the Euro-Mediterranean region did likely occur during the Pliocene as the climate became progressively cooler. As a consequence of the ongoing anthropogenic climate change, the family Hemigaleidae may re-colonise the Mediterranean Sea through the Strait of Gibraltar (with *P. pectoralis*) and/or Suez Canal (with *Hemigaleus microstoma* as well as *Hemipristis elongata*).

Late Ladinian (Middle Triassic) Alpine ichthyofaunas compared

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Keywords: fossil fishes, Triassic, paleoecology.

The Pelsa/Vazzoler (PV) Lagerstätte (Agordo Dolomites, Italy) is the richest vertebrate assemblage in the Dolomites. Recently, small fieldworks have yielded ~400 fish specimens (~20 species). The slightly older Kalkschieferzone (KSZ) (Italy-Switzerland) is the youngest fossiliferous unit of the Monte San Giorgio Lagerstätte. Since the 1980s, systematic field campaigns have unearthed several thousands of fishes (~27 taxa). Although both sites were in a tropical climate, PV was a small intraplatform basin within a carbonate build-up, surrounded by a rich reef-like biota, whereas the KSZ was a muddy shallow lagoon with periodical freshwater inputs, lacking marine benthic life.

PV and KSZ ichthyofaunas include mostly miniature and small actinopterygians but show contrasting assemblage structures. Apart from ubiquitous genera (*Peltopleurus*, *Saurichthys*), possibly other shared taxa are few (*Caelatichthys*, *Perleidus*). The KSZ is dominated by *Prohalecites*, a miniature advanced neopterygian that makes up to 95% of the fish specimens and is known only from KSZ and the Perledo area. Contrarily, PV is rich in *Marcopoloichthys* and *Placopleurus*, also advanced neopterygians, with a wide geographic and stratigraphic distribution across Tethys. Coelacanths and sharks are relatively common in PV, but much rarer in the KSZ. PV also includes the peltopleuriform *Thoracopterus wushaensis*, a flying fish originally described from China, and abundant *Habroichthys*, again as in the Xingyi Fauna.

About trophism, PV includes several suspension feeders (*Habroichthys*, *Marcopoloichthys*, *Placopleurus*), whereas in the KSZ active predators dominate also in the small taxa (*Prohalecites*, *Allolepidotus, Peltopleurus*, *Perleidus, Caelatichthys*). Top predators are medium-sized *Saurichthys* and coelacanths in both assemblages. Durophages are rare: *Felberia* in the KSZ, *Stoppania* and hybodontids in the PV, the latter possibly linked to the very rich benthic invertebrate fauna.

Preliminary report on the Late Triassic Stelvio dinosaur tracksite (Lombardy, northern Italy)

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Keywords: dinosaur footprints, Late Triassic, Stelvio National Park.

On September 15, 2025, Elio Della Ferrera discovered thousands of dinosaur tracks exposed on several steeply inclined bedding surfaces in the Fraele Valley, within Stelvio National Park (Lombardy, northern Italy). The track-bearing surfaces are exposed on several bed surfaces in a defined stratigraphic interval. To date, at least 26 "dinoturbated" surfaces have been identified across an area extending for approximately 4.5 km.

The trampled horizons occur within dolomitized shallow-marine carbonate deposits of the Dolomia Principale, exposed along the slopes of Cime di Plator and Cima Doscopa, overlooking the Cancano Lakes: the tracks are preserved in the middle-upper part of the Dolomia Principale, that is up to 1000-1500 m thick in the area. The Dolomia Principale, Norian in age (ca. 227-208 Ma), records the development of an extensive shallow-marine carbonate platform fringing the northern margin of the Tethys Ocean. This widespread peritidal system, extensively developed across the Southern Alps and the Austroalpine domain, typically shows evidence of cyclic facies organization commonly arranged in m-thick shallowing-upward cycles capped by intertidal to supratidal facies, frequently characterized by microbial (stromatolitic) horizons representing the uppermost part of the cycles. The presence of well-defined dinosaur and other vertebrate tracks confirms episodic subaerial exposure or very shallow subtidal conditions, where the passage of terrestrial vertebrates is documented. These conditions are recognized in the studied outcrops, where many tracks are deeply impressed in water-saturated carbonate mud deposited under low-energy intertidal conditions, on a shallow carbonate platform. Some footprints preserve well-defined natural casts made by darker, likely subtidal, sediments, reflecting rapid transgressions and pointing to a cyclic facies organization.

Preliminary analyses, based on in situ observations, photographic documentation, and UAV imagery, allowed the identification of thousands of footprints, most likely produced by bipedal sauropodomorphs. Although the track-bearing surfaces have been affected by intense high-altitude weathering, many footprints show distinctive morphological features, including elongated heel impressions and well-defined digit impressions, supporting a putative assignment to the ichnogenus *Pseudotetrasauropus*.

Although research is still in its preliminary phases, the available evidence already indicates that the Plator-Doscopa area represents the largest ichnosite in the Alps and one of the most extensive Triassic dinosaur tracksites worldwide.

Advantages of volumetric body mass estimation in early amniotes: a case study of Permian basal synapsids

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Keywords: "pelycosaurs", body mass, Permian.

Body mass is one of the most important biological parameters, closely related to several ecological and physiological aspects of vertebrates. However, estimating body mass in early amniotes remains challenging due to the lack of closely related modern analogues. Recent studies (Romano et al., 2021; Van den Brandt et al., 2024) have shown that in basal tetrapods with a sprawling posture, limb bones scale differently from those of extant animals, causing traditional allometric methods based on skeletal elements to over- or underestimate real body mass. Here, we present volumetric body mass estimates for three specimens of non-therapsid synapsids ("pelycosaurs") on exhibit at the Field Museum of Natural History (Chicago). "Pelycosaurs" were a key group of basal synapsids that lived from the late Carboniferous to the middle Permian and were among the first tetrapods to occupy a wide range of trophic niches and reach large body sizes. They also represent the earliest stages of the synapsid lineage leading to mammals. Using 3D photogrammetric models of the mounted skeletons, we calculated possible ranges of body mass values for the three specimens, applying different densities for living tissues to the obtained *in-vivo* models. Body mass estimates calculated through digital sculpting were compared with values derived from traditional regression equations, confirming the greater reliability of the volumetric approach. Accurate body mass reconstructions in early amniotes, such as basal synapsids, are essential for improving our understanding of tetrapod evolution and the palaeoecological role of these taxa.

Romano M. et al. (2021) - Volumetric body mass estimate and in vivo reconstruction of the Russian pareiasaur *Scutosaurus karpinskii*. Frontiers in Ecology and Evolution, 9, 692035.

Van den Brandt M.J. (2024) - First volumetric body mass estimate and a new in vivo 3D reconstruction of the oldest Karoo pareiasaur *Bradysaurus baini*, and body size evolution in Pareiasauria. Historical Biology, 36(3), 587-601.

Mind the gap: A new Early Jurassic pycnodontiform fish from the Calcari Grigi Group of northeastern Italy and its implications for the early diversification of the group

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Keywords: Mesozoic, evolution, museum collections.

Pycnodontiformes are an extinct monophyletic clade of actinopterygian fishes characterized by a distinctive set of autapomorphies, including a laterally compressed body, hypertrophied preopercle, molariform teeth on the vomer and prearticular arranged in rows, and differentiated contour scales (Poyato-Ariza & Wenz, 2002). Despite their remarkable evolutionary success, spanning nearly 175 million years from the Late Triassic to the Eocene and achieving a worldwide distribution (Kriwet, 2005), their fossil record during the Early Jurassic remains extremely sparse, representing a significant gap that precedes the diversification of most pycnodontiform families in the Middle and Late Jurassic.

Here we describe a nearly complete, albeit disarticulated, pycnodontiform specimen preserved on two limestone slabs (part and counterpart) from the Rotzo Formation (Pliensbachian) of the Calcari Grigi Group, recovered near Roverè Veronese (Verona Province, northeastern Italy). The Calcari Grigi Group records the evolution of the Trento Platform during the Early Jurassic, from the Hettangian through the end of the Pliensbachian, representing a shallow tropical carbonate platform environment punctuated by emerged areas, broadly comparable to a modern carbonate archipelago. The fossiliferous horizon also yielded a rich Early Jurassic plant assemblage, including cycadophytes and conifers, documenting the proximity of vegetated landmasses to the depositional basin. The specimen belongs to the historical De Zigno Collection of the Museum of Nature and Man of the University of Padova, where it had remained neglected since the time of Baron Achille De Zigno (1813-1892).

Morphological and comparative analysis reveals a pycnodontoid fish that cannot be assigned to any previously described genus or species, due to a unique combination of characters including peltate squamation, peculiar dental morphology and arrangement, and distinctive caudal skeleton morphology. It shows the closest affinities with *Apomesodon* and *Proscinetes* (Poyato-Ariza & Wenz, 2002; Ebert, 2026), both from the Late Jurassic, and clearly differs from *Eomesodon liassicus*, the only other holomorphic pycnodontiform known from a comparable stratigraphic interval.

As the oldest known holomorphic Jurassic pycnodontiform worldwide, this new taxon provides a rare and valuable window into an otherwise poorly documented phase of pycnodontiform evolution, immediately preceding the radiation of the major families of the group (Cawley et al., 2021). The specimen also represents an exceptional addition to the historical De Zigno Collection, significantly enhancing its palaeontological and scientific value.

Cawley J.J. et al. (2021) - Rise and fall of† Pycnodontiformes: Diversity, competition and extinction of a successful fish clade. Ecology and Evolution, 11(4), 1769-1796, https://doi.org/10.1002/ece3.7168.

Ebert M. (2026) - *Macromesodon* Blake, 1905 and *Apomesodon* Poyato-Ariza & Wenz, 2002 (Actinopterygii, Pycnodontiformes) from the Jurassic and lowermost Cretaceous of England, France, and Germany. Swiss Journal of Palaeontology, 145, 97-129, https://doi.org/10.3897/sjp.145.177263.

Kriwet J. (2005) - A comprehensive study of the skull and dentition of pycnodont fishes. Zitteliana, 135-188.

Poyato-Ariza F.J. & Wenz S. (2002) - A new insight into pycnodontiform fishes. Geodiversitas, 24(1), 139-248.

Bioapatite and the dawn of vertebrate skeletons

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Keywords: conodonts, biomineralization, crystallographic signature.

Conodonts are an extinct group of primitive jawless animals whose tooth-like elements constitute the earliest evidence of a mineralized skeleton in vertebrates and an early stage in the evolution of a dentition. The two major conodont groups (paraconodonts and euconodonts) strongly differ from one another. Euconodonts (late Cambrian-earliest Jurassic) have a distinct crown and basal tissue, each of which grows independently by adding external layers. In contrast, paraconodonts (middle Cambrian-earliest Ordovician) consist of a single primary tissue that grows only basally through the successive addition of sheath-like layers.

The presence of a crown and a basal body in euconodonts has long been debated if should be regarded analogous or homologous to enamel and dentin of later vertebrate teeth. By the integration of micro μXRD, XRPD and LA-ICPMS, complemented by the use of focused ion beam scanning electron microscopy, we investigated the crystallographic signature of bioapatite across a wide selection of paraconodonts and euconodonts to better understand their relationships, as well as the significance of conodonts and their connection to later vertebrates.

A journey through extinct lion morphologies, distribution, chemical imprints and pathologies

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Keywords: Felidae, geochronological variability.

Lions evolved in Africa 2.5 My ago. They spread across Eurasia around 1 Ma, reaching North America and Mexico since the Illinoian Stage, about 300 ka ago. The group diversified and then became extinct in the Northern Hemisphere around 12 ka ago. Today in Africa, the species faces increasing human pressure, habitat fragmentation caused by agricultural expansion, and progressive aridification. Nevertheless, throughout their long evolutionary history as apex predators, lions have adapted to diverse environments and climatic conditions, ranging from savannahs to cool temperate and humid ecosystems. Their fossil record is rich in localities but poor in occurrences, and their past ecological plasticity is demonstrated by the vast geographic range occupied by different lion lineages across three continents. Moreover, lions display the unique characteristic among felids of practicing reciprocal social acceptance. Where and when this behaviour evolved is still debated, but our studies have recently revised several ecological proxies available for the taxon to build a better understanding of its past lifestyle and long-term evolutionary trends.

Because of their role as top predators in food webs, lions have modulated herbivore abundance: their appearance and extinction triggered trophic cascades and ripple effects across ecosystems. Their disappearance from the Northern Hemisphere was likely accompanied by the establishment of new ecological equilibria, along with the demographic expansion of modern humans.

We are investigating the group's ecological envelope, proteomic signals and dietary variation among populations, ontogenetic patterns and pathologies, and interactions within different ecosystems. This multidisciplinary approach has allowed us to estimate the climatic constraints of cave lions, identify molecular markers linked to sex variation, characterize isotopic variability and dental microwear patterns, reconstruct dental eruption and skeletal ossification sequences to improve age estimation, and investigate the ability of lions to recover from traumatic injuries. Further studies are currently underway.

Our approach is providing new insights into the diversity of extinct lions, outlining a far more structured scenario than previously recognized. Our contribution summarizes current knowledge of lions as powerful predators of the past and highlights the fragility of their modern heritage.

A forgotten voyager: Review of *Protosphargis veronensis* (Pan-Chelonioidea) from the Upper Cretaceous of Northeastern Italy

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Keywords: sea turtles, Turonian, photogrammetry.

Protosphargis veronensis is the only sea turtle described from the Turonian (94-88 Ma) of northeastern Italy. The holotype was discovered in 1852 at Mount Guaiti (Lessini Mountains, Verona province) and formally described by Giovanni Capellini in 1884. Based on its large body size and reduced shell, Capellini considered it closely related to the giant protostegids from Kansas (USA), while also recognizing shared features with dermochelyids (Capellini, 1884). Over the years, however, this taxon has been assigned to the families Protostegidae, Dermochelyidae, and Cheloniidae (e.g., Cigala Fulgosi et al., 1980; Weems, 1988; Hirayama, 2005), highlighting the need for a modern anatomical revision to establish its systematic position. Here we present a reassessment of *Protosphargis veronensis*, including a preliminary anatomical analysis of the holotype, housed at the Capellini Museum of Bologna. As the specimen is displayed in a non-removable cabinet, a 3D model was generated using photogrammetry. Preliminary results indicate that *P. veronensis* resembles *Allopleuron hoffmanni* in plastron morphology, characterized by laterally positioned hyo-hypoplastra with large central fontanelles and elongated, rod-shaped xiphiplastra. Additionally, *P. veronensis* exhibits a distinctive costal morphology, with blade-like costals more reminiscent of those present in Dermochelyidae. This unique combination of characters supports the taxonomic validity of *Protosphargis veronensis* and suggests that this species was well adapted to a pelagic paleoenvironment. Ongoing phylogenetic analyses will further clarify the systematic position of this long-debated but still elusive taxon.

Capellini G. (1884) - Il chelonio veronese *(Protosphargis veronensis,* cap.*)* scoperto nel 1852 nel Cretaceo superiore presso Sant'Anna di Alfaedo in Valpolicella. Atti della Reale Accademia dei Lincei. Memorie della Classe di scienze fisiche, matematiche e naturali. Ser. 3., 18, 291-320.

Cigala Fulgosi F. et al. (1980) - Il giacimento di S. Anna d'Alfaedo. I vertebrati fossili italiani. Catalogo della mostra, Verona, pp 123-129.

Hirayama R. (2005) - Systematic position of *Protosphargis veronensis* Capellini, an enigmatic sea turtle from the Late Cretaceous of Italy. Journal of Vertebrate Paleontology, 25 (3), 70A, https://doi.org/10.1080/02724634.2005.10009942.

Weems R.E. (1988) - Paleocene turtles from the Aquia and Brightseat formations, with a discussion of their bearing on sea turtle evolution and phylogeny.Proceedings of the Biological Society of Washington, 101, 109-145, https://biostor.org/reference/74773.

An overview of the late Early to early Middle Pleistocene British hyenas

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Keywords: Carnivora, Europe, Quaternary.

The evolutionary history of hyenas (Carnivora, Hyaenidae) represents an extremely interesting case of reduction of diversity and specialization. During the Late Miocene, hyenas were very diverse, in terms of number of species and "ecomorphs", including forms that resembled, in some aspects of their morphology and inferred behavior, other extant carnivorans of other groups, and some that were basically unique (Werdelin & Solounias, 1996; Coca-Ortega & Pérez-Claros, 2019). Today, of the only four living hyena species, the aardwolf (*Proteles cristatus*) is a specialized termite-eater, whereas the brown (*Parahyaena brunnea*), striped (*Hyaena hyaena*), and spotted (*Crocuta crocuta*) hyenas are all "bone-crackers", the ecomorph that became dominant since the Pliocene. Being bone-crackers, hyenas were able to exploit trophic resources unavailable or difficult to access to for most other large mammals, resulting in the possibility to spread and live in different environments. The fossil record of "cave" hyenas (either considered conspecific with the living *C. crocuta* or recognized as a different species *C. spelea*) from the Late Pleistocene of Europe is locally extremely abundant, as exemplified by some cave deposits of England, whereas late Early and Middle Pleistocene remains of the group are relatively scarce in many countries (Iannucci et al., 2021). Here, a reappraisal of the late Early to early Middle Pleistocene British hyenas, consisting of remains of *Pachycrocuta brevirostris* and *C. crocuta* recovered from Bacton, Corton, Mundesley, Overstrand, Pakefield, Palling, Sidestrand, Westbury, and West Runton is presented and biochronological and paleobiological implications are discussed. Several localities yielded only few or fragmentary remains, but remarkable fossils are present. Moreover, the stratigraphic sequence of Westbury documents a substitution from *P. brevirostris* to *C. crocuta*, supporting the biochronological relevance of the *Pachycrocuta*-*Crocuta* replacement (Iannucci et al., 2021).

Coca-Ortega C. & Pérez-Claros J.A. (2019) - Characterizing ecomorphological patterns in hyenids: a multivariate approach using postcanine dentition. PeerJ, 6, e6238, https://doi.org/10.7717/peerj.6238.

Iannucci A. et al. (2021) - The extinction of the giant hyena *Pachycrocuta brevirostris* and a reappraisal of the Epivillafranchian and Galerian Hyaenidae in Europe: Faunal turnover during the Early-Middle Pleistocene Transition. Quat. Sci. Rev., 272, 107240, https://doi.org/10.1016/j.quascirev.2021.107240.

Werdelin L. & Solounias N. (1996) - The evolutionary history of hyaenas in the Miocene of Europe and western Asia. In: Bernor R.L., Fahlbusch V., Mittmann H.-W. (Eds.), The Evolution of Western Eurasian Neogene Mammal Faunas, Columbia University Press, 290-306.

New insights on the Middle Pleistocene paleoenvironments of Italy: stable isotopes from the large mammal fauna of Rome

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Keywords: Europe, museum collections, paleoecology.

The Middle Pleistocene witnessed remarkable changes in Earth's climate state, accompanied by the dispersal of new mammal species, extinctions, and the establishment of a relatively stable hominin presence in Europe. Many aspects of the timing, pace, and paleoecological context of these events remain unclear, pushing to investigate localities that span a long chronology and that allow robust inference. The area of Rome (central Italy) offers a key opportunity to reconstruct the paleoenvironmental conditions in the Italian Peninsula during the Middle Pleistocene, owing to its remarkable record of fossil remains of terrestrial large mammals and the geochronological constraints of its deposits (Iannucci et al., 2023). Yet, most of the paleontological findings from the area of Rome occurred in historical times and often as a by-product of the urbanization of the nineteenth and early twentieth centuries, requiring, therefore, important efforts to valorize and contextualize them by integrating indirect geological information and historical documentation. Here, we present the results of oxygen and carbon stable isotope analyses of large mammal teeth ($\delta^{13}C$ and $\delta^{18}O$ of the carbonate fraction of tooth enamel) from several sites of the area of Rome that collectively span ~300 ka (MIS 15-MIS 9), primarily based on the revision of the historical collections of the University Museum of Earth Sciences of Sapienza University of Rome (MUST). The results provide significant insights into the response of the large mammal fauna to the climatic fluctuations of the Middle Pleistocene, revealing cases of ecological differences between species and niche partitioning at a given site, in a context of important intraspecific adaptability.

Acknowledgements: This work has been supported by the Italian Ministry of University and Research, PRIN 2022 scorrimento - Prot. 2022JWFEKE "The evolution of mammals in changing ecosystems of the Middle Pleistocene of Italy".

Iannucci A. et al. (2023) - Middle Pleistocene mammal faunas of the area of Rome: recent results and ongoing work on the MUST collection. J. Mediterr. Earth Sci., 15, 19-37, https://doi.org/10.13133/2280-6148/18085.

Monitoring Langebaanweg: Further updates on the monitor lizard (Squamata, Varanidae) remains from the Early Pliocene of South Africa

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Keywords: Neogene, *Varanus*, reptile.

Langebaanweg (LBW) is a Late Miocene-Early Pliocene fossiliferous locality situated in the Western Cape Province, South Africa, located at a bee-line distance of approximately 110 km North-West of Cape Town. The site is internationally renowned for the diversity and preservation quality of its mammal and bird remains. However, few studies have been conducted on the equally abundant squamate fossil remains. This contribution focuses on varanid material from the Varswater Formation (Early Pliocene, ca. 5.1 Ma). The presence of monitor lizards (genus *Varanus*) in the LBW fauna was cursorily reported more than 40 years ago (Hendey, 1981), and no further study has been conducted on said remains since. The material abundancy (consisting of 31 cranial remains, 26 vertebrae, three ilia, and a humerus), allowed for a good comprehension of the skeletal morphology of the LBW monitor lizard. Upon morphological study, it is concluded that the LBW material belongs to a single extinct *Varanus* species previously undescribed, the second extinct species from the African continent and the eighth worldwide not represented by vertebrae alone. The LBW *Varanus* is diagnosed by the combination of six features, located on the premaxilla, maxilla, vomer and vertebrae. A preliminary phylogenetic analysis was conducted to identify the affinities of the new species with other extant and extinct monitor lizards, using a matrix with 79 taxa and 6225 characters (495 of which morphological). The results retrieve the new species in the African *Varanus* group, together with the extant *Varanus niloticus*, *Varanus albigularis*, and *Varanus exanthematicus*. *Varanus* n. sp. is preliminary reported to be more closely related to the latter two. The position of *Varanus* n. sp. in this clade is of palaeobiogeographical interest, given that *Varanus exanthematicus* currently inhabits Western and Central Africa and that *Varanus albigularis*, albeit reaching South Africa, is absent from its south-westernmost region. Therefore, the new *Varanus* from LBW represents the first confirmed evidence for a monitor lizard inhabiting this region of the African continent. Furthermore, the LBW remains constitute the oldest *Varanus* record in South Africa.

Hendey Q.B. (1981) - Palaeoecology of the Late Tertiary fossil occurrences in ‘E’ Quarry, Langebaanweg, South Africa, and a reinterpretation of their geological context. Annals of the South African Museum, 84, 1-104.

The oldest Neogene vertebrate assemblage of the Pisco Basin, Peru

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Keywords: elasmobranchii, early Miocene, Tunga formation.

Here we report a new elasmobranch assemblage from phosphorite layers exposed at Cerro Tiza, eastern Pisco Basin, southern Peru. Chronostratigraphic and biostratigraphic evidence indicates an Aquitanian (early Miocene) age and supports assignment of these strata to the Tunga Formation. This occurrence therefore represents the oldest Neogene vertebrate assemblage so far documented from the Pisco Basin. The assemblage includes at least 17 species and 15 genera of selachians and batoids assigned to Lamniformes, Carcharhiniformes and Myliobatiformes. Its taxonomic composition documents a diverse coastal marine ecosystem dominated by apex and mesopredatory taxa, mostly characterized by piscivorous feeding habits. These features are consistent with environmental conditions marked by elevated primary productivity, as also suggested by the phosphatic nature of the deposit. Taphonomic and paleoecological evidence indicates that the apparent dominance of a limited number of species within the Tunga phosphorite lag likely records the combined influence of ecological structure, local depositional dynamics and taphonomic filtering. The Cerro Tiza assemblage thus provides a key reference point for reconstructing the early Neogene history of marine vertebrate communities in the Pisco Basin and for assessing the onset of the highly productive ecosystems that later characterized this sector of the southeastern Pacific.

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A diverse suite of bioencrusters and bone modifications on a Pliocene proboscidean skeleton from the Valdelsa Basin (Tuscany, central Italy): insights on the fate of large terrestrial mammal deadfalls in coastal settings

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Keywords: barnacles, land mammal, episkeletozoan shadowing.

We report on a partial proboscidean skeleton from Pliocene coastal deposits of the Valdelsa Basin (Tuscany, Italy), which provides a premier window into the biostratinomic paths of large terrestrial mammal carcasses deposited in coastal settings. The skeleton exhibits a complex suite of barnacle bioencrusters, *Anellusichnus*- and *Thatchtelithichnus*-like traces, and subcircular pedestals of essentially unworn bone, occurring both isolated and in clusters. Several trace fossils and pedestals-like features are still capped by barnacle shells or remnants of the basal plate thereof, suggesting a causal relationship between the bioencrusters and these multifaceted bone modifications. Thin-section analysis of detached barnacle shells reveals solid radii, noncleft alae, a single row of longitudinal parietal canals, and simple interlaminate figures, allowing confident attribution to *Amphibalanus amphitrite*. This extant species typically inhabits shallow coastal and brackish environments, further supporting a nearshore setting for the studied deadfall. By extending Palmer et al.'s (1993) concept of "epibiont shadowing" from invertebrate shells to vertebrate bones, we identify a new type of bone modifications driven by barnacle-mediated surface protection. Barnacle shells locally shielded the underlying bone from microbioerosion, while the surrounding bone surfaces were progressively degraded, producing the observed pedestal-like structures in the making. The biostratinomic characters of the studied proboscidean remains testify to a long exposure on the seafloor, which allowed several generations of barnacles to colonize the bare bones. Ultimately, this specimen provides a rare, high-resolution record of marine taphonomic alteration affecting terrestrial mammal remains while highlighting the biostratinomic potential of encrusting barnacles.

Palmer T.J. et al. (1993) - Epibiont shadowing: a hitherto unrecognized way of preserving soft-bodied fossils. Terra Nova, 5, 568-572, https://doi.org/10.1111/j.1365-3121.1993.tb00307.x.

Description of a new specimen of *Keichousaurus hui*

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Keywords: taphonomy, Sauropterygia, biostratinomy.

This work presents the description and taphonomic assessment of a specimen of *Keichousaurus hui* belonging to the collection of Serrapetrona (Marche, Italy). *Keichousaurus hui* is a pachypleurosaur-like eosauropterygian from the Middle Triassic Xingyi Fauna of southwestern China. The specimen, with a snout-vent length of 166.3 mm, advanced degree of skeletal ossification and absence of cartilaginous elements, represents an adult individual and is preserved in an essentially complete and articulated state, retaining both the skull and phalanges. This state of preservation suggests a relatively short biostratinomic interval, with no clear evidence of predation, scavenging or prolonged transport. The retention of fragile anatomical elements, including the gastralia, along with the absence of bioturbation traces within the dark pelitic matrix, suggests a relatively rapid burial under low-energy anoxic water conditions that favoured exceptional preservation. Several sharp fractures affecting different parts of the skeleton are visible and likely occurred after bone permineralisation and are therefore attributable to sediment compaction during the diagenetic phase. The absence of evident weathering, combined with the remarkable articulation of the specimen, further suggests that the fossil was probably extracted directly from fossil-bearing laminated slabs rather than collected after prolonged exposure on the bedding surface. Additionally, investigations into sexual dimorphism, based on preliminary morphometric ratios and multivariate statistical analyses, suggest that the specimen may tentatively be identified as a female individual.

Pleistocene fish remains from the Aalat Formation, Dandiero Basin, Eritrean Danakil Depression

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Keywords: East Africa, fossil fishes, taxonomy.

The Pleistocene continental deposits of the Dandiero Basin (Northern Danakil Depression, Eritrea) are well known for the 1 Ma well-preserved *erectus*-like human remains. Additionally, the productive sites of this rift basin have yielded numerous fossils documenting a rich Early to Middle Pleistocene vertebrate fauna of fishes, reptiles, birds and mammals (Rook et al., 2013; Delfino et al., 2018). In the present study we describe the bony fish remains collected from the Aalat Formation exposed in three different sites of the Dandiero Basin, including the Buia *Homo* site, Mulhuli-Amo and Dioli. Fish remains from these localities comprise a relatively well-preserved articulated head skeleton plus several isolated cranial and postcranial bones pertaining to the catfish genus *Clarias*, a pharyngeal tooth tentatively referred to the cyprinid genus *Labeobarbus*, and isolated vertebrae and a median-fin spine assigned to the family Cichlidae. The fish assemblage is indicative of the presence of heterogenous fluvio-lacustrine habitats during the late Early Pleistocene of the Dandiero Basin.

Delfino M. et al. (2018) - The Early Pleistocene vertebrate fauna of Mulhuli-Amo (Buia area, Danakil Depression, Eritrea). Boll. Soc. Paleontol. Ital., 57, 27-44.

Rook L. et al. (2013) - Stratigraphic context and paleoenvironmental significance of minor taxa (Pisces, Reptilia, Aves, Rodentia) from the late Early Pleistocene paleoanthropological site of Buia (Eritrea). J. Hum. Evol., 64, 83-92.

The devil is in the denticles: Ecological implications for medium-sized Carcharodontosaurids (Dinosauria, Theropoda) from the Cenomanian Candeleros Formation (Neuquén Group, Patagonia, Argentina)

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Keywords: isolated theropod teeth, carcharodontosaurid, Principal Component Analysis (PCA).

The Candeleros Formation (Cenomanian) is recognised for yielding a diverse theropod fauna, including the iconic *Giganotosaurus carolinii*, a carcharodontosaurid considered among the largest carnivorous dinosaurs, and the sole representative of the family in this geological unit to date. Here we report ten isolated theropod teeth (MMCh-PV 306) recovered from the upper levels of the Candeleros Formation at Cañadón de las Campanas (near Villa El Chocón, Neuquén Province, Argentina). A combined morphological and morphometric approach, including Principal Component Analysis (PCA), was used to assess their taxonomic affinities. The teeth display features typical of Carcharodontosaurinae, including lateral wrinkles, transverse undulations, quadrangular denticles, and a serrated mesial carina. Wear facets at the apex indicate that the teeth were fully erupted and functional before being shed, likely during feeding activity. In the PCA based on linear measurements, the specimens fall within the morphospace of *Mapusaurus*. However, PCA analyses based on denticle counts show greater similarity to *Eocarcharia* and *Concavenator*. In carcharodontosaurids, denticle density generally decreases from basal taxa such as *Lajasvenator* and *Acrocanthosaurus*, which possess up to 17 denticles per 5 mm on the mesial carina, to *Giganotosaurus*, where the maximum count is generally 10. The analysed teeth possess 10-13 mesial denticles and 11-13 distal denticles. They also differ from *Giganotosaurus* in size, with the largest specimen reaching approximately half the length of the mesial teeth of that taxon. These teeth may belong to a subadult *Giganotosaurus*, in which smaller and proportionally more numerous denticles could reflect ontogenetic variation in feeding behaviour. Alternatively, they may represent another carcharodontosaurid taxon not yet reported from the Candeleros Formation. This interpretation is supported by evidence from *Mapusaurus*, where teeth of different sizes, potentially representing distinct ontogenetic stages, retain similar denticle counts. Theropod teeth are an important proxy for reconstructing faunal diversity and ecosystem structure. Both hypotheses, a juvenile individual with a distinct diet or the presence of another species, suggest complex trophic relationships in ecosystems where carcharodontosaurids thrived shortly before their extinction, as also indicated by the diversity documented in the Huincul Formation (Argentina) and the Kem Kem Beds (Morocco).

Biting into diversity: Morphometric insights into hidden theropod diversity of the Huincul Formation (Cenomanian-early Turonian, Argentina)

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Keywords: isolated theropod teeth, Principal Component Analysis (PCA), Gondwanan theropods.

Theropod teeth are among the most abundant vertebrate remains in continental Mesozoic deposits and represent a key proxy for reconstructing faunal diversity and ecosystem structure. However, the fragmentary nature of isolated tooth crowns often limits reliable taxonomic identification, reducing their palaeoecological and palaeoenvironmental significance. Here, we propose a combined morphological and morphometric approach based on Principal Component Analysis (PCA) designed to improve the taxonomic resolution of fragmentary theropod teeth through the selection of consistently preserved characters and linear measurements. The method was applied to the assemblage MMCh Pv 10, comprising 43 isolated theropod teeth from the La Antena locality, Huincul Formation (Cenomanian-early Turonian, Argentina), associated with the titanosaur *Choconsaurus* and the rebbachisaurid *Cienciargentina*. Comparisons between standard PCA analyses and the reduced-character dataset demonstrate a 44% increase in taxonomic assignment accuracy for fragmentary crowns, substantially improving the reconstruction of theropod assemblage composition. Eight morphotypes attributable to three theropod clades were identified: Abelisauridae, Megaraptora, and Dromaeosauridae. The abundance and diversity of theropod teeth, along with the occurrence of large-bodied sauropods, support the interpretation of a productive alluvial environment, providing additional vertebrate-based evidence for the hypothesis that the Huincul Formation developed under more humid and productive conditions than the arid settings proposed by previous authors. The megaraptoran material represents the oldest record of the clade in South America and displays crown morphologies more similar to Australian megaraptorans than to younger South American forms. These data suggest that a more homogeneous Gondwanan megaraptoran dental morphology persisted until at least the Cenomanian-Turonian faunal turnover, before the differentiation observed in later South American taxa. The dromaeosaurid teeth constitute the first record of the clade from the Huincul Formation and differ from the typical unenlagiine morphology, indicating a previously unrecognised ecological and taxonomic diversity among small-bodied South American dromaeosaurids. These results demonstrate how improving the taxonomic resolution of isolated vertebrate remains can significantly refine reconstructions of fossil communities and reveal faunal components otherwise obscured by preservational biases. In this context, theropod dental assemblages provide a powerful tool for investigating ecosystem structure, faunal dynamics, and paleoenvironmental conditions.

S19.

From Neogene to Quaternary: climate changes, proxy records, chronostratigraphy, environmental dynamics and future perspectives

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Refining the chronostratigraphy of Upper Miocene siliciclastic deposits in Valle Latina and Val Roveto using calcareous nannofossils

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Keywords: Calcareous nannofossils, syn-orogenic deposits, CARG Project.

Calcareous nannofossils are a powerful biostratigraphic tool for constraining the age and evolution of sedimentary basins. This study presents new biostratigraphic data from Upper Miocene siliciclastic deposits in the Valle Latina and Val Roveto areas (central Apennines), surveyed for the 390-Frosinone Sheet (CARG Project).

The studied successions belong to the foredeep, and wedge-top deposits associated with the Late Miocene evolution of the central Apennine orogenic system. In the Valle Latina area, the Arenarie di Torrice (TCE) represent the studied syn-orogenic succession. In the Val Roveto-Sora sector the Flysch della Val Roveto (UAP), which represent the foredeep filling, has been studied. Both consist mainly of turbidites sequences with alternating pelitic-arenaceous and arenaceous-pelitic facies associations, locally including coarse-grained sandstone beds.

Nannofossil assemblages from the Arenarie di Torrice (Monte San Giovanni Campano section) and the Flysch della Val Roveto include *Amaurolithus primus* associated with diverse *Discoaster* species, and *Reticulofenestra pseudoumbilicus*. The presence of *A. primus* (FO calibrated at 7.42 Ma; Di Stefano et al., 2023 provides a maximum depositional age. In the Arpino borehole, referred to the TCEc lithofacies of the Arenarie di Torrice, the nannofossil assemblages contain *A. primus*, *Reticulofenestra rotaria*, and *Helicosphaera sellii*, the latter indicating the Mediterranean influx event (6.48-6.30 Ma; Di Stefano et al., 2023). Abundant opportunistic taxa such as *Braarudosphaera bigelowii* and small-sized *Reticulofenestra*, suggest stressed paleoenvironmental conditions. In particular, the influx of *B. bigelowii*, calibrated at 6.168 Ma (Gennari et al., 2024), represents an important paleoenvironmental marker associated with increasing restriction and environmental perturbation preceding the Messinian Salinity Crisis. In the upper portion of the borehole, there is increase in *Sphenolithus* spp. and *Helicosphaera carteri*, possibly reflecting variations in nutrient availability and surface-water conditions. Overall, these assemblages indicate deposition under stressed marine conditions preceding the Messinian Salinity Crisis in the Mediterranean basin.

In the Flysch della Val Roveto, the assemblages point the occurrence of *Amaurolithus delicatus*, associated with *Discoaster brouwerii, D. pentaradiatus, and D. quinqueramus*. The presence of *A.delicatus*, whose FO in the Mediterranean region is calibrated at 7.13 Ma (Di Stefano et al., 2023), provides a maximum age constraint for the deposition of the succession.

Overall, the integration of geological mapping and calcareous nannofossil biostratigraphy refines the chronostratigraphic framework of these successions and improves the reconstruction of foredeep and wedge-top basin evolution during the Late Miocene. This study highlights the key role of microfossils in deciphering the timing and paleoenvironmental evolution of syn-orogenic systems.

Di Stefano A. et al. (2023) - Neogene-Quaternary Mediterranean calcareous nannofossil biozonation and biochronology: A review. Stratigraphy, 20(4), 259-302, https://doi.org/10.29041/strat.20.4.02.

Gennari R. et al. (2024) - Stress precursors of the Messinian salinity crisis as recorded by calcareous plankton and geochemistry in the Eastern Mediterranean: The Upper Metochia section of the Gavdos Island (Greece). Palaeogeogr. Palaeoclimatol. Palaeoecol., 636, 111970, https://doi.org/10.1016/j.palaeo.2023.111970.

Tracing volcanic and environmental events in tree rings: Evidence from micro-XRF dendrochemistry applied to Italian Alpine larch trees

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Keywords: dendrochemistry, volcanic proxies, micro-XRF.

Dendrochemistry, the study of element concentrations in tree rings, can be applied to detect signals of past volcanic eruptions, that are primary drivers of natural climate variability. Volcanoes outgas volatile metals that travel as fine particulate over thousands of kilometers before deposition in soils, and subsequently, uptake in vegetation (Edmonds et al., 2022). These elements may be preserved as concentration anomalies in tree rings, making dendrochemistry a promising novel volcanic proxy. Similarly, atmospheric dispersal of anthropogenic pollutants follows the same pathway and can be equally retained in wood.

We present synchrotron micro-XRF data acquired at Diamond Light Source (Didcot, UK) on Larch samples from the Italian Alps dating back to the Middle Ages. Concentration spikes of Zn, Cu, Ni, Pb and Fe, detected simultaneously across multiple samples, correspond with near-annual precision to known eruptions of major volcanic systems and to anthropogenic pollution during the 20th century. Several additional anomalies in periods with no documented volcanic activity may represent previously undetected eruptions.

These findings demonstrate that micro-XRF dendrochemistry on centuries-old larch trees can record geochemical signals consistent with both volcanic and industrial sources, and may identify eruptions not yet captured by existing proxies. The validation of this approach can improve the reconstruction of past volcanic forcing and its cascading effects on climate and society.

Edmonds M. et al. (2022) - Volcanic outgassing of volatile trace metals. Annu. Rev. Earth Planet. Sci., 50, 79-98, https://doi.org/10.1146/annurev-earth-070921-062047.

Early-Middle Pleistocene calcareous plankton biozonal maps of the Menfi basin (southwestern Sicily - Italy)

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Keywords: Calcareous plankton biostratigraphy, Calabrian-Chibanian, biozonal mapping.

Biozones are typically used to reconstruct the chronostratigraphic framework of vertical stratigraphic logs and outcrop sections. Moreover, in this work, the integrated calcareous plankton biostratigraphy has been used in an unconventional way, reconstructing the spatial distribution of the biozones recognized in the sedimentary record filling a Pleistocene wedge-top basin, using them in the same way as other geological surfaces and bodies.

The Menfi basin, one of the most recent and active wedge-top basins (WTBs) in the Plio-Pleistocene foreland basin system of southwestern Sicily, is the study area. This basin is located in the outermost sector of the Sicilian Fold and Thrust Belt (FTB), consisting of Meso-Cenozoic carbonate units (Saccense Domain) piled-up and unconformably overlain by deformed Middle-Upper Miocene sedimentary covers and Plio-Pleistocene syn-tectonic deposits (Catalano et al., 1998; Pucci et al., 2023).

The data and samples used in this work were obtained through recent geological surveys carried out for the Italian National Geological Mapping Programme (CARG sheets at 1:50,000 scale n. 628, "Sciacca", n. 618, "Castelvetrano", and n. 627, "Selinunte"). The biozonal mapping for the Menfi WTB and the reconstruction of an accurate chronostratigraphic framework of the Early-Middle Pleistocene succession were made possible by integrated calcareous plankton biostratigraphic analyses (planktonic foraminifera and calcareous nannofossils), which were combined with stratigraphic and sedimentological data on outcropping sections.

The planktonic foraminiferal biozones MPle1/2a (Lirer et al., 2019) and the calcareous nannofossil biozone MNQ19 (Di Stefano et al., 2023) were recognized, suggesting a Calabrian-early Chibanian time interval of deposition for the examined sedimentary record of the Menfi basin WTB, without notable hiatuses. The occurrence of auxiliary biomarkers, such as the benthic foraminifer *Hyalinea balthica* (marker of the mid-Calabrian age), further supported these chronostratigraphic attributions. The spatial distribution of these biozones indicates a general dipping towards the southwest of the stratigraphic succession, mainly characterised by hemipelagic sedimentation alternating with short stages during which neritic conditions were established. Tectonic forcing also played a crucial role in the distribution of these biozones, whose attitudes have been influenced by the compressional/transpressional deformations that occurred during and after the Calabrian stage. In conclusion, biozonal maps were found to be very helpful in reconstructing a detailed chronostratigraphic framework and in interpreting changes in the depositional geometries of the Menfi WTB infill, whose various growth phases during the Early-Middle Pleistocene were significantly influenced by the interplay of sedimentation, tectonics, and paleoenvironmental changes.

Catalano R. et al. (1998) - Sequences and systems tracts calibrated by high-resolution bio-chronostratigraphy: the central Mediterranean Plio-Pleistocene record. In: De Graciansky P.C., Hardenbol J., Jacquin P. & Vail P.R. (eds) Mesozoic and Cenozoic Sequence Stratigraphy of European Basins. SEPM Special Publication, 60, 155-177, https://doi.org/10.2110/pec.98.02.0155.

Di Stefano A. et al. (2023) - Neogene-Quaternary Mediterranean calcareous nannofossil biozonation and biochronology: A review. Stratigraphy, 20(4), 259-302, https://doi.org/10.29041/strat.20.4.02.

Lirer F. et al. (2019) - Mediterranean Neogene planktonic foraminifer biozonation and biochronology. Earth-Science Reviews, 196, 102869, https://doi.org/10.1016/j.earscirev.2019.05.013.

Pucci S. et al. (2023) - Geology of the lower Belice River valley, epicentral area of the M > 5 1968 seismic sequence (south-western Sicily, Italy). Journal of Maps, 19, 2242725, https://doi.org/10.1080/17445647.2023.2242725.

Comparative sclerochemistry of Plio-Pleistocene and modern *Glycymeris* shells from south-central Tuscany (Italy): Palaeoclimatic implications

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Keywords: glycymeris, comparative sclerochemistry, paleoclimatic recostruction.

Fossil mollusk shells represent excellent natural archives for reconstructing past climate variability due to their ability to record physicochemical changes during growth. Through a multidisciplinary approach, we investigated three specimens of the genus *Glycymeris*, including one Pliocene (uppermost Zanclean to lowermost Piacenzian), one Pleistocene (Emilian, mid-Calabrian) and one modern, from three different sites of Tuscany (central Italy). To verify the reliability of geochemical signals obtained from the fossil shells, a comparative taphonomic screening was carried out through micro- and ultrastructural characterization by means of optical and electron microscopy (SEM-EDS), mineralogical analyses (XRD), and measurements of trace element and rare earth element concentrations (ICP-MS). Mineralogical analyses of fossil and modern shells indicate an identical aragonitic composition, whereas SEM imaging reveals the characteristic three-layer shell structure of the genus *Glycymeris* in both fossil and modern valves. Trace element abundances, particularly Mn, Fe, Sr, Ba, Mg and U, are generally consistent between samples, with slight enrichment being observed in the fossil. The shell material was subsequently sampled along the growth lines to reconstruct oxygen- and carbon-isotope profiles for each specimen. Carbon isotopes consistently display a progressive decrease in $\delta^{13}C$ values through time, likely reflecting vital effects. Paleotemperatures were estimated using the paleotemperature equation of Grossman and Ku (1986), enabling interpretation within a seasonal framework. The results show that samples from the Pliocene specimen yielded minimum and mean temperatures higher than the modern specimen by approximately 0,8-3,4°C and 0,6-3,0°C, respectively, while maximum temperatures were overall comparable. In contrast, the analysis of the Pleistocene sample indicates overall cooler climatic conditions compared to the present day, with maximum, mean and minimum temperatures estimated to be lower than modern values by approximately 2.5-6.4°C, 2.3-6.2°C, and 3.7-7.6°C, respectively. Compared to the modern sample, seasonality appears to have been more pronounced during the Calabrian and weaker during the Pliocene, as indicated by the amplitude of $\delta^{18}O$ variations.

Grossman E.L. & Ku T.L. (1986) - Oxygen and carbon isotope fractionation in biogenic aragonite: temperature effects. Chemical Geology: Isotope Geoscience Section, 59, 59-74, https://doi.org/10.1016/0168-9622(86)90057-6.

Reconstruction of river floods in a stratigraphically expanded Holocene succession (Po Delta, Italy): Unravelling climatic and anthropogenic forcing

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Keywords: flood frequency, Holocene, Po delta.

Po della Pila is the youngest lobe of the Po delta, developed after the Porto Viro diversion (1604 CE) and resulting in 25 km delta progradation with a thickness of 30 m. We analyzed a 40 m-long sediment core (S1P), drilled through the Po della Pila lobe, by a multi-proxy analysis combining sedimentology, XRF core scanning, SEM observations and palaeoecological data, including pollen and meiofauna. These analyses allowed the identification of river (flood-related) and marine influenced processes recording past climatic and anthropogenic signals from a stratigraphically expanded succession.

Flood layers are recognized by sharp to erosive basal contacts, upward fining trends, and laminated silty-sand successions, reflecting the waning stages of high-energy river flows. This interpretation is supported by geochemical data (e.g. high Ni/Ca and low Mg), and SEM evidences of terrigenous and detrital material that help distinguish sediment source. Marine-influenced deposits are generally finer grained, contain well-preserved marine microfossils and organic matter, and geochemical indicators of reduced riverine activity; locally, storm beds occur as sharp-based, inverse graded, fine sand-dominated beds with planar to cross-lamination and occasional wave ripples. Flood events were chronologically constrained by an age-depth model based on 7 radiocarbon dates and short-lived radionuclides. Flood-event frequency variation was reconstructed through kernel density estimation (KDE), which provides a continuous representation of the temporal density of preserved event beds, allowing an estimate of the flood frequency through time.

Results show a progressive increase in event frequency towards the uppermost record, with a first clear intensification occurring after the 16th century, coincident with the Porto Viro diversion. This phase marks a major reorganization of sediment routing pathways within the Po Delta, enhancing source-to-sink connectivity and promoting the preservation of flood-related deposits. Event frequency continues to increase up-section, culminating in a two- to threefold rise over the last century. This most recent amplification occurs in a period of well-documented glacier retreat, increasing temperatures, and deforestation, which enhanced water discharge and hydrological variability within the catchment. However, this phase also coincides with a rapid increase in dam construction and widespread regulation of the river system making it difficult to disentangle climatic from anthropogenic controls on flood frequency. In contrast, earlier intervals characterized by higher event density correspond to phases of enhanced flood activity previously identified at the European scale. Overall, the S1P record highlights the potential of deltaic successions as archives of flood events, suggesting that the evolution of the Po Delta and its flood regime reflect the combined influence of climatic variability, fluvial dynamics and anthropogenic pressure.

Post-Miocene paleogeographic evolution of the External Hellenides through integrated biosphere-lithosphere analysis: A multidisciplinary approach based on sedimentary and fossil records, geophysical data, tectonics and plate-structural kinematic modeling

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Keywords: Hellenides, palaeogeographic recostruction.

The Northern Ionian Sea is a key area for understanding Mediterranean geodynamics, as it marks where the Adria Plate subducts beneath the SW-verging Hellenic fold-and-thrust belt (Soto et al., 2024). Despite its importance, a unified and agreed regional model for its post-Miocene palaeogeographic evolution is still missing. This lack is mainly due to 1) the local character of previous studies, largely restricted to Ionian islands (Corfu, Paxos, Antipaxos, Lefkada, and Cephalonia) or the Apulian margin and 2) the not-integrated multisciplinary approach adopted in these studies. The lack of a consistent framework is further due to sparse and scarce data (e.g., geophysical and well data). All these aspects also led to divergent interpretations. To resolve these discrepancies, we developed a comprehensive regional synthesis with a multidisciplinary approach integrating a systematic review of the sedimentary successions and fossil records (among the others Bossio et al., 1991; Bourli et al., 2025) with the restoration of regional seismic reflection profiles, geological cross-sections and plate movements. Our approach tracks the stepwise evolution of the system since the Late Miocene, the critical period when the Ionian Thrust, i.e., the primary structural element of the External Hellenides (Soto et al., 2024), was emplaced in this sector in response to plate kinematics. By linking the structural evolution of the chain to the fossil record, we could preliminarily quantify how the migration of the Hellenic front directly controlled paleobathymetry and shaped the marine environments of the Ionian sector. The reconstructed paleoenvironments and paleobathymetry are the base for defining the paleophysiographic evolution of this area and the attempt to trace through time the paleocurrents. Our analysis reveals high paleoenvironmental heterogeneity, capturing a transition from bathyal basins (exceeding 1000 m) to carbonate platforms and subaerial exposure events both in time and in space. Finally, this integrated dataset and results were processed using tectonic-paleobathymetric reconstruction software (Straume et al., 2020). The application of high-resolution digital models offers a comprehensive and dynamic visualization of tectonically induced paleoenvironmental shifts, providing a robust interpretative framework for the late Neogene-Quaternary paleogeographic evolution of this area.

Bossio A. et al. (1991) - Note geologiche e stratigrafiche sull'area di Palmariggi (Lecce, Puglia). Riv. Ital. Paleontol. S., 97(2), 175-234.

Bourli N. et al. (2025) - Facies and depositional architecture of Upper Miocene tidal flat sedimentation in Kefalonia and Corfu Islands, West Greece. Turk. J. Earth Sci., 34(3), 375-406, https://doi.org/10.55730/1300-0985.1965.

Soto J.I. et al. (2024) - Contrasting styles of salt-tectonic processes in the Ionian Zone (Greece and Albania): Integrating surface geology, subsurface data, and experimental models. Tectonics, 43, e2023TC008104, https://doi.org/10.1029/2023TC008104.

Straume E.O. et al. (2020) - Global Cenozoic Paleobathymetry with a focus on the Northern Hemisphere Oceanic Gateways. Gondwana Res., 86, 126-143, https://doi.org/10.1016/j.gr.2020.05.011.

Regional divergence from global trends: A high-resolution multi-proxy speleothem record of Termination I from Northern Sicily

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Keywords: Termination I, speleothem proxy, Sicily.

While the transition from the Last Glacial period to the Holocene (TI) is framed by global-scale reorganisations of the ocean-atmosphere system (Denton et al., 2010; Naughton et al., 2023), the expression of these events is profoundly filtered through regional lenses. In the Mediterranean, the "iconic" climatic phases documented in Greenland ice cores (Rasmussen et al., 2014) are identifiable but lack a uniform signature; indeed, local environmental architecture and regional feedback loops can introduce significant variations in the structure and timing of these events.

We present a high-resolution multi-proxy record from stalagmite V3 (Abisso del Vento, Sicily) to investigate the TI global climatic synchronicity. Spanning ca. 20 to 10.5 ka BP, stable isotope and trace element data reveal that the Mediterranean response is not a simple mirror of high-latitude forcing.

While the V3 proxies generally align with the broad climatic trends observed in Greenland ice cores, notable discrepancies emerge, particularly during the Greenland Interstadial 1 (GI-1), suggesting that local geographic factors and Mediterranean-specific dynamics can override or deviate from the global trend. By comparing V3 with other regional archives, we highlight the climatic complexity and environmental heterogeneity of the Mediterranean. This study underscores the necessity of local, high-resolution records in refining our understanding of how global drivers are modified—and sometimes obscured—by regional environmental conditions.

Denton G.H. et al. (2010) - The Last Glacial Termination. Science 328 (5986), 1652-1656.

Naughton F. et al. (2023). Introduction to the last Deglaciation climate. In European Glacial Landscapes, 33-36. Elsevier.

Rasmussen S.O. et al. (2014). A stratigraphic framework for abrupt climatic changes during the Last Glacial period based on three synchronized Greenland ice-core records: refining and extending the INTIMATE event stratigraphy. Quaternary science reviews, 106, 14-28.

Evaluating speleothem sensitivity to volcanic forcing in the Mediterranean region

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Keywords: speleothem, paleoclimate proxy, volcanic eruption.

Volcanic eruptions represent a primary natural forcing mechanism of the climate system, primarily inducing transient surface cooling (Sigl et al., 2013). However, our understanding of volcanically forced variability remains subject to significant uncertainties; before the instrumental era, these are further compounded by discrepancies between paleoclimate reconstructions and model simulations. Such uncertainty is amplified at the regional scale, particularly within the Euro-Mediterranean area-a region notably sensitive to volcanic forcing, yet characterized by poorly constrained response mechanisms. Consequently, the climatic impacts of even recent, well-documented eruptions remain elusive, posing a persistent challenge for the scientific community. Speleothems, specifically stalactites and stalagmites, are established archives for reconstructing paleoclimatic variability. Recently, they have been increasingly utilized as supplementary records for refining eruption chronologies and constraining the climatic impacts of volcanism (Badertscher et al., 2014; Paine et al., 2021). Within the DEMETRA Project, we present high-resolution stable-isotope and trace-element data from Central Mediterranean stalagmites (Central Italy, Balkan and Greece caves), to evaluate the capacity of these archives to detect volcanic signals and to determine the extent of subsequent impacts on local climate.

Badertscher S. et al. (2014) - Speleothems as sensitive recorders of volcanic eruptions-the Bronze Age Minoan eruption recorded in a stalagmite from Turkey. Earth and Planetary Science Letters, 392, 58-66.

Paine A.R. et al. (2021) - The trace-element composition of a Polish stalagmite: Implications for the use of speleothems as a record of explosive volcanism. Chemical Geology, 570, 120157.

Sigl M. et al. (2013) - A new bipolar ice core record of volcanism from WAIS Divide and NEEM and implications for climate forcing of the last 2000 years. Journal of Geophysical Research: Atmospheres, 118(3), 1151-1169.

A new imaging of Messinian Salinity Crisis recorded in the Central Mediterranean based on physical properties from the IODP Exp.402

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Keywords: Tyrrhenian Basin, synthetic seismogram, Messinian facies.

During the International Ocean Discovery Program (IODP) Expedition 402 in the Tyrrhenian Sea, two of the six drilled sites, the U1613 and U1617, were located on the thinned continental crust of the Cornaglia and Campania terraces, where the deposition of evaporites during the Messinian Salinity Crisis (MSC) had been imaged with seismic data. Expedition 402 recovered Messinian evaporites beneath a relatively thin sedimentary cover at both drill sites. At Site U1613, the Messinian section is extremely thin (a few meters only). In contrast, at Site U1617, a complete 102 m-thick evaporitic sequence ranging from gypsum-enriched terrigenous sediments through anhydrite to halite layers was sampled. This scientific drilling site is the only one in the Mediterranean that penetrated the complete Messinian evaporitic sequence, providing a unique opportunity to study the properties of the so-called Upper, Mobile and Lower units. A series of physical property measurements were performed on these cores on board of the JOIDES Resolution drillship, including P-wave velocity, density, magnetic susceptibility, natural gamma ray and thermal conductivity. In addition, we collected representative discrete samples to measure P-wave velocity (Vp), bulk density, grain density and porosity. These data allowed us to analyze the sealing properties of the halite unit and its interaction with salt-induced tectonics. Furthermore, from Vp and density used as input to calculate reflection coefficients, we generated a 1D synthetic seismogram at Site U1617. We compared this synthetic seismogram with the multi-channel seismic data acquired across the drill site, namely the Medoc 6 line. These new data allowed us to compare the Messinian units recovered in situ with multichannel seismic data and thereby revise seismic interpretation of these units. Thanks to the unique opportunity offered by the IODP Expedition 402, we now have reliable data on the physical properties of Messinian evaporites and we are able to provide new constraints on the interpretation of Messinian facies.

The Quaternary climatic changes in the Mediterranean deep-sea record: The planktonic foraminifera response

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Keywords: planktonic foraminifera, Mediterranean Sea, geochemistry.

The Earth's climate system is inherently dynamic and has been characterized by recurrent alternations between glacial and interglacial phases, particularly during the Quaternary (the most recent geologic period spanning the last 2.58 million years). These climatic oscillations have profoundly influenced marine ecosystems and biotic communities. In this context, the fossil record preserved in deep-sea sediments represents one of the most powerful tools for reconstructing past climate dynamics and improving our understanding of future climate evolution, a topic of primary relevance to the scientific community.

In this framework, this PhD project is situated, as part of the 41st cycle of the PhD Program in *Earth System and Global Changes* at the University of Perugia. It focuses on Quaternary climate variability in the Mediterranean region, with particular emphasis on the response of planktonic foraminiferal communities (single-celled protists) to major climatic perturbations over the last 2.3 million years (Ma).

The study is based on an integrated, multiproxy approach that combines micropaleontological analyses, stable isotope geochemistry, and additional geochemical proxies on planktonic foraminifera from different sites in the Mediterranean Sea. Samples are located in three key deep-sea marine sites in both the eastern and western Mediterranean basins, allowing basin-wide correlations and a comprehensive reconstruction of regional paleoenvironmental changes. Therefore, the main goal of the project is to reconstruct the climatic evolution of the Mediterranean Sea since 2.3 Ma, with particular emphasis on the onset of major Northern Hemisphere ice-sheet expansion at approximately 1.8 Ma, and to investigate how planktonic foraminiferal assemblages and associated oceanographic conditions responded to the intensification of glacial-interglacial variability during the Quaternary. Specific goals include: (i) the reconstruction of planktonic foraminiferal biostratigraphy over this interval in the Mediterranean basin; (ii) the establishment of a high-resolution stable isotope stratigraphy; and (iii) the reconstruction of Sea Surface Temperature (SST) variability from selected deep-sea cores. By integrating micropaleontological and geochemical data, this research aims to provide new insights into the timing, mechanisms, and ecological impacts of Quaternary climate change in the Mediterranean region.

Reconstructing past climate from rock-shelter successions: A multiproxy approach to the Riparo l'Oscurusciuto sequence (~65-43 ka, Apulia, Italy)

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Keywords: cave sediments, rock-shelter, climate.

Beyond serving as ancient human refuges, rock shelters also function as exceptional sedimentary archives, thanks to the limited erosion in their protected environments, preserving vital stratigraphic data used to reconstruct past climates, geological shifts, and prehistoric human-environment interactions.

The Riparo l'Oscurusciuto rock shelter (Ginosa, Apulia, Italy) preserves a 5.7 m-thick Middle Paleolithic sequence documenting several Neanderthals occupation phases. The upper 3.6 m comprises a dense archaeological record - including fireplaces, lithic tools, and faunal remains - that, based on the integration of ^{14}C, OSL, and tephrochronological constraints, was deposited between approximately ~42.7-65 ka BP. We thus estimate that this 20-25 kyr-long succession accumulated at a sedimentation rate of approximately 0.14-0.18 mm/yr, in average.

This contribution presents preliminary results from a multiproxy investigation of the unique Oscurusciuto succession, aimed at reconstructing local paleoclimate settings and comparing them with a coeval dataset across the Italian peninsula. Conducted within the framework of the ERC Synergy Grant Project "LAST NEANDERTHALS," our research utilizes high-resolution sampling (with sampling intervals as fine as 2 cm) to integrate legacy data with newly analyzed material. Specifically, the newly produced datasets include: 1- a sedimentological and micromorphological analysis of the overall sequence; 2- p-XRF geochemical analysis; 3- magnetic susceptibility analysis; 4- tephrochronological investigation of tephra; 5- palynological analysis. In this presentation, we focus in particular on the newly generated p-XRF and magnetic susceptibility datasets, exploring their potential to identify stratigraphic trends, sedimentary variability, and possible paleoenvironmental signals within the sequence.

By integrating these results with archaeological and archaeozoological records, we aim to reconstruct the environmental and paleoclimatic conditions of the Apulia region over the 20-25 kyr time-span preceding the Neanderthal demise in the southern Italian peninsula.

Multiproxy reconstruction of Indian summer monsoon dynamics during the Holocene in the Lower Ganga Plains

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Keywords: Indian Summer Monsoon, Holocene climate events, multiproxy lake sediment record.

The Indian Summer Monsoon (ISM) exerts a primary control on hydroclimatic conditions across the Indian subcontinent, yet its long-term response to global climate forcing remains insufficiently constrained. This study presents a high-resolution multiproxy reconstruction of Holocene monsoon variability from Hansadanga Lake, situated in the Lower Ganga Plains, covering the last ~12.2 kyr BP. Grain size, geochemical indicators (major and trace elemental ratios), and environmental magnetic parameters are integrated to capture both centennial and millennial scale variability in monsoon dynamics. The record reveals a strengthened early Holocene monsoon (~11.7 to 8.7 ka BP), characterized by intensified chemical weathering, enhanced runoff, increased detrital influx, and higher magnetic mineral concentrations, consistent with elevated solar activity and a northward displacement of the Intertropical Convergence Zone. This phase is followed by a progressive weakening of monsoon intensity from the middle to late Holocene. Superimposed on this long-term trend are distinct hydroclimatic perturbations at ~8.2, ~4.2, and ~3.2 ka BP, clearly expressed across multiple proxies. The pronounced signatures of the ~8.2 ka cooling event and the ~4.2 ka aridification event highlight their climatic significance, while their temporal correspondence with North Atlantic cooling phases indicates strong coupling between high latitude and low latitude climate systems. Overall, this study provides important insights into the mechanisms driving Holocene monsoon variability and establishes a robust long-term framework for assessing hydroclimatic change in monsoon dominated regions.

Reconstruct of Late Quaternary environmental dynamics in the Sicily Channel: A multidisciplinary approach based on planktonic foraminifera, Mg/Ca-SST and Stable Isotopes

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Keywords: planktonic foraminifera, geochemistry, Sicily Channel.

The Quaternary record of the Sicily Channel provides an exceptional archive to investigate past climate change and environmental dynamics. This research integrates quantitative data on planktonic foraminiferal assemblages, geochemical thermometers (Mg/Ca ratio on planktonic foraminifers Globigerina bulloides and Globigerinoides ruber white), stable isotope geochemistry ($\delta^{18}O$ and $\delta^{13}C$ on G. bulloides), supported by a robust high-resolution AMS ^{14}C chronostratigraphy for better understand central Mediterranean's last 20 kyr. We analysed the gravity core ND11_2013 (475 m water depth) from the NW Sicily Channel, recovered during the NEXTDATA 2013 oceanographic cruise aboard R/V CNR-Urania. The 489 cm-long core consists of grey hemipelagic sediments.

Starting from the base of the core, the multi-proxy dataset reveals a significant long-term warming trend, with SSTs rising from 8°C to nearly 22°C and an average of 16°C, punctuated by prominent short-term changes in SST signature. This is represented by a reduction in $\delta^{18}O$, which shifts from glacial values of 3.4‰ to an Holocene minimum of 0.1‰. The climatic phases identified are as follows: Last Glacial Maximum (19.8-17.3 kyr BP), Heinrich Stadial 1 (17.3-14.7 kyr BP, cyclic pattern HS1a, HS1b, HS1c), Bølling-Allerød (14.7-12.5 kyr BP), Younger Dryas (12.5-11.5 kyr BP), Sapropel S1 like (10 BP-6.4 kyr BP) and over the last 6.4 kyr BP the warm Early Bronze Age event (4.4-3.8 kyr BP), the Roman Period (2.4-1.4 kyr BP), and the Little Ice Age (700-100 yr BP).

During the Bølling-Allerød (14.7-12.5 kyr BP), the expansion of warm-water species and decreased $\delta^{18}O$ values (2‰) document a 4°C warming. Conversely, the Younger Dryas (12.5-11.6 kyr BP) is clearly marked by a 4-5°C cooling, evidenced by the peak abundance of the polar species N. pachyderma and a shift toward heavier δ18O values (2.5‰).

In the Holocene, the multi-proxy record captures the Sapropel S1-like event (10.2-6.4 kyr BP). Even if lithological signature of sapropel S1 is absent in this sector of the Mediterranean, the event is geochemically represented by a sharp negative shift in $\delta^{13}C$ (reaching -2‰) and $\delta^{18}O$, indicating a peak in primary productivity. Our data allow for a precise tripartition of this event (S1a, S1i, S1b), with the interruption of sapropel deposition at 8.2 kyr (S1i), prominently marked by N. pachyderma and increased $\delta^{13}C$ values, suggesting a temporary re-oxygenation of the water column.

Finally, the transition to the Late Holocene (post 6.4 kyr BP) is characterized by the expansion of *G. truncatulinoides*, signalling the onset of modern-like winter vertical mixing.

The correlation between faunal shifts and isotopic trends validates the sensitivity of the Sicily Channel to broader Mediterranean feedbacks, providing a comprehensive reconstruction of Quaternary climate variability, offering essential data to improve process understanding for future climate perspectives.

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In models we trust? Not yet. Testing ML vegetation models-based African biome reconstruction against palynological evidence over 2.5 Ma

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Keywords: African Quaternary, machine learning, palynological evidence.

Understanding environmental change in African landscapes is essential for uncovering the ecological context of early human evolution. However, Quaternary paleoenvironmental reconstructions based on pollen and faunal assemblages, are often spatially and temporally discontinuous, limiting the development of a cohesive framework (Edvardsson et al., 2022). Climate-driven vegetation models are widely used to reconstruct deep-time ecosystems, but they frequently introduce systematic uncertainties by oversimplifying ecological variability (Bond et al., 2008). We present a methodological framework aimed at generating spatially explicit vegetation reconstructions for the last 2.5 Ma and evaluate model performance using palynological data. By combining BIOME4 outputs for the last 120 ka (Beyer et al., 2020) with PaleoP-GEM bioclimatic variables (Barreto et al., 2023), we employ an ensemble modelling scheme (Random Forest, XG-Boost, and GLMM) to extend vegetation reconstructions across the full Quaternary record. The ensemble predicts Net Primary Production (NPP), Leaf Area Index (LAI), and discrete biome classes. Our approach assumes that the last 120 ka capture the most pronounced glacial-interglacial climatic fluctuations of the Quaternary. This provides a representative range of climatic conditions enabling the model to capture ecological responses that are applicable to the broader Quaternary record. Based on this assumption, the model reconstructs vegetation dynamics overt the past 2.5 Ma by applying climate-biome relationships learned from the training period to older climatic conditions that remain within the observed range of variability. Model outputs are validated against independent, high-resolution palynological records obtained from extensive ocean and lake drilling. By applying biomization processes to these empirical data, we assess spatial consistency and identify intervals of increased ecological heterogeneity or significant prediction uncertainty, quantified through inter-model variance and palynological residuals. This integration of process-based simulations, machine learning, and empirical validation provides a testable approach to long-term ecosystem reconstruction and a preliminary environmental framework for investigating relationships between vegetation dynamics, faunal assemblages, and early human evolution.

Barreto E. et al. (2023) - PALEO-PGEM-Series: A spatial time series of the global climate over the last 5 million years (Plio-Pleistocene). Global Ecol. Biogeogr., 32(6), 1034-1045, https://doi.org/10.1111/geb.13683.

Beyer R.M. et al. (2020) - High-resolution terrestrial climate, bioclimate and vegetation for the last 120,000 years. Sci. Data, 7, 236, https://doi.org/10.1038/s41597-020-0552-1.

Bond W.J. (2008) - What Limits Trees in C4 Grasslands and Savannas? Annu. Rev. Ecol. Evol. Syst., 39, 641-659, https://doi.org/10.1146/annurev.ecolsys.39.110707.173411.

Edvardsson J. et al. (2022) - The Integrated Use of Dendrochronological Data and Paleoecological Records From Northwest European Peatlands and Lakes for Understanding Long-Term Ecological and Climatic Changes—A Review. Front. Ecol. Evol., 10, 781882, https://doi.org/10.3389/fevo.2022.781882.

Reconstructing Holocene ecological quality status in the Bellocchio Lagoon (northern Adriatic Sea, Italy): Insights from stratigraphic and benthic foraminiferal records

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Keywords: EcoQS, PaleoEcoQS, Ecological Quality Ratio (EQR).

Transitional environments (e.g., lagoons) are highly biodiverse coastal ecosystems susceptible to anthropogenic and natural stressors (eutrophication, contaminants, storms, floods and relative sea-level rise). The assessment of the Ecological Quality Status (EcoQS) through biological indicators (e.g., benthic foraminifera), as required by the EU Water Framework Directive (2000/60/EC) and the Marine Strategy Framework Directive (2008/56/EC), is a key tool for evaluating ecosystem health in transitional environments. The strong natural variability of these systems may, however, hamper the interpretation of ecological indices and the distinction between natural and anthropogenic stress. Defining site-specific baseline conditions through palaeoecological approaches is therefore essential to contextualise present-day ecological conditions within long-term environmental variability.

In this framework, the EcoQS of the Bellocchio Lagoon (Po coastal plain) was evaluated by comparing present-day conditions with baseline conditions inferred from sedimentary records. Benthic foraminiferal assemblages from modern samples and sediment cores were integrated with sedimentological and geochemical proxies to reconstruct environmental changes and long-term ecological dynamics using the Foram-AMBI and $exp(H'_{bc})$ indices. Modern environmental conditions were reconstructed using benthic foraminiferal assemblages collected from morphologically distinct lagoon sectors. Multivariate analyses identified three main biofacies corresponding to inner lagoon, outer lagoon, and vegetated marsh/channel settings, each associated with specific sedimentological and geochemical parameters, including grain size, calcium carbonate and organic matter content. The comparison between living (biocoenosis) and dead (thanatocoenosis) assemblages highlights the spatial and temporal heterogeneity typical of transitional environments, suggesting that thanatocoenoses may provide a more integrated ecological signal for modern-fossil comparisons. Palaeoecological conditions (PaleoEcoQS) were reconstructed from well-dated Holocene successions in the Mezzano lowland, representing depositional environments comparable to the Bellocchio Lagoon. Using a Modern Analogue Matching approach, fossil assemblages were compared with modern biofacies to identify past analogues and reconstruct long-term environmental trajectories. Results show that diversity-based indices (e.g., $exp(H'_{bc})$) tend to underestimate EcoQS in lagoonal environments naturally dominated by few opportunistic taxa, reflecting the difficulty of disentangling natural from anthropogenic stress in transitional settings ("*estuarine quality paradox*"). In this context, the comparison between modern and fossil assemblages through the Ecological Quality Ratio (EQR) provides a valuable framework for contextualising present-day ecological conditions within long-term environmental variability and disentangling natural dynamics from anthropogenic forcing.

Fabric heterogeneity and paleoenvironmental constraints of upper Messinian microbialites from the Salento Peninsula (central Mediterranean)

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Keywords: microbialites, Messinian, central Mediterranean.

The Late Miocene in the Mediterranean was marked by the Messinian Salinity Crisis, a major event that triggered a transition in carbonate platforms from coral-dominated to microbialite-dominated systems. While such deposits are well documented in the western Mediterranean, new findings from the Salento Peninsula (southern Italy) provide critical insights into the diversity and evolution of microbial fabrics within the central part of the basin (Vescogni et al., 2025; Vescogni & Guido, 2026).

The studied stratigraphic succession includes different types of microbialites; here, we focus on two distinct intervals characterized by thrombolitic and dendrolitic fabrics with unusual features. A multidisciplinary approach combining field observations, microscopic analyses and biogeochemical techniques (UV epifluorescence and SEM-EDS) was applied to investigate their biotic origin and reconstruct their palaeoenvironment.

The first assemblage is a 3 × 28 m buildup composed of coalescent dendrolites and thrombolites. Dendrolites have a centimetre-scale dendritic growth form with a microlaminated microstructure. In contrast, thrombolites exhibit a decimetre-scale size, with an arborescent, anastomose growth pattern and a microfabric made of small spheroids made of acicular crystals. UV epifluorescence and SEM-EDS analyses reveal traces of organic matter closely associated with both microbialites fabrics, supporting their biotic origin, while ultrastructures suggest a major role for cyanobacteria in the biomineralization processes. The geometry and stratigraphy of the buildup, together with microfacies analysis of the associated sediments, suggest development in a shallow-water lagoon with moderate to high energy, variable salinity and tropical/subtropical climate.

The second assemblage is a 1.4 m-thick rudstone deposit rich in small, fan-shaped, lobate fragments, which occasionally form vertically elongated structures a few centimeters tall. UV epifluorescence and SEM-EDS analyses allowed the identification of organic-derived micritic clots and filamentous remains comparable to those of present-day cyanobacteria. These features support the interpretation of these structures as filamentous dendrolites. Sedimentary and microfacies data suggest a deposition in a lagoonal palaeoenvironment with moderate energy and normal marine salinity.

Overall, the fabrics described here highlight the importance of upper Messinian carbonate factories as an archive for microbialite research. The microfabrics associated with the dendrolite-thrombolite buildup appear to be extremely rare and previously unreported in the Cenozoic paleontological record. Moreover, filamentous dendrolites were previously known only from modern settings and therefore this example represents their first identification in the fossil record.

Vescogni A. et al. (2025) - New insights into upper Messinian microbial carbonates: A dendrolite-thrombolite build-up from the Salento Peninsula, central Mediterranean.Geobiology, 23, e70023, https://doi.org/10.1111/gbi.70023.

Vescogni A. & Guido A (2026) - Preservation of ephemeral microbial fabrics: late Messinian filamentous dendrolites from the Salento Peninsula (central Mediterranean). Palaeogeogr. Palaeoclimatol. Palaeoecol., 689, 113668, https://doi.org/10.1016/j.palaeo.2026.113668.

Late Quaternary glacier-glacier interactions and sediment connectivity as geomorphic proxies for environmental change in a distal lateral valley of the Adige catchment (southeastern Alps)

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Keywords: glacial dynamics, sediment connectivity, geomorphology.

Distal Alpine valleys preserve high-resolution geomorphic and sedimentary archives that are crucial for reconstructing Late Quaternary climate variability and associated environmental responses. In the southeastern Alps, the Terragnolo Valley offers an exceptional natural laboratory where the interplay between the Adige trunk glacier and minor local glaciers descending from the Pasubio massif generated a complex glacigenic succession sensitive to changes in temperature, precipitation patterns and ice dynamics.

Geomorphological evidence and sediment facies indicate that local glaciers likely maintained a degree of dynamic independence even during the maximum extent of the trunk glacier, with opposing ice-flow directions producing distinctive depositional signatures. These features provide insights into glacier-glacier interactions under build-up and climatically stable conditions. The resulting sedimentary architecture, dominated by carbonate clasts with limited trunk-glacier input, reflects shifts in ice-flow configuration, sediment sources and valley-floor aggradation during key climatic phases.

To explore how these glacial configurations influenced valley morphology, we integrate detailed geomorphological mapping, stratigraphic constraints and high-resolution palaeotopographic reconstructions across selected Late Quaternary time slices. Sediment (dis)connectivity is quantified using the Index of Connectivity (Cavalli et al., 2013), conceptualizing glaciers and associated deposits as time-dependent buffers and barriers following the framework of Fryirs et al. (2007). This approach allows us to evaluate how variations in ice extent, meltwater routing and evolving topography controlled sediment pathways, storage and release during transitions from Lateglacial to present-day conditions.

Preliminary results show that glacial dynamics strongly affected sediment connectivity, both through direct modification of valley morphology and through the subsequent reorganization of sediment pathways. These features provide new insights into hydrological reorganization and the sensitivity of Alpine catchments to rapid environmental shifts. The Terragnolo record thus contributes to a broader understanding of how Late Quaternary climate variability shaped sedimentary systems and landscape evolution in Alpine environments.

Cavalli M. et al. (2013) - Geomorphometric assessment of spatial sediment connectivity in small Alpine catchments. Geomorphology, 188, 31-41, https://doi.org/10.1016/j.geomorph.2012.05.007.

Fryirs K.A. et al. (2007) - Catchment-scale (dis)connectivity in sediment fluxes: Concepts, evidence and implications for river basin management. Geomorphology, 90(3-4), 297-316, https://doi.org/10.1016/j.geomorph.2006.01.044.

Paleoenvironmental evolution across the MIS 20-MIS 19 transition in the Ideale section (Montalbano Jonico, Southern Italy): Insights from benthic foraminifera and ostracods

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Keywords: micropaleontological analysis, palaeobathymetry, Pleistocene.

The Ideale section is part of the Montalbano Jonico succession (Southern Italy) and represents one of the global scale references for the Lower-Middle Pleistocene, as it has been approved as a Standard Auxiliary Boundary Stratotype (SABS) for the Global boundary Stratotype Section and Point (GSSP) of the Chibanian Stage. Moreover, it provides a continuous and highly expanded sedimentary archive spanning the transition between Marine Isotope Stage (MIS) 20 and MIS 19c (Ciaranfi et al., 2010), the latter considered the closest orbital analog to the Holocene.

Between 2014 and 2015, the section was resampled at high resolution (one sample every 20 cm, corresponding to approximately 90-200 years). In this study, benthic foraminiferal and ostracod assemblages from 45 samples covering the MIS 20-MIS 19c transition were analysed. According to the chronological framework proposed by Nomade et al. (2019), the onset of MIS 19c is located at about 2280 cm (~787 ka).

Both benthic foraminifera and ostracods document clear palaeoenvironmental and bathymetric variations across the glacial-interglacial transition. At the onset of MIS 19c, several benthic foraminiferal taxa that were present in low abundances during MIS 20, including *Cassidulina carinata*, *Melonis affinis*, *Quinqueloculina viennensis* and *Valvulineria complanata*, progressively increase in abundance. In contrast, taxa that were more common during MIS 20, such as the genera *Asterigerinata* and *Haynesina*, show a gradual decrease. A more marked faunal turnover is recorded at about 2600 cm (~785 ka), where the genus *Elphidium* and the species *Bulimina elongata* and *B. aculeata* sharply decrease, while *B. marginata* becomes dominant.

Ostracod assemblages display a similar trend. Species dominant during MIS 20, such as *Cimbaurila cimbaeformis*, *Leptocythere multipunctata* and *Sagmatocythere versicolor*, progressively decrease upwards, whereas deeper-water taxa, including *Henryhowella sarsii*, *Palmoconcha subrugosa* and species of *Cytheropteron*, become increasingly abundant. A further faunal change is observed around 2800 cm (~783 ka) with the first occurrence of *Bosquetina rhodiensis* and *Bairdoppilata conformis*.

The combined micropaleontological evidence suggests a progressive deepening from an upper circalittoral environment during MIS 20 (~100 m water depth) to a lower circalittoral setting during MIS 19c (~180-200 m water depth). These results provide new insights into the paleoenvironmental evolution of the central Mediterranean during the MIS 20-MIS 19 transition and highlight the strong response of benthic communities to climate changes.

Ciaranfi N. et al. (2001) - Pleistocene sections in the Montalbano Jonico area and the potential GSSP for Early-Middle Pleistocene in the Lucania Basin (Southern Italy). Mem. Sci. Geol., 53, 67-83.

Nomade S. et al. (2019) - High resolution foraminifer stable isotope record of MIS 19 at Montalbano Jonico, southern Italy: A window into Mediterranean climatic variability during a low-eccentricity interglacial. Quaternary Science Reviews, 205, 106-125.

The long-term Holocene hydrological variability of the Central Mediterranean: New data and perspective

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Keywords: Holocene, speleothems, Mediterranean.

Understanding Holocene hydroclimatic variability in the Mediterranean region is crucial for improving our interpretation of the evolution of the current climatic change. Roberts et al. (2008), in their review of $\delta^{18}O$ data from lacustrine carbonate in the Mediterranean basin noted that in the early Holocene, many lakes in the eastern and central part of the region were more depleted isotopically than in recent millennia, suggesting that during the Early Holocene wetter condition dominated in these sectors. In contrast, no such pattern was apparent from lake isotope records from the Western Mediterranean and Northen Italy, proposing a possible NW-SE hydrological contrast. Since then, several different data accumulated in the central Mediterranean region, producing different evidence using different proxies (e.g., Leng et al., 2010). This was interpreted by Magny et al. (2013) as related to a North-South hydrological contrast controlled by climate seasonality. Based on new data collected from lakes and speleothems from northern to southern Italy, we emphasize that several questions remain still without a precise answer and we can really speak of a "Holocene Central Mediterranean hydrological conundrum", far to be solved.

Leng M.J. et al. (2010) - Late Quaternary palaeoenvironmental reconstruction from Lakes Ohrid and Prespa (Macedonia/Albania border) using stable isotopes. Biogeosciences, 7, 3109-3122.

Magny M. et al. (2013) - North-south palaeohydrological contrasts in the central Mediterranean during the Holocene: tentative synthesis and working hypotheses. Climate of the Past, 9, 2043-2071.

Roberts N. et al. (2008) - Stable isotope records of Late Quaternary climate and hydrology from Mediterranean lakes: the ISOMED synthesis. Quaternary Science Review, 27, 2426-2441.

S20.

Arctic and Antarctic ice-sheet sensitivity to geological controls and climate variability

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The Wilkes Subglacial Basin in East Antarctica: Enduringly enigmatic but critically important

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Keywords: aerogeophysics, East Antarctic Ice Sheet, IPY.

The Wilkes Subglacial Basin (WSB) is attracting heightned international attention as a potential area of substantial East Antarctic Ice Sheet (EAIS) retreat. Determining whether this sector of East Antarctica was indeed a major contributor to past global sea level rise and whether it will be again in the future beyond 2100, remains a key and timely priority for new interdisciplinary research, particularly as the roadmap towards the next International Polar Year is starting to shape up.

Aerogeophysical exploration over part of the basin has unveiled that the bedrock dips inland and is grounded up to 2.1 km below sea level (bsl) within its remarkably deep sub-basins and remains at a depth 500 km inland of the present-day grounding zone. Despite a growing body of knowledge, geological, geomorphological, and oceanographic evidence for the location, amount and rate of EAIS ice sheet retreat within the WSB remains incomplete and also partially controversial, and numerical model predictions for the extent of EAIS retreat during past warmer periods (e.g. the mid-Pliocene, mid-Miocene and even more recent Quaternary times) differ significantly.

Here we review some of the results from different existing aerogeophysical campaigns and data compilations in the WSB focussing in particular on the importance of considering the heterogeneity in basal boundary conditions affecting and modulating long term EAIS behaviour, such as bed topography, geology, subglacial hydrology and geothermal heat flow. We conclude by presenting our case for the need of major new international aerogeophysical exploration efforts aimed at: 1) providing key missing bathymetric and geological data coverage over the much less well surveyed continental shelf and ice shelf cavities, adjacent to the WSB, which is critical to study ice sheet-ocean interactions and to link marine geological/geophysical and drilling observations with the dynamics of the grounded EAIS; 2) glean an improved understanding of past processes and tipping points, also in combination with marine and onshore geological records and 3) providing novel 4D (i.e. both space and time dependent) insights into Solid Earth influences on past, present and future ice sheet behaviour in this key sector of East Antarctica.

Pyroxenes provenance signature on East and West Antarctic Ice-Sheet dynamics during the Plio-Pleistocene transition (IODP Expedition 374, Site U1523)

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Keywords: pyroxene, Raman, microscope.

The mineralogy of pyroxenes analyzed from IODP sediments and cores (Site U1523, Exp. 374 - Ross Sea) represents an exceptional archive and provenance proxy for tracing source rocks and reconstructing the history of sediment erosion and transport in Antarctica. This study helps us assessing the provenance of sediments sampled in the Ross Sea, derived from the West Antarctic Rift System (WARS), from the Transantarctic Range (TAM), and from the East Antarctic Ice Sheet (EAIS), during the different glacial and interglacial periods of the Quaternary. The rocks derived from Cenozoic Magmatism-Volcanism, located in the Ross Sea and WAIS, are linked to an active rifting system dominated by markedly alkaline products, such as the Mount Erebus tephra, in which the presence of anorthoclase and green augite are a distinctive fingerprint of this eruptive center. The optical and spectroscopic characteristics of its minerals are unique, with the full-width mode width (FWHM) of clinopyroxenes reflecting the rapid cooling kinetics, typical of effusive rocks and pyroclastic products. In Continental Magmatism and Volcanism (TAM/EAIS), we find traces of the fragmentation of the supercontinent Gondwana, and this geodynamic environment is characterized by a subalkaline/tholeiitic signature, together the presence of an ancient Paleozoic metamorphic basement. In the Ferrar Group (Lower Jurassic), we find a predominantly tholeiitic magmatic suite (KCFB - Kirkpatrick Continental Flood Basalts). This suite contains a complex and diagnostic pyroxene association with orthopyroxene: Enstatite, Hypersthene with marked and diagnostic pleochroism in pale pink, pink-green, and dark pink-green tones; brown titaniferous augite and pigeonite. In the doleritic dykes (Intermediate/Hypoabyssal Intrusive rocks), we recognize colorless diopside, with intermediate order of crystallization in the crystal lattice of clinopyroxene. Aegirine (sodium clinopyroxene) is also found locally in the Alkaline Volcanism, associated with late alkaline intrusions. Thanks to this high-resolution study merging optical microscopy and Raman spectroscopy, it was possible to distinguish the different magmatic environments (deep, intermediate, and shallow) and their provenance from different sources, both in terms of formation age and geological provinces (Ferrar Jurassic vs. Cenozoic volcanism). By cross-referencing petrographic data, pyroxene mineralogical species, and varieties adding the Raman order and disorder dataset (FWHM), a new approach is being applied to provenance studies in these regions. This will allow us to more precisely characterize the sediment mineralogy during glacial and interglacial periods and to distinguish pyroxenes originating from different glacial basins that contribute to the sedimentological record in the Ross Sea through the geological time.

MYSTERO: Multidisciplinary investigation of enigmatic aubmarine mounds in the Western Ross Sea, Antarctica

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Keywords: submarine mounds, seismic stratigraphy, Ross Sea.

Fields of sub-circular submarine mounds, tens of metres high and hundreds of metres wide, occur at depths between 400 and 1200 m in the western Ross Sea, offshore southern Victoria Land and Cape Adare. Their origin and geological significance remain poorly understood.

The MYSTERO project investigates these features through an integrated geophysical and geological approach aimed at constraining their morphology, internal structure, and stratigraphic setting. During the XLI Italian Antarctic Expedition of the Programma Nazionale di Ricerche in Antartide (PNRA), onboard R/V *Laura Bassi*, over 2000 km² of multibeam bathymetry and backscatter data, sub-bottom profiler records, multichannel seismic profiles, and water-column acoustic data were acquired, complemented by sediment sampling and oceanographic measurements.

Preliminary results reveal complex mound morphologies and variable internal acoustic facies. Seismic and sub-bottom profiler data indicate heterogeneous internal architectures, suggesting the interplay of different depositional and post-depositional processes in mound formation. Morphobathymetric analyses also highlight relationships between mound distribution, seafloor morphology, and regional bottom-water circulation.

The integration of seismic stratigraphy, acoustic facies analysis, and seafloor geomorphology provides new insights into the evolution of these enigmatic features and their role within the Antarctic continental margin system.

Geomorphological evidence of EAIS oscillations from the northern Convoy Range, southern Victoria Land, Antarctica

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Keywords: East Antarctic Ice Sheet (EAIS), geomorphological mapping, glacial fluctuations.

The Antarctic continent represents the white heart of our planet, playing a fundamental role in regulating Earth's climate system and environmental dynamics. Consequently, the analysis of Antarctic landforms is essential for reconstructing the glacial history of the continent and identifying the main phases that have characterized its evolution through time. In particular, Antarctica's present-day ice-free areas constitute invaluable geological and paleoclimatic archives, preserving evidence of past glacial and environmental changes. The landforms that can be investigated in situ provide key constraints on the response of Antarctic ice sheets to climatic fluctuations, thereby offering crucial insights into the long-term interactions between climate forcing and cryospheric evolution.

Through the systematic geomorphological mapping and glacial-geological analysis of glacial landforms and deposits from the northern Convoy Range sector, we reconstructed the spatial extent of former ice advances and identified geomorphological evidence of repeated fluctuations of a dynamic EAIS. The integration of landform assemblages, stratigraphic relationships, and glacial sedimentary records allowed us to constrain the maximum thickness and extent of past ice masses, as well as to reconstruct the paleo-flow directions of glacial lobes that invaded the study sites.

The preserved geomorphological record documents successive phases of glacier expansion and ice-margin stabilization, as well as the subsequent geomorphic evolution of the survey area driven by the interaction of glacial, periglacial, and slope-related processes. Within this interpretative framework, geomorphological mapping contributes significantly to disentangling the evolution of Antarctic ice-free sites, as it provides the spatial and genetic context required for the robust interpretation of landform associations and glacial deposits. Furthermore, this approach establishes a solid methodological basis for the identification and selection of suitable targets for radiometric dating techniques, such as cosmogenic nuclide Surface Exposure Dating, which are essential for constraining the timing and magnitude of Antarctic glacier fluctuations in response to past climatic changes.

A seismic proxy identifying the transition to an ice sheet polar regime from the sedimentary sequence on the George V Land continental margin (Antarctica)

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Keywords: seismic facies, IODP, paleoclimate.

Based on the integrated analyses of seismic and borehole data from the Antarctic continental shelf and rise in the offshore area of Wilkes Subglacial Basin, we recognize two major turning points in the evolution of the East Antarctic Ice Sheet: in the early Miocene and middle Pliocene, defined by the establishment and deactivation of a noticeable channel-levee system on the continental rise. Our observation supports the earlier hypothesis that ice volume increased nonlinearly with climate before and during the Miocene Climatic Optimum (17-14.8 Ma), the warmest period of the Neogene, as a result of high snowfall under humid climatic conditions, with high moisture supply onto a more terrestrial landmass, prior to extensive erosion and overdeepening of Antarctica's continental shelves. The deactivation of the channel-levee system, evidenced by the progressive filling of the channels on the rise and the deposition of steeply dipping foreset beds at the shelf margin, occurred at about 3.3 Ma, just before the end of the Pliocene Warm Period (4.5-3.0 Ma), and represents the transition to the present polar regime. The late Miocene,and the early to middle Pliocene are also characterized by a particular high-amplitude seismic facies that is the signature of alternating terrigenous and diatom-rich layers, representing glacial and interglacial periods. This facies characterizes the upper part of the channel system and may represent a potential significant environmental and stratigraphic marker, elsewhere along the Antarctic continental margin.

Reconstructed source and sink CO_2 fluxes over the Late Pleistocene

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Keywords: carbon cycle, glacial-interglacial cycles, CO_2 fluxes.

Ice cores provide direct evidence of late Pleistocene (˜1 - 0 Myr) climate variability, constraining past carbon cycling and associated atmospheric CO_2 and global mean surface temperature variations (Lüthi et al., 2008; Jouzel et al., 2007). These records reveal systematic alternations between two contrasting climate states: relatively short, warm interglacials characterized by high CO_2 concentrations, and longer, colder glacials with reduced CO_2 levels. Orbital forcings are considered major drivers of glacial-interglacial variability, but intensified amplitude of interglacials and pronounced glacial phases since the Mid-Brunhes Transition (MBT) ~430 ka cannot be explained by orbital theory alone (Barth et al., 2018). This requires the activation of internal Earth System mechanisms, the nature of which remains debated. A major limitation to this aim is the poor quantification of atmospheric source and sink CO_2 fluxes which, more than absolute CO_2 reconstructions, may help identify tendencies in the carbon cycle and correlated temperature variations. Here, we apply a newly implemented Bayesian algorithm (Castrogiovanni et al., 2025) to invert the temporal CO_2 record of Dome C (Antarctica; Lüthi et al., 2008) and reconstruct robust time series of source and sink CO_2 fluxes over the last ˜800 kyr. We base the inversion on a simple formulation of the geological carbon cycle that takes a source and a temperature-dependent sink term. Results reveal systematic pulses of CO_2 source fluxes during glacial maxima and deglaciations, preceding peaks in CO_2 sink fluxes, with all pulses first appearing post-MBT. Qualitative process-based interpretations along with quantitative wavelet coherence and cross-correlation analyses suggest that post-MBT climate variability was amplified by feedbacks linking sea-level change, ice-sheet dynamics, and volcanic CO_2 emissions. Our findings underscore the influence of the solid Earth on late-Pleistocene carbon cycling and climate and offer critical constraints for models of past and future climates.

Lüthi D. et al. (2008) - High-resolution carbon dioxide concentration record 650,000-800,000 years before present. Nature, 453, 379-382.

Jouzel J. et al. (2007) - Orbital and millennial antarctic climate variability over the past 800,000 years. Science, 317(5839), 793-796.

Barth A.M. et al. (2018) - Climate evolution across the Mid-Brunhes Transition. Climate of the Past, 14, 2071-2087.

Castrogiovanni L. et al. (2025) - A reversible-jump Markov chain Monte Carlo algorithm to estimate paleo surface CO_2 fluxes linking temperature to atmospheric CO_2 concentration time series. Comput. Geosci., 196, 105838.

Morphological complexity and evolution of Hillary Canyon in the Eastern Ross Sea, Antarctica

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Keywords: Ross Sea, Hillary Canyon evolution, ice-ocean-sediments interaction.

This study presents preliminary results from the Italian PNRA-IOPPIERS (Ice-Ocean Past and Present Interactions in the Eastern Ross Sea) project, which investigates ice-ocean-sediment interactions in the Hillary Canyon area. The canyon lies on the continental slope and rise along the eastern flank of the Iselin Bank, serving as a preferential pathway for the cascading of dense shelf water (DSW) and the intrusion of relatively warm circumpolar deep water (CDW) onto the shelf (Morrison et al., 2020). The intrusion of CDW represents the main heat source for the ice shelf, and understanding its behaviour is essential for developing numerical models to estimate ice shelf stability and associated global sea level rise in the coming decades. To achieve this, it is necessary to understand the impact these fluxes had on canyon evolution in the past, how they relate to past climatic phases, and how they may change in the future. Despite its importance, the area remains poorly covered by high-resolution data, including bathymetry. The study integrates newly acquired geophysical, geological, and oceanographic data collected during the PNRA XLI cruise of R/V *Laura Bassi* in January 2026 with existing datasets. The aim is to investigate the relationships between seafloor morphology, bottom currents, sediment transport processes, inherited structural elements and their interactions in contributing to the long-term evolution of the area and canyon system. Preliminary results reveal a more complex evolution of Hillary Canyon than previously inferred. Along the mapped sector, the canyon is generally flat and infilled by sediments, suggesting that it underwent a major change in processes and sediment supply in the past, compared to the ancient buried sequences observed in the seismic sections. Direct data do not allow dating of the onset of the burial phase, but seismic interpretation of the Ross Sea Unconformities (RSU) (Brancolini et al., 1995), integrated with the most recent studies (Conte et al., 2021), suggests that the Late Miocene/Early Pliocene ice front progradation, associated with the growth of the Ross Sea fan, may have played a primary role in this process (Bart & De Santis, 2012). The new data also shed light on the possible relevance of tectonic processes in shaping the canyon path and the morphology of the entire area. Particular focus is given to the eastern canyon levee, which apparently shapes the canyon head below the shelf break. New seismic data highlight the potential presence of a sediment drift growing above a narrow, long ridge with a NE-SW orientation, continuing under the continental shelf. Its position probably contributed to the partial limitation of the Ross Sea fan spreading and sediment supply towards the canyon. It may preserve a record of bottom-current activity since at least the Middle Miocene. These findings provide new constraints on the evolution of Antarctic submarine canyons and have important implications for understanding ice-ocean-sediment interactions under changing climatic conditions.

Bart P.J. & De Santis L (2012) - Glacial intensification during the Neogene: A Review of Seismic Stratigraphic Evidence from the Ross Sea, Antarctica, Continental Shelf. Oceanography, 25(3), 166-183, https://doi.org/10.5670/oceanog.2012.92.

Brancolini G. et al. (1995) - Descriptive text for the Seismic Stratigraphic Atlas of the Ross Sea, Antarctica. Geology and Seismic Stratigraphy of the Antarctic Margin, Antarctic Research Series, A271-A303 pp., https://doi.org/https://doi.org/10.1002/9781118669013.app1.

Conte R. et al. (2021) - Bottom current control on sediment deposition between the Iselin Bank and the Hillary Canyon (Antarctica) since the Late Miocene: An integrated seismic-oceanographic approach. Deep-Sea Res. I: Oceanogr. Res. Pap., 176, https://doi.org/10.1016/j.dsr.2021.103606.

Morrison A.K. et al. (2020) - Warm Circumpolar Deep Water transport toward Antarctica driven by local dense water export in canyons. Science Advances, 6, 1-9, https://doi.org/10.1126/sciadv.aav2516.

Seismic oceanography reveals water column structure offshore East Antarctica

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Keywords: seismic oceanography, polar front, ocean dynamics.

Seismic oceanography provides a geophysical approach to image the thermohaline structure in the water column at high spatial resolution but its applications remain scarce. The method has great potential especially in Antarctic waters, where ocean-driven melting plays a key control on the stability of ice sheet margins and, at the same time, direct observations are sparse. Here, we integrate over 230 km of multichannel seismic reflection data acquired offshore George V Land (East Antarctica) during austral summer 2022 with coeval oceanographic measurements and models to investigate the frontal structure and water mass boundaries on the continental rise. Seismic processing was optimized to enhance water-column reflectivity, enabling fine-scale imaging of stratification and coherent reflections associated with thermohaline gradients. The seismic sections delineate a sharp frontal zone and allow identification of the southern boundary of the Antarctic Circumpolar Current in this sector. Wave-like reflections, interpreted as internal-wave signatures, and localized packages of disrupted reflectivity indicate spatially variable mixing and energetic conditions near the front. Comparison with oceanographic profiles supports correlation between seismic reflections and thermohaline interfaces and highlights the value of seismic imaging for bridging the spatial gaps inherent to conventional sampling in remote regions. These results demonstrate the capability of multichannel seismic data to provide a synoptic, high-resolution view of water-column structure in polar settings and illustrate the potential of combining new acquisitions with legacy seismic datasets for future geophysical investigations of Southern Ocean frontal dynamics. Such an approach can help constrain pathways of ocean heat transfer toward ice sheet margins, improving projections of ice sheet stability and future sea-level rise.

Phanerozoic structural inheritance as a primary driver of landscape evolution in the Transantarctic Mountains

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Keywords: Antarctica, extensional faulting, erosion.

The geometry of glacial valleys and outlet glacier pathways is fundamentally shaped by pre-existing bedrock structures, yet the deep geological origins of this topographic framework remain understudied due to limited coverage of field data. In the southern Victoria Land sector of the Transantarctic Mountains, we demonstrate that the large-scale valley network reflects a multi-stage structural inheritance rooted in ~ 500 Myr of tectonic evolution. Here, the bedrock geology comprises a Neoproterozoic-Ordovician crystalline basement cut by late orogenic dykes, unconformably overlain by Devonian-Jurassic Beacon sandstone. At 183 Ma, Ferrar LIP emplaced sills at the granite-sandstone interface and dykes crosscutting shallower sedimentary strata.

Over a ~ 500 km-long transect, we integrate: (i) measurements from 65 structural stations collected during three PNRA expeditions (from 2012 to 2019), (ii) geomorphic analysis of valley orientations and (iii) remote sensing analysis of magmatic intrusions. Statistically robust correlations exist between valley orientations and Jurassic Ferrar dolerite intrusions, which controlled drainage toward the Ross Sea; and between coastal faults and Ross dykes, whose reactivation controlled en-echelon segmentation of the rift shoulder.

We propose that Late Cretaceous-Eocene fluvial incision was guided by Ferrar-parallel fractures in Beacon Supergroup sandstones, and that subsequent glacial erosion inherited and deepened this pre-existing network. Cenozoic oblique rifting further reorganised the coastal sector, defining embayments relevant to outlet glacier geometries. These results highlight how hundreds-million-year-old structures exert first-order control on the pathways through which Antarctic ice reaches the Ross Sea.

Topography and ice dynamics interaction during early East Antarctic Ice Sheet growth: evidence from detrital records

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Keywords: source-to-sink, Antarctica, thermochronology.

The East Antarctic Ice Sheet is the largest ice mass on Earth, and its evolution depends critically on interactions between climate, ice dynamics, underlying topography and bedrock geology. Understanding how preglacial landscape modulated early ice-sheet growth remains a key open question as direct geological constraints from the Eocene-Oligocene Transition (~34 Ma) are scarce. Along the Transantarctic Mountains margin, southern Victoria Land offers a unique opportunity to address this problem, combining deglaciated bedrock exposures with offshore drill cores recovering Eocene to Miocene sediments.

Here we apply a source-to-sink approach integrating new detrital apatite fission-track thermochronology and zircon U-Pb geochronology from the CIROS-1 drill core, coupled with gravel and sand petrography, geomorphic analysis, and bedrock thermochronological constraints.

Multianalytical provenance analysis reveals systematic changes in erosional sources tracking landscape evolution from the late Eocene through the early Miocene. During the Eocene in catchments facing the Ross Sea detritus sourced from the locally exposed crystalline basement. Across the Eocene-Oligocene Transition, the provenance shifted to a progressive migration of erosional sources toward higher elevations, providing direct sedimentary evidence for outlet glacier expansion from the inner flank of the Transantarctic Mountains to the Ross Sea. Inherited fluvial valley networks and tectonic structures channelled ice flow, controlling the spatial pattern of glacial erosion. Through the Oligocene and into the early Miocene, glacial valley excavation and renewed tectonic activity along the Transantarctic Mountains margin drove a return to lower-elevation sources.

These findings demonstrate that the geometry of ice discharge pathways reflects a long-term structural inheritance rooted in Mesozoic exhumation and Cenozoic rifting, established before the onset of Antarctic glaciation. Incorporating geodynamic and landscape inheritance into ice-sheet models is necessary for assessing East Antarctic Ice Sheet sensitivity in future scenarios under the impact of climate changes.

4D Antarctica: The Geosphere modulates ice-sheet sensitivity and Earth system feedbacks

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Keywords: Antarctica, geodynamics, Earth system.

Antarctica hosts one of Earth's least understood pieces of continental lithosphere, yet its structure and long-term evolution through supercontinent cycles exert a fundamental control on ice-sheet behaviour and Earth-system processes. This contribution introduces a new 8 year-long SCAR Scientific Research Programme Antarctic Geosphere Evolution (AGE) and its central concept of 4D geological evolution, integrating spatial heterogeneity and temporal change in lithospheric and crustal architecture, tectonic inheritance, and geodynamics. AGE aims to quantify how the heterogeneous Antarctic lithosphere—shaped by deep-time geodynamic processes—governs subglacial geothermal heat flow variability, subglacial hydrology, and sedimentary and topographic basal boundary conditions, therefore modulating past, present and future ice-sheet sensitivity to climate change. By combining geological, geophysical, and geochemical observations with advanced data integration and numerical modelling, AGE seeks to provide improved, uncertainty-aware constraints on key parameters controlling basal melting, ice flow, and grounding-line stability. Beyond cryospheric processes, AGE explicitly addresses the role of solid Earth fluxes—including sediment, dust, and geo-nutrients—in linking the geosphere to the hydrosphere, biosphere, and atmosphere. These fluxes influence Southern Ocean productivity, biogeochemical cycling, and climate feedbacks, highlighting Antarctica's role in a dynamically coupled Earth system. Through coordinated international efforts, synthesis of legacy data, and targeted acquisition of new observations, AGE provides a novel framework to bridge different disciplines and datasets. The programme aims to deliver integrated 4D models of lithospheric evolution and Earth-system interactions, offering improved boundary conditions for next-generation ice-sheet and climate models. By embedding Antarctic geology within a fully coupled Earth-system perspective, AGE aims to advance understanding of how deep Earth processes shape ice-sheet sensitivity and global environmental change, and to improve predictions of Antarctic change in the roadmap towards the 5th International Polar Year.

Antarctic Geologic Evolution (AGE): SCAR science program planning group to unveil the 4D lithospheric architecture and dynamics of Antarctica

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Keywords: SCAR, solid earth, fluxes.

The Antarctic Geologic Evolution (AGE) program is a new SCAR initiative designed to integrate multidisciplinary data and expertise to resolve the complex lithospheric structure and evolution of the Antarctic continent. AGE aims to develop a four-dimensional (4D) framework of Antarctica's tectonic architecture, from Archean cratons to Cenozoic rift systems, and to understand the processes that have shaped its crust and upper mantle over geological time. Structured around three scientific pillars - Architecture, Processes, and Interactions - AGE will synthesize geophysical, geological, and geochemical data to produce high-resolution maps and models of crustal provinces, lithospheric boundaries, and heat flow regimes. The program will explore geodynamic mechanisms such as rifting, magmatism, orogenesis, and sedimentary basin evolution, and assess their role in modulating geothermal flux, surface topography, and glacial dynamics. AGE further emphasizes the coupling between the solid Earth and surface systems, seeking to constrain how lithospheric heterogeneity influences ice sheet behavior, subglacial hydrology, and biogeochemical fluxes. These investigations are essential to contextualize Antarctica's geological history within supercontinent cycles and to anticipate its future role in Earth system processes. AGE is designed as an open, inclusive, and collaborative platform supporting international polar science priorities, and aims to deliver key geoscientific products in time for the International Polar Year 2032/33.

Unveiling geothermal heat flux heterogenity beneath the weak underbelly of the West Antarctic Ice Sheet

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Keywords: aeromagnetic data, geothermal heat flow, Antarctica.

Thwaites Glacier in West Antarctica has been recognised as a major Antarctic contributor to accelerated present and future sea level rise and has been inferred to represent the weak underbelly of the marine-based West Antarctic Ice Sheet (WAIS) as it could potentially even trigger its collapse in response to persistent future climate warming. The region has therefore been the focus of major international research efforts particularly on behalf of US, UK, German and Korean research teams over the last five years, aimed at understanding the present-day dynamics and future stability of this key sector of the WAIS. These efforts have led, for example, to a significant improvement in our understanding of the bedrock topography and subglacial geology hidden beneath this part of the ice sheet that represent key geological boundary conditions that modulate ice sheet behaviour (e.g., Jordan et al., 2023). There is, however still a paucity of knowledge regarding the extent of the heterogenity in geothermal heat flow (GHF) in the region and its effects on active subglacial hydrology in the Thwaites Glacier catchment (e.g., Kim et al., 2025, JGR).

Here we present the results of enhanced spectral analysis of a new aeromagnetic anomaly compilation over the region conformed at long wavelengths with SWARM satellite magnetic data to help address this significant knowledge gap. We apply manual picking of defractal magnetic power spectra to perform Curie depth estimation as a proxy for GHF variability and compare our results with those obtained using automated workflows. Furthermore, we compare our results with independent GHF estimates from seismology, multivariate-similarity approaches and previous magnetic studies.

We show that in the Amundsen Sea Embayment in West Antarctica our manual spectral picking of aeromagnetic data resolves the spatial heterogeneity in GHF anomalies better than previous approaches. We newly define a wide coastal region of relatively lower values corresponding to recently inferred mafic intrusions within this sector of the West Antarctic Rift System (WARS) and higher GHF in the Byrd Subglacial Basin. This is a highly significant result, as it suggests that elevated GHF may contribute to the onset of enhanced ice flow deep in the interior of the Thwaites Glacier catchment. Additionally, we find localised GHF anomalies directly beneath a cluster of Thwaites active lakes, which may increase subglacial water availability, thereby potentially promoting reduced basal shear stress, despite the widespread hard bed or mixed bed conditions related to the occurrence of relatively widespread crystalline rocks beneath several parts of the glacial catchment. Overall, our magnetic results provide a new tool to help develop thermal models of the crust and upper mantle, which in turn are required to better comprehend how the structure, composition and tectonic development of the WARS can explain the heterogeneity in GHF that we imaged beneath this vulnerable sector of the WAIS.

Jordan S. et al. (2025) - Tracing the inner edge of the habitable zone with sulfur chemistry. Science advances, 11(5), eadp8105.

Kim H.R. et al. (2025). Antarctic magnetic anomalies and their gradients differentially reduced to the geomagnetic pole for enhanced crustal analysis. Journal of Geophysical Research: Solid Earth, 130(5), e2024JB029687.

Apatite (U-Th)/He thermochronology of NEGIS-derived sediments: New constraints on the origin of East Greenland's low-relief surfaces

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Keywords: Greenland, Apatite, thermochronology.

The coexistence of deeply incised fjords and high-elevation, low-relief surfaces along the East Greenland margin remains one of the most debated topographic configurations in glaciated passive margins. Two end-member hypotheses persist: the surfaces represent Mesozoic peneplains uplifted during the Cenozoic and presently inert, or they are dynamic landforms maintained by sustained glacial and periglacial erosion at high altitudes coupled with isostatic rebound driven by valley incision, a framework encompassing the glacial buzzsaw and the isostasy-climate-erosion (ICE) hypothesis (Nielsen et al., 2009). Distinguishing between these scenarios is critical for reconstructing pre-glacial topography, for quantifying the magnitude of Cenozoic valley incision, and for initialising ice-sheet models at glacial inception with realistic boundary conditions.

Detrital apatite fission-track (AFT) data from ODP sites 918 and 987 (Olivetti et al., 2022) revealed a progressive ageing of older detrital age populations through the late Cenozoic, interpreted as an increasing contribution of sediment from high-elevation source areas since approximately 3 Ma. However, Fox and Pedersen (2024) demonstrated that, once bedrock AFT ages are interpolated using a spatially variable exhumation-pace model that honours both elevation and lateral variability, old detrital ages may equally be sourced from low-elevation, high-slope terrains close to the coast as from the plateau surfaces. The AFT system alone, owing to its relatively high closure temperature and dominant control by pre-glacial tectonic and thermal events, cannot resolve this ambiguity. A lower-temperature thermochronometer, more sensitive to late Cenozoic topographic evolution, is required.

We present preliminary apatite (U-Th)/He (AHe) data from sediment sample PS100/270 (core catcher, 18-24 cm; Northeast Greenland continental shelf), sourced from the Northeast Greenland Ice Stream (NEGIS) drainage and deposited in the late Holocene. A first set of single-grain AHe analyses yields a bimodal age distribution: a dominant Palaeozoic-Mesozoic mode centred near 300 Ma, consistent with bedrock AHe signatures inherited from post-Caledonian slow cooling, and a striking young population of near-zero ages. This younger mode, if confirmed by further analyses and screened against analytical artefacts, points to active or geologically recent exhumation within the NEGIS catchment.

Our preliminary results illustrate the potential of AHe dating to constrain the late Cenozoic erosional behaviour of Greenland's low-relief surfaces and, more broadly, to discriminate between inherited and actively eroding plateau landscapes in high-latitude passive-margin settings. Ongoing work focuses on expanding the single-grain dataset and integrating the AHe ages with the bedrock exhumation-pace framework of Fox & Pedersen (2024) to localise the source of the young population within the NEGIS catchment.

Nielsen S.B. et al. (2009) - The evolution of western Scandinavian topography: a review of Neogene uplift versus the ICE (isostasy-climate-erosion) hypothesis. Journal of Geodynamics, 47.

Olivetti V. et al. (2022) - Increased erosion of high-elevation land during late Cenozoic: evidence from detrital thermochronology off-shore Greenland. Scientific Reports, 12.

Fox M. & Pedersen V. (2024) - Old detrital AFT ages from East Greenland do not require plateau erosion. Journal of the Geological Society, 181.

Garnet provenance signature on East and West Antarctic Ice-Sheet dynamics during the Plio-Pleistocene transition (IODP Expedition 374, Site U1523)

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Keywords: Antarctica, provenance, heavy minerals.

Antarctica is a unique natural laboratory for investigating interactions among climate change, ice-sheet dynamics, and subglacial geology, providing key insights into past climate variability and ongoing climate change. However, with nearly 98% of the continent covered by ice, direct access to geological and paleoenvironmental archives is limited. In this context, marine sedimentary records represent one of the few accessible natural records, allowing reconstruction of ice-sheet stability, sediment transport and climate variability.

Here, we analyse heavy-mineral assemblages from samples recovered during IODP Expedition 374 at Site U1523, located on the margin of Iselin Bank in the Ross Sea. The site records continuous sediment accumulation derived from glacial erosion of both the West and East Antarctic Ice Sheets. Sediment supply to the site is also influenced by the Antarctic Slope Current (ASC), which plays an important role in sediment redistribution along the continental margin.

Provenance analysis focuses on the micro-Raman characterization of garnet assemblages over 32 samples, spanning the last ~4 Myr. Garnet allows discrimination among metamorphic sources mostly associated with East Antarctica, magmatic sources linked to West Antarctica and sources derived from the Transantarctic Mountains (TAM). Preliminary results highlight the potential of garnet-based provenance analysis to trace sediment sources and reconstruct Antarctic ice-sheet dynamics during the Plio-Pleistocene, while providing new constraints on Antarctic geology.

Core-log-seismic integration in the Eastern Fram Strait Paleo-Archive: Filling the gaps

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Keywords: core-log-seismic integration, Bellsund Drift, IODP Expedition 403.

IODP Expedition 403 ("Eastern Fram Strait Paleo-Archive") targeted high-resolution sedimentary archives from the eastern Fram Strait and western Svalbard margin to reconstruct Arctic climate, oceanographic variability, and the evolution of the Svalbard-Barents Sea Ice Sheet during the Quaternary. The Bellsund Drift sites (U1621-U1623), drilled along the western Svalbard margin, recovered expanded contourite-dominated successions that were deposited under the influence of the northward-flowing West Spitsbergen Current.

Site U1623 recovered a continuous expanded sequence covering the last 1.5 Ma, whereas the upslope Site U1621, was specifically designed to obtain a more expanded and continuous stratigraphic record through the Mid-Pleistocene Transition and Mid-Brunhes Event. The site combines excellent recovery, physical property datasets, downhole logging, and seismic coverage, providing an opportunity for core-log-seismic integration.

The present contribution focuses on integrating sediment cores, borehole logs, and seismic data at Site U1623 to bridge stratigraphic gaps and improve the interpretation of contouritic and glaciomarine depositional processes in the Fram Strait paleoenvironmental archive. This study presents a core-log-seismic integration workflow for Site U1623 on the Bellsund Drift, where drilling recovered a predominantly siliciclastic, methane-bearing succession subdivided into two main lithostratigraphic units. Across the Bellsund Drift sites (U1621-U1623), reliable velocity information is largely absent because shipboard P-wave measurements become progressively degraded by noise and signal depletion below shallow depths. Geophysical well logs were acquired in Hole U1623D (98.4-249.8 mbsf), providing a valuable in situ sediment-seismic calibration that must be integrated with core-based measurements. Given the type of sediments and the presence of gas, physically plausible combinations of matrix and fluid velocities were tested using a grid search against the U1623D sonic log, and the optimal parameters were selected by maximizing Pearson correlation between measured and Wyllie-derived velocities. The reconstructed pseudo-velocity, combined with a composite density pseudo-log derived from harmonized core and log datasets, was subsequently used to generate a synthetic seismogram and establish a seismic tie between Site U1623 and seismic reflection profiles. This calibrated tie is then transferred to nearby Site U1621 and adapted to the surrounding seismic traces, extending seismic calibration across the drift and enabling the imaging of key petrophysical properties.

In summary, core-log-seismic integration allows seismic reflections to be accurately dated and tied to lithological and paleoenvironmental changes identified in the boreholes. At the same time, it bridges the gap between the punctual stratigraphic information from drilling sites and the regional-scale geometry and continuity of depositional units imaged in seismic profiles.

Ice-ocean past and present interactions in the Eastern Ross Sea (PNRA-IOPPIERS project): Preliminary results

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Keywords: Antarctica, geology, oceanography.

We present preliminary results of the Italian PNRA-IOPPIERS project. The main objective is to investigate past and present ice-ocean-sediment interactions in the area of the Hillary Canyon (Eastern Ross Sea) to shed light on the sensitivity of the Antarctic Ice Sheet. To achieve this goal, the project integrates a wide range of temporal scales, from instantaneous/seasonal (oceanographic measurements) to recent timescales (multiproxy sediment analyses) and further back into the geological past (seismics crossing IODP boreholes). The Hillary Canyon area was selected because it represents a preferential pathway for the export of dense shelf water (that interacts with the along-slope current) and for the intrusion of warm water masses that enhance ice shelf melting. The area is located at the mouth of the Glomar Challenger and Pennell basins, two major troughs carved by paleo-ice streams originating from the West Antarctic Ice Sheet and responsible for transporting large volumes of glacigenic sediment. This region remains poorly constrained in data coverage, which constitutes one of the major limitation for numerical modelling efforts aimed at reconstructing past conditions and predicting future sub-ice shelf melting, ice-sheet collapse and sea-level change. We aim to conduct an integrated geophysical, geological and oceanographic investigation to better understand the relationship between seabed morphology, bottom currents, sedimentation and benthic environmental conditions. The IOPPIERS project will compare contemporary processes with those reconstructed for past climatic changes, including the last deglaciation, past warm intervals and glacial maxima. During the PNRA Italian XLI cruise performed with RV Laura Bassi in January 2026, 375 km of multichannel seismic lines, nearly 1,700 km of sub-bottom profiles and over 2,000 km2 of multibeam data were acquired along with the collection of 3 multicorer, and deployment of 25 CTDs, one mooring and one Arvor float in the Hillary Canyon area. Preliminary analyses propose new interpretations through a multidisciplinary approach.

Middle Pliocene ocean temperature thresholds driving ice-sheet sensitivity at Wilkes Land (East Antarctica): Insights from integrated TEX_{86} and diatom proxies

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Keywords: Wilkes Land, middle Pliocene Warm Period, multi-proxy investigation.

The Wilkes Land region of East Antarctica is one of the most vulnerable sectors of the Antarctic Ice Sheet (Escutia et al., 2011) to ocean-driven melting, making it a key area to investigate ice-sheet sensitivity to climate variability, particularly during the middle Pliocene Warm Period (mPWP, also known as the PRISM interval: 3.264 to 3.025 Ma; de Boer et al., 2015), characterized by atmospheric CO_2 concentrations comparable to present-day levels (Escutia et al., 2011) and sustained ocean warming, and thus represents a valuable analogue for future climate scenarios.

This study reconstructs ocean temperature variability and associated paleoenvironmental conditions in the Wilkes Land region using an integrated multiproxy approach. TEX_{86}-derived temperature estimates (Varma et al., 2024; Bijl et al., 2025) are obtained from mPWP in sediment cores recovered during IODP Expedition 318 (Site U1359) and combined with quantitative analyses of diatom assemblages from the same stratigraphic interval. This integration enables reconstruction of surface-water conditions, sea-ice extent, and water column stratification, providing a comprehensive view of oceanographic variability.

The comparison between biomarker-based proxies and micropaleontological indicators allows evaluation of their consistency and associated uncertainties in high-latitude temperature reconstructions. This approach provides tighter constraints on ocean temperature thresholds and their role in driving ice-sheet dynamics.

The results are expected to improve constraints on the sensitivity of the East Antarctic Ice Sheet to ocean forcing during past warm periods, contributing to a better understanding of feedback mechanisms between climate, ocean circulation, and cryosphere stability, with potential implications for future Antarctic ice-sheet response under ongoing global warming.

Bijl P.K. et al. (2025) - Reviews and syntheses: Best practices for the application of marine GDGTs as proxy for paleotemperatures: sampling, processing, analyses, interpretation, and archiving protocols. Biogeosciences 22.21, 6465-6508, https://doi.org/10.5194/bg-22-6465-2025.

de Boer B. et al. (2015) - Simulating the Antarctic ice sheet in the late-Pliocene warm period: PLISMIP-ANT, an ice-sheet model intercomparison project. The Cryosphere Discussions 8.6, 5539-5588, https://doi.org/10.5194/tc-9-881-2015.

Escutia C. et al. (2011) - IODP Expedition 318: From greenhouse to icehouse at the Wilkes Land Antarctic margin. Scientific Drilling 12,15-23, https://doi.org/10.2204/iodp.sd.12.02.2011.

Varma D. et al. (2024) - Evaluating isoprenoidal hydroxylated GDGT-based temperature proxies in surface sediments from the global ocean. Geochimica et Cosmochimica Acta 370,113-127, https://doi.org/10.1016/j.gca.2023.12.019.

Geological controls on permafrost degradation and greenhouse-gas emissions in McMurdo Dry Valleys, Antarctica

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Keywords: Antarctic permafrost, greenhouse-gas emissions, McMurdo Dry Valleys.

Climate warming is accelerating permafrost degradation and the associated release of greenhouse gases to the atmosphere, a process widely documented in the Northern Hemisphere but still poorly constrained in Antarctica. The McMurdo Dry Valleys, the largest ice-free region of the continent, provide a unique natural laboratory to investigate the sensitivity of Antarctic permafrost to both climatic forcing and geological controls. Here we present results from the multidisciplinary SENECA project, conducted in Taylor Valley and Wright Valley, integrating soil-gas geochemistry (CO_2, CH_4, He, H_2), radon-isotope tracing (^{222}Rn and ^{220}Rn), and Deep Electrical Resistivity Tomography (DERT).

The geophysical data reveals a complex hydrogeological architecture in Taylor Valley, characterized by a shallow confined circulation system and a deeper regional reservoir of overpressurized brines beneath the permafrost (Romano et al., 2024). This subsurface organization exerts a primary geological control on fluid mobility. Soil-gas surveys identified anomalous degassing zones, with CO_2 up to 3.44 vol% and CH_4 exceeding 18,000 ppmv, associated with He and H_2 and aligned along an ENE-WSW trend. These anomalies indicate localized high-permeability structures, likely buried faults or fractures, acting as preferential pathways for the ascent of geogenic gases (Ruggiero et al., 2023). Radon isotopes further constrain transport processes: ^{220}Rn records shallow permeability and active-layer dynamics, whereas strong ^{222}Rn anomalies point to deep convective migration sustained by carrier gases and cannot be explained by local production alone (Ruggiero et al., 2026). In contrast, the nearby Wright Valley, lacking a deep brine system and dominated by dry-frozen permafrost, does not show comparable evidence of persistent gas-migration pathways.

These geological constraints interact dynamically with climate variability. The present-day permafrost distribution in Taylor Valley appears to be controlled by two concurrent mechanisms: bottom-up degradation driven by upward migration of overpressurized brines, and top-down thawing induced by atmospheric warming. Interannual comparison between the 2019/2020 and 2022/2023 field campaigns shows that short-term meteorological fluctuations, especially soil and air temperature, regulate active-layer thickness and strongly modulate subsurface connectivity and gas-transport efficiency.

Overall, our results indicate that Antarctic permafrost response and greenhouse-gas release are tightly coupled to both deep hydrogeological architecture and surface climate variability. In lower Taylor Valley, CO_2 emissions are estimated for the first time at about 15 t/day over an area of 21.6 km^2, highlighting the importance of thaw-triggered degassing for assessing future Antarctic feedbacks to the global carbon cycle.

Romano V. et al. (2024) - Permafrost hydrogeology of Taylor Valley, Antarctica: Insights from deep electrical resistivity tomography. Geophysical Research Letters, 51, e2023GL106912, https://doi.org/10.1029/2023GL106912.

Ruggiero L. et al. (2023). Antarctic permafrost degassing in Taylor Valley by extensive soil gas investigation. Science of The Total Environment 866, 161345. https://doi.org/10.1016/j.scitotenv.2022.161345.

Ruggiero L. et al. (2026). Radon isotopes as tracers of climate-sensitive subsurface connectivity in Antarctic permafrost. Environmental Research 301, 124523, https://doi.org/10.1016/j.envres.2026.124523.

Volcanoes as archives of ice sheet fluctuations - The Pleiades Volcanic Field, Antarctica

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Keywords: ice loading, plumbing system, Antarctica.

Volcanoes connect the Earth's deep interior with the external environmental spheres (atmosphere, hydrosphere and cryosphere), thereby providing valuable records of the interaction between the climate and the lithosphere, particularly in polar regions where climatic fluctuations regulate the glacial loading. The Pleiades Volcanic Field (Northern Victoria Land) represents an excellent case study for this type of interaction, comprising more than 20 monogenetic cones and lava domes emplaced within a glacially evolving landscape from ~900 ka to the present.

In this study, we investigate the petrogenetic processes responsible for the geochemical and isotopic variability to assess whether and how these processes relate to climate-controlled forcings. To this end, we integrate radiogenic isotope geochemistry and thermodynamic modelling with new high-precision $^{40}Ar/^{39}Ar$ geochronological data.

The Pleiades eruptive products generally display a Na-alkaline affinity and are characterised by high variability in the alkalinity index, major and trace element compositions, and Sr-Nd-Pb isotopic signatures. We identify two distinct evolutionary trends, both deriving from a common alkali-basalt parental magma and diverging during the differentiation in the middle-upper crust. Specifically, the strongly alkaline suite is consistent with fractional crystallisation (FC) processes, whereas the mildly alkaline suite results from a combination of fractional crystallisation and crustal assimilation (AFC) processes.

New $^{40}Ar/^{39}Ar$ ages indicate that the less evolved products, together with those belonging to the strongly alkaline suite, cluster mainly in the intervals 800-630 ka and 360-300 ka. In contrast, mildly alkaline products erupted only during two narrow time intervals: a few trachytes date to 900-800 ka, while most of this suite erupted between 100 ka and the present. These results suggest that distinct petrogenetic regimes, i.e., closed-system FC versus open-system AFC, operated during discrete time intervals.

We interpret these temporal variations as the geochemical expression of climate-driven changes in the ice load. Periods of thicker ice cover, associated with a higher lithostatic pressure, likely promoted longer residence times, enhancing crustal assimilation and diversifying the differentiation pathways. In this framework, the Pleiades magmatic system records signals of Late Quaternary cryospheric fluctuations, demonstrating how integrated geochemical and geochronological datasets from polar volcanic fields can be used to evaluate the interaction among volcanic activity, climate, and glacial cover.

Tracing the past West Antarctic Ice Sheet dynamics through gravel composition: Preliminary results from the SWAIS2C project

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Keywords: Antarctica, provenance, petrography.

The SWAIS2C (Sensitivity of the West Antarctic Ice Sheet to 2 degrees Celsius) project is an international partnership to use geological archives obtained from underneath the Ross Ice Shelf to assess the state of the West Antarctic ice sheet (WAIS) during past climate states, including temperatures exceeding the +2 °C target set by the Paris Climate Agreement.

The project focuses on sediment drilling at two sites (ICDP project 5072). The first site, where gravity and hammer cores of unconsolidated diamicton were recovered during the 2023/24 and 2024/25 field seasons, is located close to the grounding line of the Kamb Ice Stream (KIS3) and sensitive to ocean forcing of ice shelf and ice sheet collapse. The second site on the Crary Ice Rise (CIR), was drilled using the Antarctic Intermediate Depth Drill (AIDD) in 2025/26, and demarks a pinning point of the ice shelf and offers a complementary view on processes that can (de)stabilize the WAIS.

Sediments retrieved from remote and poorly characterized regions of Antarctica are essential to addressing key questions related to ice-sheet stability and subglacial geology. Sediment provenance provides insights into changes in source areas and the evolving dynamics of the WAIS. In addition, petrographic analyses offer a unique opportunity to better constrain the largely unknown, ice-covered geology of West Antarctica.

Here we present the first petrographic and mineralogical results from the gravel fraction within the diamicton recovered at KIS3. Preliminary data reveal that the geological composition of the Kamb Ice Stream catchment is dominated by intrusive, metamorphic, and volcanic lithologies. Furthermore, variations in clast lithology along the length of the recovered cores indicate a compositional shift in the sediments, with implications for changes in ice-flow routing and discharge patterns in the region.

S21.

Mineral exploration in Italy

CONVENERS & CHAIRPERSONS:

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Integrated workflow for CRM Recovery from Rosas Mine Tailings (Sulcis, Sardinia)

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Keywords: CRM, Mine Tailings, Geochemistry.

The European Regulation (EU) 2024/1252, implementing the Critical Raw Materials Act (CRM Act), requires Member States to develop National Exploration Programs assessing the potential for extraction and recovery of critical raw materials (CRM) and strategic raw materials (SRM) also considering unexplored deposits and mining waste reprocessing. In Italy, this framework has been transposed by D.L. n. 84/2024, which assigns to ISPRA the role of coordinating activities alongside with research projects for the identification of potential sites for CRS/SRM recovery. Funded by the Italian Ministry of Environment and Energy Security (MASE) within the framework of the National Power System Research 2025-2027 triennial plan and conducted by RSE S.p.A. - Ricerca sul Sistema Energetico, the present project complements these goals by investigating the potential reuse of extractive waste in the historical mining district of Sulcis, southwestern Sardinia, with a particular focus on the inactive site of Rosas, that primarily exploited polymetallic sulfide ores like galena and sphalerite, with subordinate chalcopyrite and other mixed sulfides. We retrieved historical and recent geological, geochemical, and geophysical data about the study area from the national archives of Basic Mining Research (RIMIN), the Sardinia Region geoportal, the GeMMA portal, and the CARG project (Barca et al., 2009; Funedda et al., 2009), integrating them in QGIS to select the most promising site for the subsequent characterization phase. Therefore, Rosas Mine was selected within the study area as a case study due to significant mineral bodies, large reprocessable waste volumes, historical data availability, and site accessibility. The preliminary geospatial analysis of existing geochemical datasets from adjacent areas highlighted the occurrence of mixed sulfides and skarn parageneses, with recovery potential for critical elements including V, Mn, Co, Ni, Cu, Ga, and REE (Boni & Malafonte, 1983). Using historical series of satellite imagery from Google Earth and CARG project maps of the area, mining waste deposits within Rosas boundaries were identified for carrying out, by 2027, sampling and analyses aimed at investigating the effective concentration of CRM and SRM across the various deposits identified, thus addressing the technical and economic feasibility of potential recovery projects. Overall, the applied methodology consists of a replicable workflow for the characterization of mine tailings, potentially supporting the production of national guidelines, contributing to the objective of reducing CRM external dependency, and promoting the circular economy.

Barca S. et al. (2009) - Note illustrative della Carta Geologica d'Italia alla scala 1:50.000, foglio 565 "Capoterra". Servizio Geologico d'Italia - ISPRA, Regione Autonoma della Sardegna, Progetto CARG, Roma.

Boni M. & Malafronte A. (1983) - Structural setting and genesis of ore bodies in carbonate rocks in the M.te Atzei-M.te Ega mining area (Sulcis, SW Sardinia). Mineral. Deposita 18, 57-69, https://doi.org/10.1007/BF00206695.

Funedda A. et al. (2009) - Note illustrative della Carta Geologica d'Italia alla scala 1:50.000, foglio 556 "Assemini". Servizio Geologico d'Italia - ISPRA, Regione Autonoma della Sardegna, Progetto CARG, Roma.

Integrated analysis of oil and gas and complementary datasets for assessing natural hydrogen potential in the western South-Alpine sector

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Keywords: natural hydrogen, geophysics, oil&gas.

Natural hydrogen is increasingly considered a promising energy resource due to its non-intermittent nature and low land-use impact, although significant uncertainties persist regarding its generation, migration, and accumulation mechanisms. Proposed processes include serpentinization, water-rock interaction in ophiolitic settings, mantle degassing, and radiolysis (e.g., Liu et al., 2023), but the conditions required for economically viable accumulations remain poorly constrained. In this context, the present study contributes to the advancement of hydrogen exploration by investigating the potential for the indirect identification of natural subsurface accumulations through the reinterpretation of historical oil and gas exploration data. The methodology is based on a basin-scale screening approach that integrates existing geological, geophysical, and geochemical datasets with the analysis of well logs sensitive to gaseous fluids, including neutron, density, sonic, resistivity, spontaneous potential, and gamma-ray logs. Among these, the neutron log is particularly relevant due to its sensitivity to hydrogen content (Maiga et al., 2023), while the integrated interpretation of multiple logs enhances the reliability of identifying potential gas-bearing intervals. Where available, gas geochemistry data (from operators) are also considered to support fluid characterization. The selected pilot area is the Western South-Alpine sector, which is characterized by both existing exploration data and a favorable geological setting, including ophiolitic sequences and structurally complex domains that may support hydrogen generation, migration (Zwaan et al., 2025), and accumulation (Ballentine et al., 2025). Fifteen wells of interest were identified in the study area, where public and proprietary data were collected, digitized, and georeferenced, enabling integration with seismic profiles and stratigraphic correlation of potential anomalies. Future work will focus on expanding the database and refining the well-scale interpretation of hydrogen-related signatures through the integration of mineralogical, geochemical, structural, and remote sensing data, including information derived from the literature.

Ballentine C.J. et al. (2025) - Natural hydrogen resource accumulation in the continental crust. Nature Reviews Earth & Environment, 6(5), 342-356, https://doi.org/10.1038/s43017-025-00670-1.

Liu J. et al. (2023) - Genesis and energy significance of natural hydrogen. Unconventional Resources, 3, 176-182, https://doi.org/10.1016/j.uncres.2023.01.002.

Maiga A. et al. (2023) - Characterization of the spontaneously recharging natural hydrogen reservoirs of Bourakebougou in Mali. Scientific Reports, 13(1), 11876, https://doi.org/10.1038/s41598-023-38977-y.

Zwaan F. et al. (2025) - Rift-inversion orogens are potential hot spots for natural H2 generation. Science Advances, https://doi.org/10.1126/sciadv.adr3418.

Integrating artificial intelligence and geospatial data for critical raw materials recovery potential assessment from extractive waste in Italy

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Keywords: critical raw materials, extractive waste recovery, urban mining.

The accelerating green and digital transition is driving a rapid increase in the demand for Critical Raw Materials (CRM) and Strategic Raw Materials (SRM). Europe's strong dependence on imports has renewed interest in secondary sources, particularly extractive waste from abandoned mining districts and urban mining streams. In Italy, large volumes of potentially CRM-bearing materials are still stored within historical mine waste deposits, many of which remain poorly characterized at the national scale. The URBES project was developed to support the systematic mapping and assessment of these secondary resources in accordance with the EU Critical Raw Materials Act (Regulation (EU) 2024/1252). The project integrates extractive waste deposits from abandoned mining sites and urban mining streams within a national geodatabase. To date, more than 2,000 closed extractive waste deposits have been geolocated across the Italian territory (ISPRA, 2022). Preliminary commodity-based correlation analyses indicate that approximately 78% of mapped deposits are potentially associated with at least one CRM and 62% with at least one SRM. In addition to extractive waste, urban mining streams, represent a potential secondary source of Au, Ag, Pd, Cu and Rare Earth Elements. To overcome data fragmentation, the platform leverages Artificial Intelligence (AI) algorithms to automate the retrieval, analysis, and semantic organization of heterogeneous datasets, including the processing of non-digital and unstructured historical documents. This AI-driven infrastructure provides the backbone for integrating geospatial data, enabling advanced spatial queries, thematic mapping, and preliminary interpretative analyses. The collected information is integrated into a national geodatabase developed according to FAIR principles and INSPIRE/M4EU standards and made available through an open access online WebGIS platform supporting future assessments of secondary raw materials from extractive waste in Italy.

ISPRA (2022) - Inventario nazionale delle Strutture di Deposito di Rifiuti Estrattivi, Chiuse o Abbandonate, di tipo A. Rapporto di Aggiornamento 2022. https://www.isprambiente.gov.it/files2023/pubblicazioni/rapporti/rapporto-inventario-strutture-deposito-rev-3782022.pdf.

Regulation (EU) 2024/1252 - Establishing a Framework for Ensuring a Secure and Sustainable Supply of Critical Raw Materials (Critical Raw Materials Act), Official Journal of the European Union (2024).

Extraction of rare earth elements by sulfuric acid leaching of bauxite from Olmedo mine (Sardinia, Italy)

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Keywords: bauxite, REEs, acid leaching.

Bauxite is mainly exploited as the primary ore for alumina production, but its content of Rare Earth Elements (REEs) and other critical metals is receiving increasing attention (Sofis et al., 2025). Recovering these valuable elements by leaching, while limiting the simultaneous dissolution of the major matrix components, represents one aspect of its exploitation (Mondillo et al., 2019). In the present study, both wet and dry sulfuric acid leaching were applied to karst bauxite samples from the Olmedo mine in the North-Western Sardinia (Italy), aiming to evaluate their extraction behaviour and recovery potential.

When performing leaching tests at 90 °C under wet conditions, reaction time emerges as a controlling factor for the extent of element extraction. The most favourable response comes from Ga and Ce, which reach the highest recoveries under the most effective conditions. Sc extraction increases more moderately yet progressively with longer reaction times. In contrast, Ti and Zr remain poorly dissolved. As leaching proceeds, the extraction of major elements, particularly Fe, likewise increases. Dry leaching results, instead, show that an appreciable fraction of critical metals can also be mobilized through acid-solid treatment before aqueous extraction, while iron dissolution remains limited.

Therefore, the proposed leaching approaches offer a promising route for assessing and exploiting bauxite's resource potential, beyond its conventional use.

Mondillo N. et al. (2019) - Rare Earth Elements (REE) in Al- and Fe-(Oxy)-Hydroxides in Bauxites of Provence and Languedoc (Southern France): Implications for the Potential Recovery of REEs as By-Products of Bauxite Mining. Minerals, 9(9), 504, https://doi.org/10.3390/min9090504.

Sofis N. et al. (2025) - REE Mineralogy and Geochemistry of the Lower Karstic Bauxite Strata (b1), in the Parnassos-Ghiona Unit, Greece. Minerals, 15(8), 804, https://doi.org/10.3390/min15080804.

Critical Raw Materials from unconventional sources in mountain fronts: Hydrogeochemical, stratigraphic and structural controls on the Monticelli Terme brine area (Northern Apennines, Italy)

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Keywords: Northern Appennines, Critical Raw Materials, energy transition.

The global energy transition has accelerated the demand for minerals and elements, essential for the generation, storage, and distribution of renewable energy (Fu & Alariqi, 2026). In response to limited domestic availability, the European Union (Regulation EU 2024/1252) has prioritized the identification of strategic elements, including barium, boron, lithium, and strontium. In Italy, geothermal and formation waters represent significant non-conventional reservoirs for such elements (Dini et al., 2022). Although these non-conventional reservoirs are non-renewable, their occurrence at shallow depths (around 100 m depth) foster a more sustainable extraction of the Critical Raw Materials (CRMs). On the other hand, extraction is strictly controlled by the element concentrations in the fluids, which are often poorly constrained.

This study focuses on the Monticelli Terme area, where historical data from boreholes report significant CRM concentrations (median values: 82 mg/L Ba, 14 mg/L B, 8 mg/L Li, and 300 mg/L Sr). Despite these promising indicators, the exploitation of such resources is currently hindered by significant knowledge gaps regarding the origin, accumulation mechanisms, and migration pathways of CRM-rich waters, which are closely linked to the specific geological context of the area. To address these limitations, we present a multidisciplinary investigation that integrates surface and deep-subsurface geological data with hydrogeochemical analyses, supported by a 3D structural model. This approach allows for a high-resolution characterization of the hydrogeological framework and the stratigraphic-structural controls governing fluid circulation. The results, consistent with the National Mineral Exploration Program (ISPRA, 2025), reveal a strong correlation between water geochemistry and the tectonic architecture of the Monticelli Structure. This structure serves as a representative model of the buried, syn-depositional frontal belts characteristic of the Apennine foreland basin system. Furthermore, this study addresses a critical discrepancy in lithium abundance: historical reports from abandoned boreholes (e.g., Illari & Cattadori, 1938) indicate values up to ten times higher than current measurements. Although these anomalies may reflect limitations of earlier analytical techniques, their verification is essential to assess the potential for higher-grade reservoirs.

This study provides a preliminar updated evaluation on the amount of CRM in the case study area and a predictive framework for CRM exploration and exploitation in similar tectonic settings along active or recently active mountain fronts.

Dini A. et al. (2022) - Lithium Occurrence in Italy - An Overview. Minerals, 12, 945.

EU Regulation (EU) 2024/1252 of the European Parliament and of the Council of 11 April 2024 Establishing a Framework for Ensuring a Secure and Sustainable Supply of Critical Raw Materials and Amending Regulations (EU) No 168/2013, (EU) 2018/858, (EU) 2018/1724 and (EU) 2019/1020 (Text with EEA relevance). Available online: https://eur-lex.europa.eu/legalcontent/EN/TXT/?uri=OJ:L_202401252.

Fu H. & Alariqi M. (2026) - Critical mineral supply chains and the economics of energy transition: A carbon decomposition perspective of growth and decoupling. Geosci.Frontiers, 17(1). https://doi.org/10.1016/j.gsf.2025.102181

Illari A. & Cattadori L. (1938) - Analisi delle acque minerali di Monticelli (Parma). Nota 1 e successive. Ataneo Parmense, 10, 179-214.

ISPRA (2025) - Programma Nazionale di Esplorazione, 168 pp., https://www.isprambiente.gov.it/files2025/attivita/pne_finale.pdf.

Titanite as a tracer of critical raw material mobility in lower crustal shear zones: Insights from the MADAM project (Fondazione Cariplo, grant n°2024-0348)

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Keywords: elements mobility, melt-transfer shear zone, unconventional resources.

Critical Raw Materials (CRMs) are strategic elements/minerals required for advanced technologies, renewable energy systems, industrial applications and medical devices. The increasing demand for CRMs and the instability of global supply chains have recently placed the reassessment of European domestic resources at the centre of sustainable development policies. In this framework, understanding the geological processes responsible for the genesis, mobilization and concentration of CRMs is essential for future exploration strategies.

The project MADAM (Mobility And Distribution of Critical RAw Materials through the crust) investigates how deformation, fluids and melt interact to control element mobility and redistribution in the continental crust. The selected natural laboratory is the Ivrea-Verbano Zone (IVZ, NW Italy), one of the best-preserved lower crustal sections worldwide, characterized by exposed (ultra)mafic complexes, metasedimentary sequences and high-grade shear zones. Recent studies have highlighted the role of long-lived mass transfer processes in promoting metal mobility across the lower crust-upper mantle transition, although the metallogenic potential of large sectors of the IVZ remains poorly constrained. Three key crustal sectors are currently investigated within the project: Isola village (Val Sesia), Anzola (Val d'Ossola) and Finero (Val Cannobina). These areas have been interpreted as potential melt-transfer zones where mineralizations enriched in Co, Ni, Ti, Cu, Li and PGE occur, including sulphides, chromitites, pegmatites and carbonatitic associations. Because these transfer pathways are commonly cryptic and structurally overprinted, MADAM adopts a multidisciplinary micro-scale approach integrating field observations, SEM, EBSD, EPMA, XRF, LA-ICP-MS, numerical modelling and 3D tomography to characterize mineralized rocks and quantify melt/fluid-rock interaction processes controlling CRM redistribution. Within this framework, titanite is used as a key accessory mineral tracer because it can host significant concentrations of REE and HFSE, records fluid-mediated recrystallization, and dated by U-Pb geochronology. Preliminary observations from lower crustal shear zones indicate that titanite behaviour is highly heterogeneous and controlled by local bulk composition, strain partitioning and fluid availability. In Val Sesia mylonitic domains, titanite locally occurs in pseudotachylyte veins and carbonate-rich bands, where it may preserve intracrystalline deformation, fragmentation and subgrain development related to transient high-stress conditions and seismic damage processes in the deep crust. These results suggest that deformation-assisted fluid pathways may strongly enhance metal remobilization in lower crustal environments.

MADAM therefore provides an integrated framework for identifying fertile crustal pathways for CRM concentration in Italy and contributes to national and European exploration strategies through innovative scientific approaches to sustainable mineral resource assessment.

Valorization of the heavy mineral fraction in the marine terraces of the Lazio coastal area

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Keywords: heavy minerals, critical raw materials, circular economy.

One of the strategic objectives of Critical Raw Materials (CRM) Act approved by the European Union and entered into force in May 2024 is the achievement of a significant share of domestic supply of critical and strategic raw materials through extractive activities as well as the recycling of secondary resources within the European territory. This issue has developed during the last years significant studies of novel sources for CRMs; in this context, numerous mineralogical, sedimentological, and ore deposit studies carried out over the years have highlighted the widespread occurrence of heavy mineral concentrations within the alluvial terraces and coastal deposits of the Lazio region (Bonatti & Gottardi, 1950), some of which were historically exploited as primary mineral resources (Anselmi et al., 1978; Brondi et al, 1979; Luppi & Salvati, 1997).

This study addresses the technical and economic assessment of recovering the heavy mineral fraction as an associated by-product of sand and gravel quarrying activities. The analysis aims at evaluating the feasibility of integrating mineral recovery processes into conventional quarry operations, according to a model consistent with the principles of circular economy, sustainability, and reduction of land consumption.

The study includes the granulometric, mineralogical, and geochemical characterization of the sands, with particular focus on the concentration of heavy minerals potentially hosting critical and strategic elements such as titanium, zirconium, rare earth elements, and associated metals (Fe, Mn). Furthermore, the main technologies available for gravimetric, magnetic, and electrostatic separation of the heavy mineral fraction are examined, together with the achievable enrichment levels.

The final objective is at defining the technical, economic, and environmental sustainability of an integrated recovery chain capable of transforming materials currently considered of low economic value into a potential strategic resource for the European energy and industrial transition (Wills et al., 2025; Jones, 2023).

Anselmi B. et al. (1978) - Lineamenti granulometrici e mineralogici generali dei sedimenti fluviali e costieri del territorio italiano: Studio di supporto a ricerche sulla dinamica costiera e sulla contaminazione marina. Mem. Soc. Geol. It., 19, 307-314.

Bonatti S. & Gottardi G. (1950) - Perrierite, nuovo minerale ritrovato nelle sabbie di Nettuno (Roma). Rend. Acc. Lincei, s. 8, 9, 361-368.

Brondi A. et al. (1979) - Analisi granulometriche e mineralogiche dei sedimenti fluviali e costieri del territorio italiano. Boll. Soc. Geol. It., 98, 293-326.

Luppi A. & Salvati L. (1997) - Le risorse minerarie nei fondi marini italiani / Mineral resources of Italian sea floor (Memorie descrittive della Carta Geologica d'Italia, Vol. XLIII). Servizio Geologico Nazionale.

Jones G. (2023) - Mineral Sands: An Overview of the Industry. Iluka Resources Technical Paper.

Wills B.A. & Finch J. (2015) - Wills' mineral processing technology: an introduction to the practical aspects of ore treatment and mineral recovery. Butterworth-Heinemann, 2015.

From geological surveys to mineral exploration: experiences from the CARG Project "Guspini" 546 thematic sheet"

Deidda M.L.*[1], Caracciolo D.[2], Carta R.[3], Cocco F.[1], Funedda A.[1], Lai A.[2], Lecca C.[2], Lonis R.[2], Muntoni F.[2], Pieruccioni D.[3], Sarria N.[2], Sau A.[2], Scano I.[3] & Naitza S.[1]

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Keywords: ore deposit, mineral deposit, mineralization.

The CARG Sheet 546 "Guspini" was selected by ISPRA as a pilot area for developing a prototype metallogenic map applicable to other Italian regions. The project, carried out by DSCG-UniCA and ARPA Sardegna, concerns a geologically complex Paleozoic sector affected by pre-Variscan and Variscan deformation and intruded by the late-Variscan Arbus and Linas granitoids (305±1 Ma and 289±1 Ma). This setting hosts one of Italy's most important historical mining districts, including Montevecchio, Buggerru and Arenas, characterized by Zn-Pb mineralization and several Critical Raw Materials (CRMs). Four main deposit groups are recognized: 1) pre-Variscan MVT/Irish-Type Zn-Pb(-Fe) deposits (Santoro et al., 2023); 2) late-Variscan granite-related greisen, skarn and vein deposits enriched in Zn-Pb-Fe-Cu-W- Sn-Mo-As-F-Au-Te-Bi; 3) post-Variscan low-temperature hydrothermal veins, including Montevecchio-type polymetallic deposits, five element-type As-Ni-Co-Bi-Sb veins, F-Ba-Pb systems and Ba-Pb "quartzites"; 4) supergene deposits, including non-sulfide Zn-Pb and Ba-Pb karst ores. The project was conducted by collecting historical mining maps and reports, field surveys, sampling, petrographic and geochemical analyses. Metallogenic data were integrated into a dedicated database and a legend simultaneously with the geological mapping of Sheet 546, highlighting a close relationship between ore forming processes and the tectonic-magmatic evolution of the district. Several key conclusions emerged: 1) many Variscan to post-Variscan complex ore systems such as Su Zurfuru and Arenas derive from remobilization of older MVT/Irish-Type ores during later tectonic and magmatic events; 2) tectonic slices and reactivated Variscan structures related the Arburese Nappe thrusting over the External Zone produced physical traps for mineralization and controlled both Ba-Pb and F-Ba-Pb deposits, as well as some skarns; 3) the emplacement of the Monte Linas pluton is a key magmatic event, being the main source for As-Sn-Mo-W-Bi-Te-Au-LREE-F mineralization, whereas the Arbus pluton played only a minor role (Naitza et al., 2017); 4) hydrothermal fluid circulation along pyrite- and methane-rich Ordovician and Silurian siliciclastic units triggered redox reactions and precipitation of peculiar ore assemblages, particularly evident in late-Variscan W-Bi-Te-Au mineralization and post-Variscan low-temperature five element-type veins (Deidda et al., 2021; Scano, 2022); 5) preliminary U/Pb dating on calcite and siderite of the Montevecchio vein system suggests a post-Variscan age of the mineralization, with a main event between Middle Triassic and Early Cretaceous (189±48 Ma), and a later Oligocene-Early Miocene hydrothermal phase (24±5 Ma), probably linked to the onset of Cenozoic volcanism in the nearby areas. These results confirm the exceptional metallogenic complexity and mineral potential of the district, making it one of the most promising areas in Italy for future mineral exploration.

Deidda M.L. et al. (2021) - Spatial and Metallogenic Relationships between Different Hydrothermal Vein Systems in the Southern Arburèse District (SW Sardinia). Environ. Sci. Proc., 6, 13, https://doi.org/10.3390/iecms2021-09363.

Naitza S. et al. (2017) - A Late Variscan tin province associated to the ilmenite-series granites of the Sardinian Batholith (Italy): The Sn and Mo mineralization around the Monte Linas ferroan granite. Ore Geol. Rev., 80, 1259-1278, https://doi.org/10.1016/j.oregeorev.2016.09.013.

Santoro L. (2023) - Base-metal sulphides and barite in the Palaeozoic of SW Sardinia: From tectonically deformed SedEx and Irish-type deposits to post-Variscan hydrothermal karst and vein ores. In Irish-Type Deposits around the World; Andrew, C.J., Hitzman,M.W., Stanley, G., Eds.; Irish Association for Economic Geology: Dublin, Ireland, 425-442.

Scano I. (2022) - Vein intersection zones and host rock composition as controlling factors in polymetallic ore shoots genesis: insights from the Southern Arburèse five-element (Ni-Co-As-Bi-Ag) vein system (SW Sardinia). Rend. Online Soc. Geol.It., 61, 20, https://doi.org/10.3301/ROL.2023.42.

Mechanisms of formation of the reduced-intrusion related W-Bi-Te-Au mineralization of Tògoro (SW Sardinia): Insights from fluid inclusions, trace elements and U/Pb dating of wolframite

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Keywords: ore, hydrothermal, Reduced Intrusion Related Gold Systems.

The Togoro mineralization (Gonnosfanadiga, SW Sardinia) is set in a sequence of Upper Ordovician quartz-sericite metasandstones (Rio San Marco Fm) and Silurian-Devonian black shales with carbonate lenses (Genna Muxerru Fm.). The sequence is deformed by E-W-trending isoclinal folds and overthrust by Cambrian-Lower Ordovician metasandstones (Arburese unit), intruded and affected by contact metamorphism by Early Permian (289±1 Ma; Boni et al, 2003) ilmenite-series leucogranites of the Monte Linas massif (Naitza et al 2017). The mineralization consists of a E-W-trending system of sheeted subvertical veins, with variable thickness from centimetric up to 1 metre, roughly parallel to the axial planes of the isoclinal folds (Deidda et al, 2021). The mineral assemblage of the veins includes ferberite ($FeWO_4$), scheelite ($CaWO_4$), bismuth, joséite-B ($BiTe_2S$), $Bi_5(Te,S)_4$, electrum (AuAg) and rare pyrite and arsenopyrite, within a milky quartz gangue with subordinate white mica. Fluid inclusions on quartz record a polyphase evolution: 1) barren quartz deposition from low-salinity, CO_2-rich magmatic fluids at >400°C; 2) the main mineralizing stage, consisting of ferberite, pyrite, arsenopyrite, joséite-B, $Bi_5(Te,S)_4$ and bismuth in a fine-grained recrystallized quartz, formed from CH_4-rich, reducing and relatively saline (20-30 wt% NaCl equiv., with Mn-Fe-W-bearing solid phases) fluids under a 320-230°C range; 3) formation of secondary scheelite, goethite, russellite, bismutite, bismoclite and electrum from H2O-dominated and diluted (0.5-22 wt% NaCl equiv.) fluids at lower temperature (~201°C). The genetic relationship with ilmenite-series granites is shown by wolframite trace elemental contents and U/Pb ages of ~288 Ma. The W-Bi-Te-Au association, geometry and link with reduced granites make the Togoro mineralization comparable to Reduced Intrusion-Related Gold Systems (RIRGS; Hart, 2002). The hydrothermal system began with the escape of CO_2-rich fluids from the cupola of the intrusion and circulation along new fractures and pre-existing Variscan structures. The interaction of fluids with CH_4-rich Silurian-Devonian units caused a shift towards more reducing conditions which favoured the transport of metals. Precipitation of ferberite and Bi-sulfotellurides in the ore stage was mostly controlled by temperature decrease. Lastly, mixing with meteoric waters resulted in a significant dilution and shift towards oxidizing conditions, promoting a widespread scheelite-goethite alteration and the precipitation of AuAg and secondary W-Bi-Te phases.

The W-Bi-Te-Au vein field of Togoro is included in the National Exploration Plan as one of Italy's most interesting areas for a future evaluation of Critical Raw Materials (CRMs) like W and Bi. This study highlights how a further understanding of the factors that contributed to its formation are key to future mineral exploration in the area, as well as in the definition of new potentially similar targets.

Boni M. et al. (2003) - Re-Os age for molybdenite from SW Sardinia (Italy): a comparison with 40Ar/39Ar dating of Variscan granitoids. In: Eliopoulos, D.G., et al. (Eds.), Mineral exploration and sustainable development. Millpress, Rotterdam, 247-250.

Deidda M.L. et al. (2021) - Spatial and Metallogenic Relationships between Different Hydrothermal Vein Systems in the Southern Arburèse District (SW Sardinia). Environ. Sci. Proc., 6,13, https://doi.org/10.3390/iecms2021-09363.

Hart C.J.R. (2007) - Reduced intrusion-related gold systems. In: Goodfellow WD (ed) Mineral deposits of Canada: A Synthesis of Major Deposit Types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods: Geological Association of Canada, Mineral Deposits Division, Special Publication No. 5, 95-112.

Naitza S. et al. (2024) - Post-Collisional Tectonomagmatic Evolution, Crustal Reworking and Ore Genesis along a Section of the Southern Variscan Belt: The Variscan Mineral System of Sardinia (Italy). Minerals, 14, 65, https://doi.org/10.3390/min14010065.

From historical mining waste to Critical Raw Materials: New mineral exploration perspectives on VMS ore deposits from Emilia-Romagna Region (Italy)

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Keywords: critical raw materials, VMS deposits, Northern Apennines.

The increasing strategic relevance of critical and strategic raw materials within the framework of the European CRM Act, approved in 2024, has renewed interest in abandoned mining district and their waste as potential secondary resources. In this contest, Cyprus-type volcanogenic massive sulfide (VMS) deposits hosted in the ophiolitic units of the Northern Apennines (Italy) represent key targets for assessing the extractive potential of historical mining areas and for updating mineral-resource inventories. The Emilia-Romagna region (Italy) hosts several historical copper and iron mining sites, some exploited from prehistoric times to the 20th century and progressively abandoned during the 1960s. This research is focused on reassessing in the extractive potential of the mineralized localities in Emilia-Romagna, identifying new mineral resources, and updating the inventory of VMS deposits in the provinces of Parma and Piacenza. Among them, the Vigonzano-Groppallo-Ferriere district in western Emilia-Romagna is particulary relevant as sulfide mineralization occur as stockworks veins crosscutting serpentinite bodies within sedimentary mélanges. These deposits are associated with remnants of the ancient oceanic lithosphere belong to Jurassic Ligurian Tethys; they formed through hydrothermal fluid circulation near active magmatic centres, in seafloor to sub-seafloor environments (Piccardo, 2007; Garuti et al., 2008; Zaccarini & Garuti, 2008). The most common VMS mineralizations are characterized by a pyrite + chalcopyrite + sphalerite ± pyrrhotite assemblage with massive or cataclastic texture, while the gangue minerals include quartz, chlorite, carbonates and clay minerals, reflecting seafloor hydrothermal alteration processes (Zaccarini & Garuti, 2008). This work focuses on the Ferriere mining area, which remains comparatively under-documented despite its long mining history. Unlike Vigonzano and Groppallo, where mining activities mainly developed during the 19th century, Ferriere has been known since Roman times and was extensively exploited for iron during the 15th century. At this locality, quartz, carbonate, chlorite, and siderite veins, intensely mineralized with pyrite, chalcopyrite and minor pyrrhotite, are exposed in two collapsed galleries known as Galleria delle Roncalle and Cantiere degli Inglesi. The Ferriere serpentinites are characterized by a longer and more ancient history of extraction compared with the other two mining sites within the district (Groppallo and Vigonzano), resulting in large accumulation of sulfidic waste materials whose mineralogical and geochemical features remain poorly constrained. An assessment of mining waste, integrating detailed geological mapping, mineralogical characterization and geochemical investigations, could support the re-evaluation of historical mining districts in terms of secondary raw-material potential and environmental legacy.

Garuti G. et al. (2008) - Geological setting and structural styles of Volcanic Massive Sulfide deposits in the northern Apennines (Italy): evidence for seafloor and sub-seafloor hydrothermal activity in unconventional ophiolites of the Mesozoic Tethys. Boltetìn de la Sociedad Geológica Mexicana, 60(1), 121-145, https://doi.org/10.18268/BSGM2008v60n1a9.

Piccardo G.B. (2007) - The Jurassic Ligurian Tethys, a fossil ultraslow spreading ocean. In: Coltorti, M., Gregoire, M. (Eds.), Metasomatism in Oceanic and Continental Lithospheric Mantle, 293. Geological Society, London, Special Publication, 11-33, https://doi.org/10.1144/SP293.2.

Zaccarini F. & Garuti G. (2008) - Mineralogy and chemical composition of VMS deposits of northern Apennine ophiolites, Italy: evidence for the influence of country rock type on ore composition. Miner. Petrol., 94, 61-83, https://doi.org/10.1007/s00710-008-0010-9.

Women in geosciences and extractive sector: Structural barriers and strategic opportunities for a sustainable transition

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Keywords: raw materials, georesources, gender equality.

Women's participation in geosciences and the extractive sector has increased significantly over recent decades; however, significant gender disparities persist across regions and throughout different career stages. Despite strong representation in education and at early-career levels, women remain markedly underrepresented in academic, technical, and decision-making positions, particularly within mining, raw materials, and energy-related industries. Structural barriers—including persistent gender bias, limited access to leadership opportunities, career instability, and challenges in work-life balance—continue to constrain women's long-term retention and career progression. We provide a comparative analysis of women's roles by integrating scientific evidence and professional experience across Italy, Spain, Portugal, Brazil, and Mozambique. In Europe, regulatory frameworks and gender-equality policies have facilitated women's entry into geoscience education; however, vertical segregation and uneven career progression persist. In South America, women increasingly contribute to mineral resources research, environmental monitoring, and sustainable mining practices, although disparities remain in access to funding, institutional recognition, and academia-industry collaboration. In African contexts, women play a critical role in artisanal and large-scale mining, environmental management, and community engagement, but face compounded barriers related to education access, professional networks, and work-life balance. Furthermore, gender inclusion represents a strategic opportunity to enhance innovation, improve governance quality, and strengthen resilience when addressing demanding issues such as raw material supply, environmental risks, and the core challenges associated with the green and digital transitions. In this context, geosciences play a crucial role. Integrating gender equity into Environmental, Social, and Governance (ESG) frameworks improves risk management, stakeholder engagement, and sustainable decision-making in the extractive sector. Aligning women's participation with the UN Agenda 2030 goals, particularly SDG 5 (Gender Equality), SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation and Infrastructure), and SDG 13 (Climate Action); it is essential to ensure that geosciences-driven solutions are effective and equitable. Achieving these goals also depends on strengthening SDG 4 (Quality Education) as a foundational pillar for capacity building.

Ultimately, reducing gender inequality in geosciences and mining is not only a matter of social justice but a strategic requirement for ensuring responsible resource governance and a sustainable energy transition. Accordingly, targeted actions across education, academia, and industry—such as mentoring programmes, inclusive leadership pathways, gender-responsive training, and transparent ESG metrics—are key to fostering the advancement and retention of women in geoscience professions.

Carbonate-hosted Sb (±Au) deposits of southern Tuscany (Italy): Constraining the ore-forming processes through sulfide trace elements and stable isotopes of quartz and calcite

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Keywords: Sb (±Au) ore deposits, trace elements, stable isotopes.

Antimony (Sb) is a critical raw material and understanding the processes that concentrate Sb in the Earth's crust to form ore deposits is pivotal to developing new exploration approaches necessary to support domestic supplies. Furthermore, given its association with other precious and strategic materials (e.g. gold), exploring domestic ore deposits is becoming increasingly important. In central Italy, hydrothermal Sb (±Au) mineralizations developed at the edges of the Larderello, Monte Amiata and Latera geothermal systems in an extensional tectonic setting. Italian ministerial mining reposts (RIMIN, 1989) document over forty Sb-occurrences in southern Tuscany, of which only a few sites have been explored or exploited. Here, we investigate five representatives Sb occurrences associated with the silicification of carbonate rocks, forming jasperoids beneath low-permeability sedimentary formations (Filimon et al., 2025).

We use trace element composition of stibnite and pyrite, coupled with the $\delta^{18}O$ composition of quartz and $\delta^{18}O$-$\delta^{13}C$ composition of calcite to constrains the origin of the ore-bearing fluids and the ore-forming process (Filimon et al., 2026). Our results provide new insights into the possible relationship between Sb occurrences, intrusion-related hydrothermal systems, and fossil/active geothermal systems.

Filimon D.I. et al. (2025) - The Sb±As±Au mineralizations from Corsica (France) to Tuscany (Italy): a review. In Proceedings of the 18th SGA Biennial Meeting, Mineral Resources for Our Ever-Changing World. August 3-7, Golden, Colorado, USA, 3, 864-867.

Filimon D.I. et al. (2026) - Genesis of carbonate-hosted Sb (±Au) deposits in southern Tuscany (Italy): Tracing ore-forming processes through stibnite and pyrite trace elements composition and stable isotopes of quartz and calcite. Applied Geochemistry, 201, 106754, https://doi.org/10.1016/j.gexplo.2026.108097.

RIMIN (1989) - Mineralizzazioni ad oro invisibile nella Toscana meridionale. Relazione conclusiva sui lavori svolti nell'ambito della convenzione con il Ministero dell'Industria, del Commercio e dell'Artigianato. Direzione Generale Miniere, Roma (in Italian).

The paper mines: The value of historical data in modern exploration for critical raw materials

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Keywords: historical mining data, archive retrieval, national database.

The urgent need to secure the supply of Critical and Strategic Raw Materials (CRM/SRM) calls for exploration strategies that are fast, efficient, and sustainable. In this context, the recovery and digitisation of historical mining documentation represents an extraordinary tool for geological, economic, and environmental de-risking, an approach explicitly recognised and encouraged by the European CRM Act. Old maps, technical reports, drilling data, and sampling records, confined to disused historical archives, offer irreplaceable information on ore bodies; they also provide data on accessory elements that once held no industrial value but are now central to European supply strategies.

At national level, this heritage finds an institutional framework in the GEMMA national database, developed by ISPRA for the cataloguing of Italian mineral resources. Despite its relevance, GEMMA still suffers from gaps in coverage and completeness. A decisive contribution to its improvement comes from the full recovery of data produced by the Basic Mineral Research Project carried out between 1982 and 2000 (known as RIMIN), from the potential retrieval of data generated by state-owned mining companies (Rimin, Samim, Aquater, etc.), from the digitisation of regional archives, and from the recovery of materials produced by the scientific community. Following the physical work of locating and scanning documents, dedicated AI agents will facilitate their digitisation, georeferencing, and systematic integration into GEMMA, strengthening the platform as a comprehensive, open knowledge base developed in line with European INSPIRE standards.

The integration of heterogeneous historical data within GIS platforms, new exploration data, AI tools, and predictive modelling positions GEMMA as the essential foundation for all future activities of the Italian Geological Survey and private mining companies. Results demonstrate that leveraging this “mining memory” guides exploration targets, reduces the costs and environmental impact of new exploration campaigns, and proves essential for the characterisation of waste deposits in the context of the circular economy, in full alignment with the objectives of the European Critical Raw Materials Act. The paper documentation retrieved from dusty, forgotten archives is a true mine of information, not only geological, but also historical, economic, and social, that must be properly valorised before it is lost forever.

The Italian National Exploration Programme

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Keywords: CRM Act, NEP, exploration.

In the framework of the European Critical Raw Materials Act, which mandates Member States to enhance domestic exploration, diversify supply chains, and improve recycling to ensure strategic autonomy, the Italian National Exploration Program (NEP) represents a crucial institutional response. Entrusted to the Italian Geological Survey by the Ministry of the Environment and Energy Security and the Ministry of Enterprises and Made in Italy, this five-year program is structured into three phases to define the national mineral potential. In this keynote, I will present its structure, operational workflow, and the broader strategic vision it embodies.

The program's operational core begins with the collection, revision, and validation of historical mining data from over 3,000 sites documented since 1870. Although roughly 1,000 are associated with CRMs, domestic extraction currently remains limited to only two active fluorite mines and twenty feldspar operations. To optimize resources and promptly demonstrate Italy's geological potential, 14 targeted research projects have been launched in the most promising areas, covering fluorite, barite, and REEs in the Southern Alps, Sardinia, and Latium's volcanic provinces; lithium within geothermal fluids in the Tyrrhenian region; copper and manganese in Liguria; graphite in Calabria and Piedmont; and polymetallic deposits in Sardinia. Funded with an initial 3.0 million euros for its first phase, the initiative is complemented by approximately 10 million euros dedicated to the URBES project, which drives a paradigm shift in how we regard approximately 200 million cubic meters of extractive waste, transitioning them from liabilities to secondary resources.

In compliance with current legislative frameworks (DLgs 84/2024), all exploration relies strictly on non-invasive investigations, combining data re-evaluation, remote sensing, geological mapping, and geochemical and geophysical surveys to develop new conceptual models.

I will conclude by addressing what I consider the three most persistent obstacles to progress: the false narrative of fully depleted national resources, the systematic association of mining with environmental disaster, and the assumption that recycling alone can immediately meet industrial demands. The ultimate ambition of the NEP is not only to advance mineral knowledge and build a comprehensive national database, but to reconstruct a national mining ecosystem integrating public administration, science, and industry. In this regard, social acceptability is not a secondary concern, but a founding condition. Building genuine trust with local communities requires moving beyond mere consultation, toward inclusive processes that acknowledge legitimate concerns, communicate environmental safeguards transparently, and recognize communities as active stakeholders. Without this foundation, even the most scientifically robust exploration program risks failing where it matters most.

From legacy data to 3D implicit models: A multi-scale approach to reappraisal Antimony (Sb) resources in the Mancianese District

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Keywords: historical mining, 3D geological modeling, antimony.

In the framework of the European Critical Raw Materials (CRM) Act, the reassessment of domestic metallogenic potential has become a strategic priority (European Commission, 2023). Antimony (Sb), classified as a CRM since 2011, is among the minerals targeted by the Italian National Exploration Plan (PNE). The PNE explicitly mentions the Southern Tuscany Antimony District, where Sb was extracted up to the 1980s, as a strategic site for Sb resource evaluation.

Three dimensions implicit geological modelling approach offers the opportunity to estimate the volume of residual potential ore resources combining drill logs, mining reports and geological fieldwork. In the present study, a 3D geological model of the Montauto (Manciano, GR) mining is presented. It represents the first instance in Italy of an integrated workflow specifically developed for the reassessment of Sb resources. At Montauto, Sb production ceased driven by economic constrains rather than resource depletion. An extensive, historical database dating back to the 1960s, offers significant potential for identifying unexploited Sb mineralization at depths of approximately 5 to 20 meters.

The first steps of the study involved the digitization and organization of historical data - including drill logs and mining reports - within a GIS environment (QGIS). These georeferenced data were essential for the transition from traditional 2D interpretations to advanced 3D implicit geological modelling. After that, 3D modelling was carried out using GemPy, an open-source Python-based software, to reconstruct the complex subsurface geometries of the orebody (De la Varga et al., 2019). The model successfully reproduced the stratigraphic contacts between formations, which have been validated by the control dataset (cross-sections and logs). The study also enabled the modeling hydrothermal alterations occurring at the tectonic contact between the carbonate rocks (the so-called “Calcare Cavernoso” of the Tuscan Nappe), which mainly hosts the Sb mineralization, and the allochthonous sedimentary cover (Ligurian Units) (Lattanzi, 1999). These alteration zones frequently exhibit anomalously high Sb grade (> 1 wt. %), highlighting their significance for Sb resource evaluation.

A first quantification of the volume of extracted materials from the Montauto open-pit mine was obtained by comparing the DEMs extrapolated before and after mining activity. The amount of extracted material accounted to 163,000 m³. Crucially, the 3D model, when completed, will also incorporate the distribution of Sb grades throughout the orebody, enabling an accurate quantification of both the tonnage of the extracted rock volume and more importantly of the remaining intact mineralized bodies.

De la Varga M. et al. (2019) - GemPy 1.0: open-source stochastic geological modeling and inversion, Geosci. Model Dev., 12, 1-32, https://doi.org/10.5194/gmd-12-1-2019.

European Commission: Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, Study on the critical raw materials for the EU 2023 - Final report, Publications Office of the European Union, 2023, https://data.europa.eu/doi/10.2873/725585.

Lattanzi P. (1999) - Epithermal precious metal deposits of Italy-an overview. Mineralium Deposita, 34(5), 630-638.

QuarREE Project: Multi-Scale hyperspectral remote sensing and Nd/Biotite proxies for assessing REE potential in the Verbano Cusio Ossola district in NW Italy

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Keywords: hyperspectral imaging, remote sensing, granite waste.

The renewed strategic relevance of Critical and Strategic Raw Materials (CRMs and SRMs) in Europe is accelerating the reassessment of domestic extraction potential, not only in underexplored primary settings but also in brownfields and secondary resources such as quarry by-products, legacy stockpiles, and mining wastes. In Italy, this direction is explicitly reflected in the goals of the *National Exploration Program (PNE)* and in complementary initiatives (such as the recently launched *Urbes* project) that target raw materials from mining waste, encouraging systematic mapping and (re)evaluation through advanced, sustainable exploration technologies.

Within this framework, non-destructive, scalable ore-body characterization is increasingly important (Tusa et al., 2019). Hyperspectral imaging (HSI) - deployed from satellite, airborne/drone, and ground/laboratory platforms - has emerged as a mature approach for mineral mapping as it links diagnostic absorption features to mineral chemistry and abundance, offering a consistent basis for multi-scale decision workflows on ore bodies' potential (Carano et al., 2026). However, direct detection of REE-bearing minerals at low grades remains challenging due to grain-size effects, mixed pixels, and signal-to-noise limitations; therefore, proxy-based approaches (e.g., Nd absorption features or mineralogical associations, such as Fe-bearing phyllosilicates) are often required to bridge remote observations with resource potential (Asadzadeh et al., 2024).

The Verbano Cusio Ossola (VCO) district in NW Italy has historically quarried and processed granitoids that supply dimension stone and industrial minerals for decades. These operations generated (and continue to generate) significant volumes of by-products, creating an opportunity to reassess "waste" streams as potential secondary resources for CRMs and SRMs (Gioiello et al., 2025). In this contribution, we focus on REE-bearing granite materials from Minerali Industriali's Verbania granite ore system, which were investigated with Theia-X in the ***QuarREE project***, to evaluate whether REE prospectivity indicators can be retrieved from hyperspectral data across scales. The overarching hypothesis was that even when REE minerals are sparse or fine-grained, systematic spectral proxies tied to mineral associations and compositional variability (e.g., Fe-rich biotite) can be mapped and used to prioritize sampling and guide in situ surveys.

To de-risk a future in-situ hyperspectral campaign in the VCO district, Theia-X performed a controlled laboratory hyperspectral imaging campaign on a set of granite materials representative of both primary and secondary streams. The sample set includes coarse hand specimens (~5 cm), milled feeds (0.1-0.6 mm), and magnetic/non-magnetic separation products, including magnetic granite waste fractions. This study demonstrates that hyperspectral mapping can reliably characterize the main mineralogical architecture of REE-bearing granites and associated waste fractions in the VCO district, while direct REE-mineral detection remains conditional on grade and grain size. The key advancement is the identification of Fe-biotite as a robust, mappable proxy for total REE variability in the tested materials, enabling a scalable pathway from laboratory evidence to the planning of in situ UAV- and satellite-supported surveys.

Asadzadeh S. et al. (2024) - Detecting rare earth elements using EnMAP hyperspectral satellite data: a case study from Mountain Pass, California. Scientific Reports, 14(1), 20766, https://doi.org/10.1038/s41598-024-71395-2.

Carano G. et al. (2026) - Compositional zonation in carbonatite complexes along the Kudu Lineament, Namibia, from EMIT spaceborne hyperspectral imagery. Journal of African Earth Sciences, 106174, https://doi.org/10.1016/j.jafrearsci.2026.106174.

Gioiello S. et al. (2025) - Re-use of Montorfano granite waste (Verbania, Piedmont, Italy) for REEs-recovery along the feldspar industrial chain. Results from pre-concentration tests. Minerals Engineering, 228, 109309, https://doi.org/10.1016/j.mineng.2025.109309.

Tusa L. et al. (2019) - Mineral mapping and vein detection in hyperspectral drill-core scans: Application to porphyry-type mineralization. Minerals, 9(2), 122, https://doi.org/10.3390/min9020122.

The fluorite-baryte(-REE) mineralization of Sardinia: exploration targets of the Italian National Exploration Plan

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Keywords: Fluorite-Barite mineralization, Critical Raw Materials (CRM), Sardinia (Italy).

Fluorite and baryte became main commodities after World War II, leading to a temporary flourishing of several fluorite and baryte mines in Sardinia until their closure between 1980s and early 2000s due to declining fluorite and baryte prices.

Nowadays, the Silius mine (Sardinia SE) is the only active fluorite mine in Italy, and the other numerous mineralization of the region remain poorly explored by modern standards. The Paleozoic basement of Sardinia hosts several F-Ba massive mineralization linked to a post-Variscan, low-temperature hydrothermal event that remobilized F-Ba and base metals from F-rich granites and their related mineralization. Fluid circulation and vein formation occurred along important fault-controlled pathways. Host-rock composition regulates the relative abundance of elements: carbonaceous black shales-hosted veins are enriched in Ag and base metals; volcanic-hosted veins may be significantly enriched in REE (Sarrabus-Gerrei, SE Sardinia); limestone-hosted veins locally contain Zn-Pb-Cu and moderate REE contents (Sulcis-Iglesiente, SW Sardinia).

Although in the CRM list since 2011, a renewed interest towards fluorite arose after the Critical Raw Material Act of 2024. Following this path, the Italian National Exploration Plan identified three F-Ba(-REE) brownfield targets in Sardinia. The Bruncu Molentinu area (Sarrabus, SE Sardinia) hosts a 3.5 km quartz-baryte-fluorite vein system. Vertical zoning features shallow baryte, intermediate fluorite, and quartz at higher depth; Pb-Zn sulfides, especially galena, recur in fluorite-rich sectors. The surroundings area also includes other fluorite (Is Crabus and Monte Genis) and polymetallic veins (historical Ag mine Monte Narba). The Castel Medusa district (central Sardinia) contains an 85 km² quartz-fluorite-baryte vein field. Veins are subvertical, with a "pinch-and-swell" geometry, featuring intercalated fluorite- and baryte-rich zones and poorly mineralized zones; sulfides are rare. This vein system has been poorly explored, and their knowledge is limited to shallow levels. The Santa Lucia area (Sulcis-Iglesiente, SW Sardinia) hosts several fluorite-baryte veins with minor Pb-Zn-Cu sulfides within Cambrian limestones, associated with reactivated early Variscan backthrusts, microgranite intrusions and locally, paleo-karst cavities. Moreover, the presence of accessory REEs and Ni-Co-Bi has been recently assessed. In conclusion, Sardinia remains one of the most promising regions of Italy for identification of F-Ba(-REE) exploration targets, both brownfield and greenfield, whose potential will be better defined by the exploration results of the National Exploration Plan.

Geochemical distribution and mineralogical control of scandium in karst bauxite, NW Sardinia, Italy

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Keywords: bauxite, scandium, zircon.

In the last years, karst bauxite have attracted considerable attention as secondary sources of critical metals, including scandium and, in this respect, we investigated the geochemical pathways of scandium in oolitic karst bauxites from the Nurra district in north-west Sardinia (Italy). The Nurra karst bauxite mainly consists of boehmite, goethite, hematite, kaolinite, and anatase. In the whole-rock the average Sc concentration is 51 mg/kg. Microanalysis show that Sc is, by far, hosted in Fe-rich domains where the average Sc content is 171 mg/kg. An unusual content of Zr is measured all along the micro analyses, dispersed ubiquitously in both Fe-rich domains and Al-rich domains. The distribution of Sc and Zr in neo-formed structures, such as Fe -"agate" and Fe-veins, suggests that both these elements were mobile during the formation of these Fe-rich textural components. The Nurra bauxite hosts three main zircon populations of different ages that, regardless their provenance, are disrupted, fractured and corroded. Only one zircon population has been identified as the main Sc host (from 1184 to 4164 Sc mg/kg). We suggest that the source of Sc in the Nurra bauxite comes from the partial dissolution of the Sc-rich zircon for the following reasons: (i) no other Sc-bearing primary mineral has been detected; (ii) the UCC-like parent material and (iii) the Zr content dispersed in all the bauxite micro domains suggesting that Zr may experience a significant degree of mobility during karst bauxite formation and, more in general, during intense weathering conditions. On these basis, further studies are needed to investigate the pH oscillations during karst bauxite formation and their implications on the geochemical mobility of critical elements.

Extracting lithium from kaolin: Potential of the Torniella raw ceramic material deposit (southern Tuscany)

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Keywords: lithium recovery, kaolin, Torniella.

Given the strategic importance of lithium (Li) and the limited availability of primary resources in the European region, EU policies are increasingly focusing on re-evaluating domestic mineral deposits and exploring alternative sources. Within this framework, the ARTÙ project investigates the potential recovery of Li and other critical metals from Tuscany (Italy) mines by-products, including Torniella mine (GR).

At Torniella, hydrothermal fluids circulating through the fractured rhyolitic body of the Tertiary Tuscan magmatic province generated a complex veins network. Preliminary mineralogical, petrographic, and microchemical analyses of the veins revealed a composition of more than 80% kaolinite, with minor quartz, trace amounts of svanbergite, and interesting Li concentrations (Finto, 2025), ranging from 1600 to 6000 mg/kg. No Li-bearing mineral phases were identified, suggesting kaolinite as the only phase with the potential to host Li. Given the significant Li contents, experimental protocols were applied to assess the Li extraction potential from the kaolin veins, employing sustainable, low-energy, and environmentally friendly approaches (Liu et al., 2024; Zhong et al., 2024). Results indicated a limited Li mobility under mild conditions: ion exchange with 1 M $MgCl_2$ at room temperature resulted in negligible Li release (~0.2%). In contrast, thermal activation was found to be more effective; roasting at 850 °C with sodium sulfate followed by hot water leaching yielded about 35% recovery, whereas roasting alone at 600 °C followed by hot oxalic acid leaching achieved up to 60% recovery.

Even though the Torniella deposit is not currently economically viable, due to the limited amount of the Li-rich material in the quarry front, this study highlights the potential for Li recovery as a by-product of kaolin extraction. Specifically, acknowledging kaolinite as a Li host phase supports further investigations of similar deposits across the European region.

Finto G. (2025) - Caratterizzazione di sfridi di cava e prodotti industriali non conformi per la valutazione del potenziale estrattivo del litio. https://sol.unifi.it/tesi/consultazione.

Liu J. et al. (2024) - Lithium Extraction from Lithium-Bearing Clay Minerals by Calcination-Leaching Method. Miner., 14(3), 248, https://doi.org/10.3390/min14030248.

Zhong W. et al. (2024) - Lithium extraction from a Li-rich kaolin resource through Na_2SO_4 roasting and water leaching. Miner. Eng., 218, 109004, https://doi.org/10.1016/j.mineng.2024.109004.

Lithium potential of clay deposits in the Latera Caldera, Lazio, Central Italy

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Keywords: lithium-bearing clays, CO_2-rich fluid degassing, Latera Caldera (central Italy).

The growing demand for lithium driven by electric mobility and energy storage requires the identification of alternative resources beyond conventional deposits. Lithium-bearing clay systems hosted in volcano-sedimentary basins represent an emerging exploration target because of their large tonnage potential, favorable mining conditions, and relatively easy extractability and processability (Putzolu et al., 2025). The Latera Caldera (Vulsini Volcanic District, central Italy) is an active geothermal system where intense CO_2 degassing interacts with a thick volcano-sedimentary succession. In this environment, acidic CO_2-rich fluids promote alkali leaching from volcanic glass and feldspars, mobilize Li^+, and may favor its fixation through: (I) adsorption and ion exchange on smectites and illite-smectite mixed layers; (II) structural incorporation into octahedral vacancies of 2:1 phyllosilicates during diagenetic heating; and (III) neoformation of Li-phyllosilicates such as hectorite-saponite and lepidolite under reactive alkaline fluid conditions (Benson et al., 2023; Fulignati, 2020).

The Li prospecting campaign, targeting the uppermost portion of the volcano-sedimentary deposits of the Latera endoreic basin, has been carried out in areas with concentrated CO_2 degassing (Chiodini et al., 2007). Top soil and sediment were sampled at different depths down to 1.5 m by hand auger. Forty representative samples were analyzed by XRPD using internal standards and Rietveld refinement to quantify crystalline and amorphous phases. Samples showing evidence of Li-bearing micaceous phases were digested by microwave-assisted protocols optimized according to mineralogical composition: Test 1 (aqua regia) for kaolinite-rich matrices and Test 2 (HCl-HNO_3-H_2O_2 multi-acid digestion) for mica-rich samples. Lithium and trace-element concentrations were determined by ICP-OES. This study integrates Li concentrations, clay mineralogy, CO_2-rich fluid pathways, and fault-controlled circulation within the endoreic basin of the Latera caldera to constrain the spatial distribution and genesis of Li enrichment. Key objectives include defining the geological controls on Li accumulation, identifying Li-bearing clays and Li-micas, and assessing volcano-sedimentary geothermal systems as unconventional Li resources. Prospecting targeted zones of elevated CO_2 flux to evaluate whether structural features govern Li mineralization and to outline viable exploitation targets.

Benson T.R. et al. (2023) - Hydrothermal enrichment of lithium in intracaldera illite-bearing claystones. Sci. Adv., 9(2), eadd8183, https://doi.org/10.1126/sciadv.add8183.

Chiodini G. et al. (2007) - Carbon dioxide degassing at Latera caldera (Italy): Evidence of geothermal reservoir and evaluation of its potential energy. J. Geophys. Res. Solid Earth, 112(B12), B12204, https://doi.org/10.1029/2007JB005144.

Fulignati P. (2020) - Lithium concentration and mobility in geothermal clay systems: The Latera caldera example. Appl. Clay Sci., 190, 105590, https://doi.org/10.1016/j.clay.2020.105590.

Putzolu F. et al. (2025) - Volcano-Sedimentary Deposits: Overview of an Emerging Type of Lithium Resource. Economic Geology, 120(3), 541.573, https://doi.org/10.5382/econgeo.5135.

Tectonic control on magnesite mineralisation in the serpentinites of central Tuscany: Implications for Mg exploration

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Keywords: magnesite, serpentinite carbonation, tectonic control.

The magnesite deposits of central Tuscany represent one of the most significant historical Mg resources in Italy and a potentially important target within the new European framework for Critical Raw Materials (CRM) exploration. Approximately 1.5 Mt of magnesite were extracted during the first half of the twentieth century from several hydrothermal deposits hosted by serpentinite bodies of the Ligurian Units, mainly at Castiglioncello and Querceto, before mining activities were abandoned as a result of changing economic and market conditions. Despite their historical importance, these deposits have never been systematically assessed using integrated geological, geophysical and geochemical approaches, and their subsurface potential remains largely unconstrained. The Tuscan magnesite deposits consist of massive cryptocrystalline magnesite lodes, locally up to 15 m thick and traceable for kilometres along strike, emplaced within serpentinite lenses affected by extensional tectonics related to the Miocene-Quaternary evolution of the Northern Apennine back-arc (Boschi et al., 2009). Mineralisation occurs as steeply dipping to sub-vertical NW- to N-trending lodes associated with hydrothermal alteration of the serpentinite host rocks, including silicification and argillification. The deposits formed through the interaction between mantle-derived CO_2-rich fluids and serpentinites during tectonic deformation under hydrothermal conditions (Rielli et al., 2022).

This contribution presents a framework for reviving magnesite exploration in Tuscany through the reassessment of historical deposits and the integration of tectonic, geological, geophysical and geochemical datasets. Particular attention is given to reconstructing the structural architecture controlling ore emplacement, evaluating the down-dip continuity of high-grade lodes, and assessing the potential of lower-grade stockwork mineralisation largely overlooked by historical mining. The preservation of underground exposures, combined with extensive historical documentation, provides a rare opportunity to directly investigate the geometry of hydrothermal magnesite bodies and refine genetic models for magnesite ores in serpentinites. This framework also contributes to defining new exploration criteria for concealed Mg ore bodies and supports the reassessment of domestic Mg resources promoted by the European CRM Act. Beyond their economic significance, the Tuscan magnesite deposits also represent a unique natural laboratory for studying fluid-rock interaction, mineral carbonation and long-term geological CO_2 storage in ultramafic systems.

Boschi C. et al. (2009) - Enhanced CO_2-mineral sequestration by cyclic hydraulic fracturing and Si-rich fluid infiltration into serpentinites at Malentrata (Tuscany, Italy). Chem. Geol., 265, 209-226, https://doi.org/10.1016/j.chemgeo.2009.03.016.

Rielli A. et al. (2022) - Tectonically driven carbonation of serpentinite by mantle CO_2: Genesis of the Castiglioncello magnesite deposit in the Ligurian ophiolite of central Tuscany (Italy). Ore Geol. Rev., 149, 105022, https://doi.org/10.1016/j.oregeorev.2022.105022.

Geochemical prospecting of Critical and Strategical Raw materials (C/SRM) in stream sediments of the Emilia Romagna Region

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Keywords: sediments, Critical Raw Materials, geochemical prospection.

Stream-sediment geochemistry offers an effective framework for resolving provenance patterns and detecting weak mineralization signals in geologically complex regions. This study examines fine and coarse sediment fractions from four Northern Apennine catchments (Nure, Taro, Scoltenna and Trebbia) to quantify lithological contributions and evaluate the influence of mafic-ultramafic sources, including ophiolitic units and minor VMS occurrences that represent the main potential hosts of CRM in the region (Amorosi et al., 2014, Zaccarini & Garuti, 2008). Major and trace element data processed using the multivariate statistics, reveal for a proxy immobile element (Ni, Cr, Zn, B) distinct geochemical fingerprints reflecting variable inputs from carbonate units, felsic bedrock, and mafic bodies.

To refine these geochemical interpretations, major elements contents of the magnetic fractions were analysed and then mounted in resin and examined through SEM-EDS imaging and microanalysis. Mineral chemistry results are still under investigation.

Grain-size partitioning reveals complementary behaviours: sands preferentially host dense ultramafic minerals and capture localized inputs potentially linked to ophiolite-derived CRM (Garzanti et al., 2008) whereas muds highlight the presence of weak VMS-type contributions. PCA and clustering isolate subtle anomalies consistent with focused ultramafic contributions rather than broad geochemical dispersion. Overall, integrating bulk geochemistry, statistical tools, and SEM-based mineral characterization provides a robust approach for resolving complex source mixing and supporting early-stage exploration in heterogeneous lithological settings.

Amorosi A. (2014) - Tracing provenance and pathways of late Holocene fluvio-deltaic sediments by heavy-metal spatial distribution (Po Plain-Northern Apennines system, Italy) Sediment Provenance Studies in Hydrocarbon Exploration and Production 2013 386. Geological Society, London, Special Publications, https://doi.org/10.1144/SP386.6.

Garzanti E. et al. (2008) - Settling equivalence of detrital minerals and grain-size dependence of sediment composition. Earth and Planetary Science Letters, 273(1-2), 138-151.

Zaccarini F. & Garuti G. (2008) - Mineralogy and chemical composition of VMS deposits of northern Apennine ophiolites, Italy: Evidence for the influence of country rock type on ore composition. Mineralogy and Petrology, 94(1-2), 61-83, https://doi.org/10.1007/s00710-008-0010-9.

Beyond sustainability: Social acceptability and new forms of legitimacy in the European extractive sector

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Keywords: Critical Raw Materials, sustainable development, social licence to operate (SLO).

In the contemporary geopolitical context, characterized by increasing international tensions and a gradual reshaping of globalization dynamics, the supply of raw materials has regained strategic importance. At the European level, initiatives such as the Green Deal and the Critical Raw Materials Act highlight the need to rebuild domestic supply chains, largely dismantled over the past decades.

At the same time, the industrial sector, particularly the extractive industry, has undergone a significant paradigm shift toward sustainable development. This concept, given in Our Common Future, is rooted in broader reflections on the limits of growth and intergenerational responsibility (Jonas, 1984; Attfield, 2018), as well as on the legitimacy of decision-making processes in complex societies (Habermas, 1996), including more recent precautionary approaches (Birch, 2024).

Recent European sustainability reporting frameworks, such as GRI 14, impose increasingly stringent ESG criteria on the extractive sector (Global Reporting Initiative, 2024). But compliance with regulations is insufficient for territorial legitimacy. Extractive projects, marked by long-term time frames and major impacts need approaches integrating social and territorial dimensions (Bookchin, 1982).

In this perspective, social acceptability emerges as a key issue, understood as a participatory process based on stakeholder engagement. The concept of Social Licence to Operate (SLO) is a key component of legitimacy, grounded in trust and transparency (Black, 2017), and has been introduced in the Italian debate as a means to overcome the limits of purely regulatory approaches (Savoca, 2019).

This approach has been further developed by the CIRAN project at the European level by proposing operational models to develop a "social contract" between industry and local communities (CIRAN Project, 2025) with the importance of integrating social acceptance and participatory governance in strategies for critical raw materials (Lucarini et al., 2024).

Attfield R. (2018) - Environmental ethics: A very short introduction. Oxford University Press.

Birch J. (2024) - The edge of sentience: Risk and precaution in humans, other animals, and AI. Oxford University Press.

Bookchin M. (1982) - The ecology of freedom: The emergence and dissolution of hierarchy. Cheshire Books.

Black L (2017) - The social licence to operate: Your management framework for complex times. The Social Licence to Operate: Your Management Framework for Complex Times, 1-100.

CIRAN Project (2025) - CrItical RAw materials extraction in environmentally protected areas. Horizon Europe Programme, Grant Agreement No. 101091483.

Global Reporting Initiative (2024) - GRI 14: Mining sector 2024. Global Sustainability Standards Board. https://www.globalreporting.org/standards/.

Habermas J. (1996) - Between facts and norms: Contributions to a discourse theory of law and democracy. MIT Press.

Jonas H. (1984) - The imperative of responsibility: In search of an ethics for the technological age. University of Chicago Press.

Lucarini M. et al. (2025) - The CIRAN Project: Sustainability Strategies and Social Acceptability for Critical Raw Materials Supply. European Geologist, 59, https://doi.org/10.5281/zenodo.16442530.

Savoca D. (2019) - La "Social Licence to Operate" quale strumento del futuro per l'accettabilità sociale delle attività estrattive. Notiziario ANIM - Quarry and Construction, 4/2019.

CRMs in Central Italy's LREEs-F-Rich belt: a potential REE resource?

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Keywords: CRMs, F-Ca carbonatite, REEs extraction.

Recent development in green and sustainable technologies, particularly for decarbonisation and the energy transition, has led to a growing demand for CRMs. In response, the European Commission is encouraging exploration for economically viable CRMs deposits. The LREEs-F-rich belt of the Roman Comagmatic Province (RCP; Washington, 1906) has emerged as a promising target (Mastrangelo, 1976; Stoppa et al., 2016, 2019). Here we present the advancements of an on-going geological and geochemical survey carried out over two F-Ca carbonatite ± fluoritite deposits (Pianciano and Santa Maria di Sala, SMdS), including the first detailed mapping of the SMdS deposit and preliminary REE extraction tests.

Both deposits occur in a 20 km-wide 60 km-long LREEs-F-rich carbonatite belt (Stoppa et al., 2016, 2019) that extends from northern Latium to Rome. SMdS is located in the Vulsini volcanic complex near the town of Farnese, inside the Latera caldera. Based on some borehole data, the deposit extends over an area of almost 10 km² with a "potential" volume of ~40 × 10^8 tonnes (Mastrangelo, 1976). The Pianciano deposit is located in the Sabatini volcanic complex, SW of the Bracciano lake, and consists of extrusive F-Ca carbonatite dykes and domes which intrude a plastically deformed fluoritite layer (Stoppa et al., 2016; 2019). It is estimated to contain 18 × 10^8 t of material, with an average fluorite content of 56%, making it the largest underdeveloped fluorite resource in Western Europe. Both deposits probably formed from carbothermal fluids derived from carbonatite magmas and exhibit interesting concentrations of LREEs (Ce, La, Nd, Sm) and barite, suggesting their potential for CRMs recovery.

The SMdS deposit shows an outcropping extension of ~2.5 km², with average fluorite grade of ~20%, but up to 40% in some areas. In its northern sector, the deposit is almost continuously exposed, whereas in the southern sector it has a heteropic character, intercalated with volcanic and fluvial deposits, and developed in at least two distinct series. The first series is up to 20-25 m-tick, while the second series rarely reaches more than 5 m. The deposit is characterised by a very fine grain size (200 μm to XRPD and SEM-EDS analyses reveal that the dominant mineral phases in both deposits are fluorite (up to 90% in fluoritite and 50% in carbonatite), calcite, and barite, with subordinate apatite, Ce-La-bearing fluorapatite, clay minerals, coronadite, diopside, zeolites, spinel, rare Ce-Ca-vanadate, microcline, zircon and occasional Ce-wakefieldite, vanadinite, zirconolite, and titanite. XRF and ICP-MS data indicate LREEs concentrations up to 2700 ppm in fluoritites and up to 800 ppm in carbonatites, hosted principally in Ce-Ca-vanadates, apatite and coronadite. Vanadates often form inclusions within, or rims around, coronadite.

REE extraction tests using variably concentrated citric acid (up to 0.5M), with or without the addition of NaOH to control pH, showed excellent extraction rates for carbonatites (up to 100%) and good rates for fluoritites (up to 59%). Although the extraction rate from fluoritites is lower, the amount of LREEs recovered for a given mass of sample is much higher due to the higher initial concentration. Optimization of extraction protocols for more efficient REEs recovery is ongoing.

Mastrangelo F. (1976) - I giacimenti. Rendiconti Soc. Italiana di Mineralogia e Petrologia 32, 29-46.

Stoppa F. et al. (2016) - State of the art: Italian carbonatites and their potential for critical-metal deposits. Gondwana Research, 37, 152-171, https://doi.org/10.1016/j.gr.2016.07.001.

Stoppa F. et al. (2019) - Italian carbonatite system: From mantle to ore-deposit. Ore Geology Reviews, 114, 103041, https://doi.org/10.1016/j.oregeorev.2019.103041.

Washington H.S. (1906) - The Roman comagmatic region. Carnegie Institution of Washington 57.

In the way towards EU raw material sovereignty: From exploration to extraction and value creation sustainably

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Keywords: raw materials, sustainable resource management, EU Opportunities.

The permitting from exploration to new extraction projects in EU can last from 10-15 years in average. Within the Criticality Raw Materials Act, the permitting timeline is restricted to 27 months excluding the Environmental Impact Assessment (EIA). The Critical Raw Materials Act sets also a non-binding target to boost domestic extraction of strategic materials up to 10 % and processing to 40 %. To meet these goals multiple factors such as access to finance, legal certainty and administrative bottlenecks hamper faster progress in this area, as they contribute to unpredictable timeline and investment planning decisions by operators.

The exploration, extraction, and processing of raw materials are taking place in a very limited scale in the EU. This is due to the multiple bottlenecks listed above and combined with a fragmented & uneven permitting process across EU countries or sometime region/local level, depending on where the permitting is taking place.

To boost the EU domestic raw material extraction and processing, we need:

- Better awareness at national/regional level in terms raw material needs
- Assessment of existing resources for early or advanced exploration activities towards deposit development
- Development of strategies and follow up actions towards implementation to boost national raw material supply
- Better coordination between various involved authorities (water; environment; water; forest; etc)
- Better predictability in terms of timelines from the legislations in place for the operators & authorities.

The EU's raw materials policy sets a strategic course, but rests on incomplete foundations which can be listed as accumulation of multiple EU legislations that operators need to comply with. Without a fundamental step-change in the permitting reform we will be unable to boost the EU raw material and deliver locally and sustainably sourced & process raw materials from within the European Union. Missing the opportunity now, means that our raw material dependencies will become even more prominent soon. The national raw material strategic plans developed by countries such as France and Italy are a step in the right direction towards raw material sovereignty.

Reconstructing a fossil VMS chimney system: Insights from sulfide mineralization in Piacenza Province, Italy

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Keywords: VMS deposits, sulfide minerals, ophiolites.

Three dismissed mine sites in Piacenza Province, Ferriere, Vigonzano, and Groppallo, located in the External Ligurian (EL) ophiolites, Northern Apennines, Italy, were studied to evaluate sulfide genesis and formation conditions. Volcanogenic Massive Sulfide (VMS) deposits are sulfide accumulations precipitated from hydrothermal fluids (Franklin et al., 2005). In Italy, several VMS deposits occur within the EL domains, intruded as olistholiths associated with serpentinites (Saccani et al., 2015). Due to complex orogenic deformation from plate convergence, reconstructing the primary VMS stratigraphy and proximity to original feeding systems remains challenging. All three mines used to be exploited, but existing scientific literature remains scarce (Garuti et al., 2009).

Petrography revealed a paragenetic sequence of: 1) euhedral, 2) colloform, 3) anhedral, and 4) framboid sulfides. Petrographic observations, mineral chemistry (EMPA) and bulk rock $\delta^{34}S$ revealed several sulfide precipitation stages at different temperatures, including a final low-temperature (LT, 300-350°C) hydrothermal system. The paragenesis indicates a HT VMS system, marked by euhedral pyrite and chalcocite in Groppallo, pyrrhotite in Vigonzano, and a lack of LT elements (Cd, Zn, As, Sb). Conversely, Se (up to 0.23 wt%), and Cd (0.13 wt%) high contents in chalcopyrites indicate subsequent medium- to LT fluid circulation. Chalcopyrites usually occur as fracture or vein fillings, witnessing a LT overprint. Co (0.10 wt%) and Ni (0.20 wt%) enrichments in pyrrhotite further support LT re-deposition. A final LT stage is highlighted by framboid textures in pyrite/iron oxides at Vigonzano and Ferriere. Bulk rock $\delta^{34}S$ in Groppallo, up to +20‰($_{VCDT}$) testifies cold seawater interaction with the sulfides, while the negative value, -6‰($_{VCDT}$) in Ferriere proves sulfate-reducing bacterial activity. These evidences suggest the three mines are genetically parts of the same initial system. Groppallo was closest to the high-temperature chimney system; Ferriere represents a distal, LT surficial portion dominated by framboid textures; Vigonzano occupies the mid-part of the system, preserving intermediate features and overprinting textures.

Franklin J. et al. (2005) - Volcanogenic Massive Sulfide deposits. Econ. Geol. 100th Anniversary Volume, 523-560, https://doi.org/10.5382/AV100.17.

Garuti G. et al. (2009) - Sulfur-isotope variations in sulfide minerals from massive sulfide deposits of the Northern Apennine ophiolites: Inorganic and biogenic constraints. Ofioliti, 34(1), 43-62, https://doi.org/10.4454/ofioliti.v34i1.377.

Saccani E. et al. (2015) - Continental margin ophiolites of Neotethys: Remnants of Ancient Ocean-Continent Transition Zone (OCTZ) lithosphere and their geochemistry, mantle sources and melt evolution patterns. Episodes, 38(4), 230-249, https://doi.org/10.18814/epiiugs/2015/v38i4/82418.

Recovery potential of Critical Raw Materials from Sardinian antimony mining wastes: Su Suergiu and Corti Rosas case studies (SE Sardinia, Italy)

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Keywords: Antimony, CRM, Sardinia.

The supply of Critical Raw Materials (CRM) is a key priority for the European Union due to its strong dependence on non-EU suppliers. The EU CRMAct (2024) aims to strengthen the domestic supply of CRM within EU, also promoting their recovery from secondary sources such as mining waste, which could become an important resource to reduce the CRM supply risk for EU, which currently produces approximately 600 Mt/y of mine waste, added to the historic stockpile of ~28,000 Mt (NEMO Horizon, 2020). Antimony (Sb) has been classified as a CRM since the first EU list (2011), due to its high supply risk and strong dependence on non-EU production (Kanellopoulos et al., 2024). Given its critical importance and low recycling rate (Dupont et al., 2016), Sb-rich mine waste is now investigated in many old districts of Europe.

The study focuses on the abandoned Su Suergiu and Corti Rosas mines in SE Sardinia, the largest in Italy until the 1980s. Su Suergiu hosted a smelter for Sb ore processing into Sb_2O_3 and metallic Sb (Contini et al., 2009), while Corti Rosas operated as a secondary extraction and beneficiation site using gravity, flotation after an initial period of smelting at the site. Between 1901 and 1948, 86,523 t of Sb ore were extracted. Previous studies report that Su Suergiu slags contain Sb-bearing phases such as senarmontite/valentinite (Sb_2O_3), mopungite, and metallic Sb, whereas tailings are dominated by stibnite. Scheelite ($CaWO_4$) is also commonly present. In contrast, waste rocks and tailings are Sb-depleted and dominated by gangue minerals.

The most promising materials from Su Suergiu (slags and tailings) were tested for ore mineral enrichment using hydrodynamic separation techniques (shaking tables) applied to two different particle size fractions. Yellow slags, with an initial grade of 12.9 wt% Sb, produced concentrates containing up to 70 wt% Sb. EPMA analyses showed that Sb mainly occurred as Sb_2O_3 (valentinite/senarmontite), metallic Sb, and minor Sb-Fe-As alloys. Metal recovery is around 60% for the coarse fraction. In contrast, the glassy slags were characterized by lower Sb contents in both the raw waste (1.5 wt%) and in the concentrates (up to 2.8 wt% Sb), mainly due to Sb entrapment in the silicate glass matrix. Significant amounts of scheelite (up to 4 wt%) were detected, especially in the fine fraction concentrates, with a W recovery of around 43%, suggesting potential for co-recovery. Tailings waste contained 9-10 wt% Sb in the raw material, while shaking table separation produced concentrates up to 28 wt% Sb, mainly as stibnite. Estimated Sb recovery range is around 30-45% for both coarse and fine fraction. Good separation of scheelite (up to 1.7 wt%) was also achieved. These results demonstrate the potential of Sardinian Sb mine wastes as secondary resources for the recovery of Sb and associated CRMs.

Contini E. et al. (2009) - Fenomeni di contaminazioneda discariche minerarie e metallurgiche nel Distretto dell'Antimonio del Sarrabus-Gerrei (Sardegna Sud-Orientale): l'area di Su Suergiu-Villasalto. Resoconti Dell'Associazione Mineraria Sarda, 112-113, 45-83.

Dupont D. et al. (2016) - Antimony Recovery from End-of-Life Products and Industrial Process Residues: A Critical Review. J. Sustain. Metall., 2, 79-103, https://doi.org/10.1007/s40831-016-0043-y.

Kanellopoulos C.et al. (2024) - Antimony's Significance as a Critical Metal: The Global Perspective and the Greek Deposits. Minerals, 14, 121, https://doi.org/10.3390/min14020121.

NEMO Horizon 2020 project (2020) - Near-zero-waste recycling of low-grade sulphidic mining waste for critical-metal, mineral and construction raw-material production in a circular economy. https://doi.org/10.3030/776846.

CRM evaluation and preliminary environmental assessment in an abandoned silver mining district: the case of Monte Narba mine, SE Sardinia

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Keywords: mine waste, CRM, Sardinia.

The domestic supply of Critical and Strategic Raw Materials (CRM, SRM) is a current challenge for EU due to its strong reliance on imports. The implementation of recycling is one of the main strategies addressed by the 2024 EU Critical Raw Materials Act for the recovery of CRM and SRM within EU, and mining waste is a major potential secondary resource of such raw materials. In EU, Extractive Waste, represents the largest waste stream in the EU, with an estimated annual production of 600 Mt (NEMO Horizon, 2020), added to the historic stockpiles (28,000 Mt).

This study focuses on the abandoned Monte Narba mine, historically the most important for the exploitation of hydrothermal Ag-bearing mineralization associated with Pb, Zn, F, Ba and other metals in the Ag SE Sardinia Mining District (Naitza et al., 2019). Mining activity began in the second half of the 19th century, with production reaching approximately 1,000 t/y of Ag and Pb minerals. Recently, the site attracted interest due to the presence of industrial minerals such as barite and fluorspar in the mine wastes, historically considered waste but today classified as CRM and potentially suitable for recovery. However, no valorisation of the site has ever taken place, and today the area remains abandoned, with information coming from few historical documents (Mezzolani & Simoncini, 1989).

Monte Narba mine wastes cover an area of approximately 51,000 m² and an estimated volume of about 103,000 m³ (RAS, 2003). Two main waste bodies can be distinguished: a main stockpile of gravity tailings (42,000 m^2), located near the old processing plant and a more heterogeneous landfill (Rio Figu), composed of both waste rock and fine residues (9,000 m^2). Results of geochemical analyses indicate the presence of significant concentrations in mine wastes of Ag (average 596 ppm), both in the gravimetric tailings and in the Rio Figu waste dump. The central part of the tailings dump showed strong enrichments in CRM such as fluorite (up to 18 wt%) and barite (0.2-0.3 wt%), together with Pb (up to 1.2 wt%) and Zn (up to 1.9 wt%). The presence of fluorite is also confirmed by XRD and SEM-EDS investigation, which also reveals some phosphate phases associated with LREEs such as La (44 ppm) and Ce (85 ppm). The results indicate that, in addition to Ag, the possibility of recovering associated by-products could be considered.

A preliminary environmental assessment of the site was carried out through ABA and SPLP tests on samples from both the fine tailings and the Rio Figu dumps. Overall, the results indicate that most of the samples show neutral to slightly alkaline pH conditions (pH 7-8), with negative or slightly positive AMD Net Acid Potential Production. However, the concentrations of PTEs (including Pb, Zn, Cd, As and Sb) in the raw waste always exceed the Italian contamination threshold values for industrial soils, highlighting a potential environmental concern due to their release in waters.

Mezzolani S. e Simoncini A. (1989) - La miniera d'argento di Monte Narba, storia e ricordi. Cagliari: GIA Editrice, 1989.

Naitza S. et al. (2019) - The metallogenic potential of an old European mining region: The case of Sardinia (Italy). In Life with Ore Deposits on Earth, Proceedings of 15th Biennial SGA Meeting, Glasgow, UK, 27-30 August 2019; Society for Geology Applied to Mineral Deposits: Mountain View, CA, USA, Volume 4, pp. 1458-1461.

NEMO Horizon 2020 project (2020) - Near-zero-waste recycling of low-grade sulphidic mining waste for critical-metal, mineral and construction raw-material production in a circular economy, https://doi.org/10.3030/776846. Available at: https://cordis.europa.eu/project/id/776846.

Regione Autonoma Sardegna (2003) - Piano Regionale di gestione dei rifiuti. Piano di Bonifica siti inquinati, Allegato 5, Schede dei siti minerari dismessi. Available at: https://www.regione.sardegna.it/documenti/1_39_20051011122623.pdf.

Geochemical constraints on the formation of Permian-Triassic Fluorite deposits and their REE potential in Trentino-Alto Adige

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Keywords: Fluorite, Southern Alps, REE.

This study investigates Permian-Triassic hydrothermal fluorite veins from the Trento Province (Southern Alps, northern Italy), integrating trace-element geochemistry, microthermometry, and in situ calcite U-Pb geochronology. These deposits are part of a broader system of small critical mineral occurrences, historically exploited and spatially associated with Paleozoic-Mesozoic magmatic activity. Geological evidence suggests that fluorite mineralization is linked to two main phases: a Permian post-Variscan phase and a Triassic phase related to magmatism of the Athesian Volcanic Group and possibly the Monzoni-Predazzo volcanic center (e.g. Bakos et al. 1972). The studied fluorite veins occur within a geological framework consisting of a pre-Permian metamorphic basement overlain by Permo-Mesozoic volcanic and sedimentary sequences. The mineralization developed through multiple hydrothermal events filling fracture systems. The veins are typically metric in thickness and composed mainly of fluorite, quartz, and base metal sulphides (sphalerite and galena), with calcite crystallizing during late stages.

Microthermometric analyses of fluid inclusions indicate that fluorite precipitated from H_2O-NaCl-$CaCl_2$ fluids. Primary fluorite formed from moderately to highly saline fluids (~12-26 wt% NaCleq) at temperatures between 114 and 298 °C, whereas secondary fluorite in breccias formed from less saline fluids (6-10 wt% NaCleq) at lower temperatures (105-150 °C). These data suggest at least three distinct hydrothermal phases characterized by evolving physicochemical conditions. Trace-element analyses show REE+Y contents up to 1000 ppm and geochemical signatures comparable to other late- to post-Variscan fluorite deposits. Bulk and in situ analyses reveal different REE patterns: bulk samples show positive Y and negative Eu anomalies, while fluorite analyses display positive Y and Eu anomalies. The positive Eu anomaly in fluorite suggests crystallization at temperatures below 200 °C and indicates that fluids were previously enriched through high-temperature interaction with granitic or gneissic rocks. Variations in LREE fractionation could be attributed to inclusions of REE-rich minerals (synchysite, xenotime, and bastnäsite), mainly hosted in calcite. U-Pb dating of calcite, which formed later than fluorite, yields Jurassic (168 ± 15 Ma), Cretaceous (74 ± 27 Ma), and Oligocene (27 ± 14 Ma) ages. These ages correspond to major tectonic events, including Jurassic extension in the Southern Alps and later reactivation phases of the Valsugana Line (e.g. Schettino and Turco 2011; Curzi et al. 2024). Although not directly dating the primary mineralization, these results constrain the timing of late hydrothermal processes and fluid circulation.

The data suggest a complex hydrothermal evolution involving multiple mineralizing and post-mineralizing events. Fluorite formation was controlled by changing temperature and salinity conditions, while later tectonic activity played a key role in fluid remobilization and calcite recrystallization. Overall, the study improves the understanding of post-Variscan hydrothermal systems in the Southern Alps and their relationship with magmatic and tectonic processes.

Bakos F. et al. (1972) - The age of mineral deposits in the Permian volcanites of Trentino-Alto Adige (Northern Italy). Geologija, 15(1), 181-194.

Curzi M. et al. (2024) - Tectonic evolution of the Eastern Southern Alps (Italy): A reappraisal from new structural data and geochronological constraints. Tectonics, 43(3).

Schettino A. & Turco E. (2011) - Tectonic history of the western Tethys since the Late Triassic. GSA Bulletin, 123(1-2), 89-105, https://doi.org/10.1130/B30064.1.

Origin of ore-forming fluids in a Cu-W System from the Southern Italian Alps: Insights from Pb and B isotopes

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Keywords: Lead Isotopes, Boron Isotopes, Tungsten.

New lead and boron isotope data are presented for tourmaline-bearing hydrothermal Cu-W deposits of the Predazzo area (Trento Province, north-eastern Italy) and for possible parent units of the Triassic Predazzo intrusive-volcanic complex. The aim of this work is to constrain the sources of mineralizing fluids within the Triassic Predazzo Intrusive Complex (PIC). Previous studies proposed different genetic models, linking mineralization to leucogranites, monzonitic intrusions, or later magmatic events. Here, isotopic data from tourmaline, scheelite, and chalcopyrite are used to clarify these relationships.

The PIC is a multi-phase complex, consisting of calc-alkaline to shoshonitic monzonitic bodies (M1 and M2) emplaced between ~238 and 236 Ma, subordinate alkaline intrusions, and a central composite granite unit (biotite granite and tourmaline leucogranite; Visonà, 1997; Visonà et al., 2025). Later lamprophyre and phonolitic dykes cut the entire complex. The main Cu-W mineralization (Bedovina deposit) occurs as stockworks of veins along structural discontinuities and developed in two stages: an early W-rich phase (scheelite-bearing) and a later Cu-rich polymetallic phase (chalcopyrite-dominated).

Lead isotope data show that scheelite and most chalcopyrite samples from the Cu-W deposits have isotopic compositions close to those of the monzonitic intrusions (M1 and M2), suggesting that these magmas were the dominant source of Pb. In contrast, chalcopyrite from tourmaline-rich orbicules within the leucogranite matches the isotopic signature of the host granite, but differs significantly from that of the ores. This demonstrates that leucogranitic fluids were not the primary source of metals in the deposits. A single analysed chalcopyrite from the deposit displays a more radiogenic Pb composition, suggesting a mixing trend between the monzonitic and leucogranitic signatures and a minor contribution from granitic sources superimposed on a dominant monzonitic component. Additionally, Pb isotope ratios do not support a genetic role for biotite granite and foid-bearing syenite dykes, which are isotopically incompatible with the mineralization.

Boron isotope data further support a multi-source model. Tourmaline from leucogranite-hosted orbicules shows uniform $\delta^{11}B$ values (around -10‰), indicating limited fractionation during crystallization. In contrast, tourmaline from the Cu-W ores exhibit strong isotopic zoning, with higher $\delta^{11}B$ values in the cores and significantly lower values in the rims. This large isotopic variation cannot be explained by fractionation alone and points to distinct fluid sources.

The combined Pb and B isotope data indicate that the Predazzo tourmaline leucogranite was neither the sole nor the dominant source of mineralizing fluids. Instead, the Cu-W mineralization mainly derived from monzonitic magmas, with a subordinate contribution from granitic sources. The isotopic variability recorded in ore minerals and tourmaline reflects fluid mixing and a complex hydrothermal evolution. These results highlight the importance of multiple magmatic sources and fluid interactions in the formation of the Predazzo Cu-W deposits.

Visonà D. (1997) - The Predazzo multipulse intrusive body (Western Dolomites, Italy). Field and mineralogical studies. Mem. Sci. Geol., 49, 117-125.

Visonà D. et al. (2025) - Alkaline magmatism in the post-orogenic Triassic Predazzo complex, Dolomites, NE Italy: ages and significance. Lithos, 494-495, 107912.

Reassessing the Cu-Mo-Au potential of the Siliqua structural high and Cixerri valley, SW Sardinia, through legacy data and airborne electromagnetic exploration

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Keywords: mineral exploration, airborne electromagnetics, Siliqua-Cixerri.

The Siliqua structural high and the adjacent Cixerri valley, in SW Sardinia, represent a poorly re-evaluated Cu-Mo-Au exploration target along the western edge of the Campidano half-graben. Here, Oligocene calc-alkaline andesitic to tonalitic subvolcanic bodies intrude Paleozoic basement rocks and are partly covered by younger pyroclastic, epiclastic and continental deposits. Widespread propylitic and potassic alteration, together with disseminated and vein-hosted Fe-Cu-Mo sulphides, supports the interpretation of a porphyry-style mineralizing system, locally comparable to a quartz-diorite porphyry environment.

The area was explored between the late 1980s and 2000 by Progemisa S.p.A. and Sardinia Gold Mining through geological-structural mapping, soil and rock geochemistry, diamond drilling, ground magnetometry and induced-polarization surveys. These investigations focused mainly on the Monte Silixianu-Monte Idda-Monte Perdosu sector and documented low-grade disseminated mineralization, locally around 0.4% Cu and about 1 g/t Au, as well as shallow polarizable bodies north of Monte Idda (Granitzio, 2000; Progemisa S.p.A., 1991; Sardinia Gold Mining, 2000). However, this sector represents only a limited part of a broader volcanic-hydrothermal system. Geological, geochemical and alteration evidence suggests that further shallow mineralized bodies, and possibly analogous subintrusive stocks concealed beneath pyroclastic and recent sedimentary cover in the Cixerri valley, may remain undetected.

We propose a renewed exploration strategy based on the critical reappraisal of legacy geological, geochemical, drilling and geophysical data, followed by airborne electromagnetic (AEM) surveying using the EQUATOR system available at the University of Cagliari. EQUATOR was designed to combine time- and frequency-domain AEM responses, providing high-resolution near-surface information (Karshakov et al., 2017). Its compact design makes it well suited to high-productivity surveys in logistically difficult or rugged terrains. The survey would first focus on a high-priority block, flown with 100 m line spacing and oriented approximately orthogonal to the main geological trends and available ground electrical profiles, followed by wider-spaced coverage of less constrained brownfield sectors. The expected investigation depth of about 80-100 m and near-surface lateral resolution on the order of tens of metres would allow comparison with legacy induced-polarization and drilling results and extension of the investigation beneath poorly exposed or covered sectors.

This approach would provide a new, spatially continuous geophysical framework for reassessing the Cu-Mo-Au potential of the Siliqua-Cixerri system, supporting target ranking and future direct investigations. More broadly, the case study illustrates how legacy mining data, integrated with modern airborne geophysics, can contribute to the renewed evaluation of critical and strategic raw materials in Italy.

Granitzio F. (2000) - Studio dell'evoluzione di un sistema idrotermale associato a corpi subvulcanici calcoalcalini terziari: il sistema tipo porphyry copper di Siliqua-Decimoputzu (Sardegna sudoccidentale). Modello e guide per la prospezione. Tesi di dottorato, Dipartimento di Geoingegneria e Tecnologie ambientali, XII ciclo, 217+XV pp.

Karshakov E.V. et al. (2017). Combined frequency domain and time domain airborne data for environmental and engineering challenges. Journal of Environmental and Engineering Geophysics, 22(1), 1-11.

Progemisa S.p.A. (1991) - Mineralizzazioni a rame di Siliqua. Relazione conclusiva, rapporto interno.

Sardinia Gold Mining (2000) - Siliqua Exploration IP Survey - June 2000. Internal report.

Quality monitoring of a ceramic tile industry supply: An example from an Italian kaolin mine

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Keywords: kaolin, ceramic, hydrothermal.

Piloni di Torniella mine (Tuscany, Italy) has been supplying raw materials to Italian ceramic industry since the early 2000s, thus representing one of the most important kaolin mines in our country (Viti et al., 2007). The disruption in Ukrainian ball clays supply in 2022, caused by the outbreak of war, has highlighted the importance of relying on national raw materials (Fantini et al., 2024), possibly enhancing the role of this kaolin mine. Nevertheless, Piloni di Torniella deposit is characterized by a marked spatial heterogeneity, intrinsically connected to its hydrothermal genesis (Ece & Ercan, 2024). This feature can result in fluctuations in time of the chemical and mineralogical compositions of the extracted material (Cáceres & Emery, 2026), which can influence its suitability for ceramic tile industry. The goal of this study is to characterize this variability over a time scale of six years, from 2018 to 2024, by applying an analytical protocol, including X-Rays Fluorescence (XRF), Fourier-Transform Infrared Spectroscopy (FT-IR), X-Rays Powder Diffraction (XRPD), Scanning Electron Microscopy with Energy-Dispersive Spectrometry (SEM/EDS) and micro-Raman Spectroscopy. Overall, heterogeneity in the extracted material is more evident at the spatial than at the temporal level; however, in single extractive sites, significant variations in time in the extracted material composition have been registered, both chemically and mineralogically. Furthermore, the protocol has evidenced the impact of mining license constraints on the extracted material quality. Nevertheless, the mining strategy adopted by the license holder is effective in keeping constant in time the composition of the raw material supplied to the ceramic industry. The results of this study can offer valuable insights into the management of extractive activity in hydrothermal kaolin mines, thus supporting mining planning in other deposits characterized by a similar geological context.

Cáceres A. & Emery X. (2026) - The financial value of geological data acquisition: Optimizing mining investments by mitigating geological uncertainty. Miner. Econ., https://doi.org/10.1007/s13563-026-00643-w.

Ece Ö.I. & Ercan H.Ü. (2024) - Global Occurrence, Geology and Characteristics of Hydrothermal-Origin Kaolin Deposits. Minerals, 14, 353, https://doi.org/10.3390/min14040353.

Fantini R. et al. (2024) - Reappraisal of red clays in porcelain stoneware production: Compositional and technological characterization. Appl. Clay Sci., 250, 107291, https://doi.org/10.1016/j.clay.2024.107291.

Viti C. et al. (2007) - Weathering sequence of rhyolitic minerals: the kaolin deposit of Torniella (Italy). N. Jb. Miner. Abh., 183(2), 203-213, https://doi.org/10.1127/0077-7757/2007/0072.

S22.

Waste-Derived Geomaterials in the Circular Economy: From Advanced Mineralogical Characterization to Sustainable Reuse

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Bone ashes as alternative fluxing agent in the ceramic sanitary-ware production

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Keywords: ceramics, waste reuse, critical raw material.

The partial substitution of feldspar fluxing agent with bone ashes into the traditional ceramic sanitary-ware formulation was investigated. Both technological properties (rheology, water absorption, fired shrinkage, thermal expansion and flexural strength), crystallographic insights (XRD and NMR) and microstructural details (SEM) were evaluated.

The study was divided in two main steps. The first one revealed that the simple substitution of feldspar (2.5 and 5 wt.%) with bone ashes is not recommended, due to a higher level of fusibility reached in the case of bone ashes-bearing formulations, especially at the typical process temperatures (i.e. higher than 1200°C), that is responsible of pores development into the material as well as sagging effect. Conversely, the second step demostrated that, if the whole body composition is tuned to become more refractory by further replacement of feldspar (~ 10 wt.% total replacement) with quartz, good technological results can be reached with a small amount of bone ashes (i.e. 2.5 wt.%) in the formulation.

These results are very important to suggest alternative fluxing minerals to feldspar, which was recently inserted into the critical raw materials list by the European Union.

Recycle of textile waste in geopolymers-based binders for applications as new insulation materials in the construction sector

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Keywords: textile waste, geopolymer mortars, insulation panels.

The rapid increase in clothing consumption since the late 1990s has established a “buy-throw-away” culture that poses severe environmental threats, with global textile waste exceeding 92 million tonnes per year. Morover, fast fashion, defined by high-volume, low-quality production, relies heavily on synthetic materials like polyester, which are carbon-intensive, non-renewable, and take centuries to biodegrade. The EU is implementing measures such as the Extended Producer Responsibility (EPR) schemes to force brands to manage the full lifecycle of their products, which is projected to boost recycling efforts (https://www.europarl.europa.eu/topics/en/article/20201208STO93327/fast-fashion-eu-laws-for-sustainable-textile-consumption). An increased attention is stimulating new options for the recycling of textiles, which could contribute to the reduction of waste as well as production of new materials.

In this study, we tested the possibility of incorporating textiles into a geopolymer binder, with the aim to find a way to recycle this waste avoiding complex separation processes, which are undermined by the presence of a variety of synthetic and natural fibers mixed. We approached this problem by mechanically shredding textiles waste to obtain fragments of different sizes (2 mm and 6 mm), without preliminary separation by fabric type, which have been added to a mix of metakaolin and potassium silicate for geopolymer synthesis. Textiles quantities used vary from 2 to 10 wt.% and the materials produced have been tested to determine chemical, physical and mechanical performance.

Optical/Scanning Electron Microscope images confirmed good textural properties of the textile-reinforced geopolymer, with good interfacial bonding and limited microcracking. The addition of shredded textiles resulted in a significant reduction in material density compared to the standard sample, which is advantageous for the production of lightweight materials. The manufactured composites exhibited strong acoustic and thermal insulation performance, as well as good mechanical characteristics, marking these materials as suitable candidates for a more sustainable construction sector while enabling efficient upcycling oftextile waste.

Crystal-chemical variability in CDW across grain-size fractions: insights from XRPD, XRF and ATR-FTIR

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Keywords: CDW, ATR-FTIR, XRPD.

Construction and Demolition Waste (CDW) is one of the largest waste streams in the EU; it is highly heterogeneous, originating from buildings, infrastructure, civil engineering works, and natural-disaster debris. Despite their recycling potential, their intrinsic spatial and temporal heterogeneity leads to poorly predictable physical-mechanical properties. Indeed, their chemical and mineralogical attributes strongly depend on the source materials and regional geology (Galderisi et al., 2023).

Consequently, most of CDW is still largely downcycled or landfilled (Blengini & Garbarino, 2010; Galderisi et al., 2023) because effective reuse requires sorting into sub-populations with homogeneous, well-defined properties such as those needed for recycled-aggregate concrete (RAC).

Compared with Natural Raw Material (NRM; Rodrigues et al., 2013), mortars and concretes prepared with CDW have reduced and more variable mechanical performance than those prepared with natural aggregates (Galderisi et al., 2023), due to the crystal-chemical features and textures of the constituent phases; in turn, they have to be known to implement adequate sorting.

Currently, industrial CDW treatment is largely limited to crushing and sieving; notwithstanding information on distribution and enrichment/depletion of crystalline and non-crystalline phases across different grain sizes is still scarce.

To uncover these limitations, two CDW samples from different Italian geological contexts were investigated: Macerata (MCM), a seismically active perimountain area, and Ferrara (FEM), representative of the Po Plain. Both were sampled in industrial plants, crushed below 1.6 and 3.2 cm, and sieved into 10 and 12 grain-size fractions for MCM and FEM, respectively. Representative powdered samples were prepared from each grain-size population for XRPD, XRF-WDS and ATR-FTIR (400-4000 cm^{-1}) analyses.

XRPD and XRF results identified crystalline phases typical of aggregates in mortars and concretes, masonry and ceramic materials, along with CSH-hardened cement phases. However, carbonates dominate MCM, while silicate phases characterise FEM CDW grain sizes. These results, along with literature IR standards, guided the deconvolution of ATR-FTIR spectra using the fewest possible Pearson VII components to reproduce them. While band positions and widths are similar for both sites, their relative intensities vary significantly. Below 1500 cm^{-1}, bands related to silicates and carbonates are evident, whilst at the highest frequencies, mainly > 3000 cm^{-1}, multicomponent bands of CSH phases are observed and fitted. IR area% of these bands was used to calculate the amounts of silicates, carbonates, and CSH, showing strong correspondence with XRPD and XRF-WDS data.

These results testify that ATR-FTIR in the MIR region is a rapid and valuable tool to derive crystal-chemical attributes and relative abundance of phases in a CDW, potentially paving the way for a real sorting of CDW in homogeneous sub-fractions.

Blengini G.A. & Garbarino G. (2010) - Resources and waste management in Turin (Italy): The role of recycled aggregates in the sustainable supply mix. J. Clean. Prod., 18, 1021-1030. https://doi.org/10.1016/j.jclepro.2010.01.027.

Galderisi A. et al. (2023) - Physico-mechanical performances of mortars prepared with sorted earthquake rubble: the role of CDW type and contained crystalline phases. Materials, 16(7), 2855, https://doi.org/10.3390/ma16072855.

Rodrigues F. et al. (2013) - Physical-chemical and mineralogical characterization of fine aggregates from construction and demolition waste recycling plants. J. Cleaner Prod., 52, 438-445, https://doi.org/10.1016/j.jclepro.2013.02.

Rice husk as raw material in the synthesis of analcime

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Keywords: rice husk, zeolitic synthesis, ANA zeolite.

Silica is the most abundant free oxide (mainly as quartz) in the earth's crust, yet despite this abundance, quartz is not extensively used in chemical engineering since amorphous silica is required for easy reaction leading to industrial mineral synthesis. Amorphous silica is mainly produced by synthetic means for its use in technological applications and it is one of the valuable inorganic multipurpose chemical compounds. Naturally or anthropic amorphous silica can provide an alternative source to replace commercial silica precursor; the sources of silica include fly ash, high-temperature calcined kaolinite, diatomite, tripolaceous rocks, halloysite and rice hisk (RH). RH is an agricultural waste from rice milling usually composed of organic compounds such as lignin, cellulose, but the most abundant constituent of RH is amorphous silica.

Analcime, with the ANA framework structure, is the smallest-pore zeolite and it exhibits a compact structure compared to other zeolites with an idealized unit cell of $Na_{16}Al_{16}Si_{32}O_{96}$ $16H_2O$. Analcime is a zeolite which can be used for water retention and as pozzolanic material in cement mortar and concrete, in catalysis (Liu et al., 2005), stomatology, i.e. ceramics for dental repair and implants (Rasmussen et al, 1998). Synthesis of monomineralic powders of Analcime by RH is here achieved with the conventional hydrothermal method; an improvement in synthesis conditions compared to the past is achieved by lowering rice-husk calcination temperatures, synthesis temperatures, crystallization times and by avoiding aging times. RH is subjected to calcination at the temperature of 550 °C and then mixed with NaOH and $NaAlO_2$. The experiment is performed at environment pressure and 170 ± 0.1°C for 77 h. Analcime is characterized by X-ray diffraction, scanning electron microscopy, infrared and Raman spectroscopy. Cell parameters and the amount of amorphous phase in the synthesis powders is described with quantitative phase analysis using the combined Rietveld and reference intensity ratio methods. The degree of purity of Analcime is calculated in 97,53% at 12 h. The results show that RH waste represents a good alternative silicon source, and it can be used to produce pure analcime crystals.

Liu B. S. et al. (2005) - Fabrication of analcime zeolite fibers by hydrothermal synthesis. Microp. Mesop. Mat., 86, 106-111, https://doi.org/10.1016/j.micromeso.2005.07.020.

Rasmussen S. T. et al. (1998) - Stress induced phase transformation of a cesium stabilized leucite porcelain and associated properties. Dent. Mater., 14, 202-211, https://doi.org/10.1016/s0109-5641(98)00033-5.

Synthesis of zeolite Li-A(BW) obtained using rice husk ash as silica source

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Keywords: rice husk, zeolitic synthesis, Li-A(BW) zeolite.

Li-A(BW) zeolite is a low-silica synthetic zeolite, like FAU and the X, Y, characterized by a structure consisting of 4, 6 and 8 tetrahedral rings and a fully ordered Si/Al distribution. The synthesis of Li-A(BW) zeolite has been performed in the past using commercial chemical reagents. The great demand for low-silica zeolites, such as the Li-A(BW) type, widely applied in the fields of absorption, gas separation and carbon dioxide capture, has led to research into the identification and use of less expensive natural raw materials from which to extract the chemical reagents necessary for the synthesis processes. These secondary raw materials include kaolinite, smectite, bentonite, tripolaceous rocks, halloysite and rice husk (RH) (Novembre et al., 2024; Jin Y. et al., 2023).

RH is an agricultural waste material resulting from the processing of rice grains. The composition of RH is essentially given by organic components (lignin, cellulose) and by amorphous silica. RH is usually burned to produce electricity in countries that are dependent on energy imports; however, sometimes this causes health problems and environmental pollution (Petkowicz et al., 2008). In some cases, RH is burned in the boiler of industries and the SiO_2 content can reach high values (from 85% to 98%) depending on the rice variety, and the instrumental conditions of burning. In some other cases it is used as a raw material for producing solar-grade silicon (Si-GS) or in the production of mullite for the ceramic industry.

This work deals with the hydrothermal synthesis of Li-A(BW) zeolite using rice husk as the starting material. Rice husk is calcined at the temperature of 550°C to obtain rice husk ash. Li-A(BW) zeolite is synthesized starting from rice husk ash, LiOH, and $Al(OH)_3$ at 180°C. Li-A(BW) zeolite begins to appear at 2h and reaches its crystallization climax at 29h. The synthesized phase was subjected to morphological characterization. The Raman and infrared response have also been investigated. The cell parameters have been calculated using the Rietveld method. The combined Rietveld and reference intensity ratio methods allowed to exclude the presence of impurities and confirm a minimal residual amorphous phase in the conducted experiment (zeolite Li-A (BW) purity of 95.2 %). Testing rice husk as a source of amorphous silica in the synthesis of Li-A(BW) represents both economic and environmental advantages. The high yields and the results of the experiment open the way for the transfer to an industrial production scale.

Jin Y. et al. (2023) - Enhancement in CO_2 adsorption by zeolite synthesized from co-combustion ash of coal and rice husk modified with lithium ion. J. Energy Inst., 110, 101348-101359, https://doi.org/10.1016/j.joei.2023.101348.

Novembre D. et al. (2024) - Rice Husk as Raw Material in Synthesis of NaA (LTA) Zeolite. Molecules, 29, 43-56, https://doi.org/10.3390/molecules29184396.

Petkowicz D.I. et al. (2008) - Zeolite NaA from Brazilian Chrysotile and rice husk. Micropor. Mesopor. Mat., 116, 548-554, http://dx.doi.org/10.1016/j.micromeso.2008.05.014.

Life Cycle Assessment of CDW-based geopolymer mortars for construction applications

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Keywords: geopolymer mortars, construction and demolition waste, life cycle assessment.

The management of heterogeneous waste streams, such as construction and demolition waste (CDW) generated by both building dismantling activities and catastrophic natural events, represents a critical challenge for sustainable development and requires the adoption of circular economy principles. The 2016 earthquake in Central Italy generated a substantial amount of CDW, which is difficult to recycle and is therefore typically downcycled for use as backfilling material or, to a lesser extent, as aggregate in concrete (Nixon, 1978; Zhang et al., 2022). This practice, while enabling partial material recovery, does not fully exploit the potential value of these waste streams.

The incorporation of CDW into geopolymer-based materials has been explored by Volpintesta et al. (2023), who designed and tested a series of mortar mixtures for both structural and non-structural applications, thereby enabling the upcycling of CDW. The present study builds on these findings by assessing the environmental performance of such mortar mixtures. Specifically, the Life Cycle Assessment (LCA) methodology is applied to evaluate whether, and to what extent, the use of CDW contributes to the production of more sustainable mortars compared to conventional alternatives made with virgin raw materials. For this purpose, cradle-to-gate system boundaries are defined, encompassing all processes from CDW transport and raw material extraction to mortar production. Particular attention is paid to the representativeness of the life cycle inventory, which is based on a combination of primary and secondary data sources. In addition, LCA is employed to compare this waste management strategy with landfilling. In this case, the environmental impacts associated with landfill disposal are compared with those related to mortar production, including both the burdens from production processes and the benefits arising from the avoidance of primary raw material use.

Ultimately, this work contributes to advancing sustainable construction practices by supporting the integration of secondary raw materials into high-quality geopolymer systems and by providing quantitative evidence of their environmental performance.

Nixon P.J. (1978) - Recycled concrete as an aggregate for concrete: a review. Matériaux et Constructions, 11, 371-378.

Volpintesta F. et al. (2023) - Geopolymers-based application for the up-cycling utilization of construction and demolition waste from the 2016 central Italy earthquakes. Mater. Lett., 336, 133849.

Zhang C. et al. (2022) - An overview of the waste hierarchy framework for analyzing the circularity in construction and demolition waste management in Europe. Sci. Total Environ., 803, 149892.

Enhanced arsenic and selenium removal by Fe^{3+}-modified clinoptilolite: A structural investigation by SEM, XRD and XAS

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Keywords: zeolite, XAS, contaminant.

Heavy metal contamination represents one of the main environmental and public health issues worldwide. In particular, arsenic (As) and selenium (Se) are especially critical because they occur in aqueous environments as anionic species, namely arsenate and selenite, characterized by high mobility and difficult removal. In Italy, the widespread occurrence of As and Se contamination in water requires the development of innovative, sustainable, and cost-effective remediation methods (Baroni et al., 2004).

This study investigated the use of a natural zeolite, K (Ca, Na)-clinoptilolite, for the removal of these contaminants from aqueous solutions. Since zeolites mainly act as cation exchangers, the adsorption of anionic species is generally limited. Preliminary adsorption tests, evaluated by ICP-MS analysis, showed low removal efficiencies (7.35% for As and 6.16% for Se) with adsorption capacities (qe) of 0.19 and 0.17 mg/g, respectively.

Mineralogical and morphological characterization by X-Ray Powder Diffraction (XRPD) and Scanning Electron Microscope (SEM) revealed a composition consisting of 58.6% clinoptilolite, 23.6% anorthite, 13.6% illite, and 4.2% quartz. Due to the poor adsorption performance, the zeolite was treated with Fe^{3+} using a supersaturated ferric chloride solution, promoting iron incorporation into both the channels and the surface of the material. The presence of iron increases the affinity toward anionic species through the formation of active surface sites capable of establishing electrostatic interactions with arsenate and selenite (Akgül, 2014).

Subsequent batch tests showed a significant improvement in adsorption performance, with removal efficiencies of 99.92% for As and 99.89% for Se and qe values of 4.74 and 4.88 mg/g, respectively. XRD analyses confirmed the formation of hematite and goethite, while SEM images showed that As and Se were mainly localized in iron-rich areas, highlighting the key role of iron treatment in the adsorption process.

Further structural investigations were carried out through X-Ray Absorption Spectroscopy (XAS) analyses at the Fe-K, As-K, and Se-K edges on raw, treated, and post-adsorption samples. The results indicate that iron maintains a trivalent oxidation state in all samples; however, in the treated zeolite it assumes an intermediate configuration between structural and surface iron. EXAFS analyses also revealed the first Fe-O coordination shell, while As and Se showed tetrahedral and trigonal coordination, respectively. The absence of significant variations in bond distances demonstrates the preservation of the zeolite structure during the treatment process.

Overall, the study demonstrates that Fe^{3+}-modified clinoptilolite represents an effective, sustainable, and low-cost strategy for the removal of arsenic and selenium from contaminated waters.

Akgül M. (2014) - Enhancement of the anionic dye adsorption capacity of clinoptilolite by Fe^{3+}-grafting. J. Hazard. Mater., 267, 1-8, https://doi.org/10.1016/j.jhazmat.2013.12.040.

Baroni F. et al. (2004) - Arsenic in soil and vegetation of contaminated areas in southern Tuscany (Italy). J. Geochem. Explor., 81, 1-14, https://doi.org/10.1016/S0375-6742(03)00208-5.

Building a globally representative Life Cycle Inventory to assess decarbonization pathways for primary copper production

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Keywords: life cycle assessment, decarbonization, copper production.

Life Cycle Assessment (LCA) is increasingly being recognized as a key tool for setting targets and monitoring progress in the decarbonization of industrial sectors (Yao et al., 2024; Dang et al., 2026), particularly for its capacity to rigorously evaluate the true effectiveness of emission reduction strategies. This is especially relevant for the copper industry, where ambitious long-term decarbonization pathways have been announced but their implementation remains highly uncertain.

In this context, robust and representative Life Cycle Inventories (LCIs) for primary copper production are crucial to evaluate whether proposed strategies can succeed at the global scale and to support credible, science-based roadmaps. For this purpose, a reference dataset for global copper production needs to reflect the main structural and technological features of the primary copper supply chain (Kuipers et al., 2018). With this goal in mind, we systematically collected and critically reviewed publicly available LCIs for primary copper production.

The review showed that, despite the extensive body of literature on copper LCA, the development of a globally representative LCI is hindered by several recurring issues: limited data disaggregation, poor reproducibility, insufficient transparency in the underlying methodological assumptions, and inadequate geographical coverage of existing datasets. To overcome these limitations, we developed a new composite LCI by systematically combining existing datasets. To improve global representativeness, electricity mixes were adjusted to match the actual geographical distribution of mining and processing operations, and dedicated representations were built for key copper-producing regions which exhibit markedly different carbon intensity profiles and therefore call for distinct decarbonization strategies. The resulting LCI offers a more transparent, reproducible, and geographically differentiated baseline that supports more robust assessments of decarbonization scenarios for the global copper industry and helps identify where mitigation efforts are likely to deliver the greatest environmental benefits.

Dang W. et al. (2026) - Decarbonization and clean production in China's cement industry: Strategies from the LEAP-LCA perspective. Environ. Impact Assess. Rev., 116, 108124, https://doi.org/10.1016/j.eiar.2025.108124.

Kuipers K.J.J. et al. (2018) - Assessing environmental implications associated with global copper demand and supply scenarios from 2010 to 2050. Global Environ. Chang., 49, 106-115, https://doi.org/10.1016/j.gloenvcha.2018.02.008.

Yao Y. et al. (2024) - Models for Decarbonization in the Chemical Industry. Annu. Rev. Chem. Biomol. Eng., 15(1), 139-161, https://doi.org/10.1146/annurev-chembioeng-100522-114115.

Maximization of vitreous China fired scraps in sanitary-ware at the expense of high-plasticity clays: Impact on mineralogical composition and technological properties

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Keywords: fired ceramic scraps, thermal expansion, XRD-QPA.

Traditional sanitary-ware production is characterized by high energy consumption and the intensive use of primary raw materials. A key issue is the growing demand for specific minerals that are becoming strategic, such as high-plasticity clays and sodic feldspars. Consequently, the ceramic industry is called toward more sustainable production patterns, in line with Goal 12 of the United Nations Agenda, which encourages the reuse of waste materials. In this sector, most of the waste is generated during the firing process, consisting of pieces that don't meet technological or aesthetic requirements (Fired Ceramic Scraps - 'FCS').

As reported in (Bernasconi et al., 2025), increasing the 'FCS' content at the expense of feldspar and quartz decreases the body linear thermal expansion coefficient. This reduction is mainly due to a lower amount of residual quartz in the fired body and can result in glaze cracking or defects (Plesingerova & Kovalchikova, 2003) because of the lack of thermal agreement between the body and the glaze.

In order to increase the body linear thermal expansion, ceramic slips were prepared by introducing 6% and 12% of fine fired ceramic scraps (V6 and V12, respectively) at the expense of high-plasticity clay, compared to a reference slip with no 'FCS' (V0). To prevent rheological issues, both V6 and V12 were maintained at a higher density to ensure adequate thickness during the casting process. Regarding the technological properties of the fired bodies, specifically water absorption and thermal expansion behaviour, the introduction of 'FCS' resulted in a slight increase in water absorption from 0.07% in V0 to 0.12% in V6 and 0.23% in V12. However, all values remained below the 0.5%, in accordance with UNI EN 997. Furthermore, the body thermal expansion coefficient (measured in the 30-600°C range) increased from 7.00 to 7.10 and 7.15 ($x10^{-6}$ $°C^{-1}$) for V0, V6, and V12 respectively, confirming the effectiveness of the proposed substitution in improving the thermal behaviour. RIR-Rietveld quantitative phase analysis (QPA) (Gualtieri, 2000) was used to determine both amorphous and mineralogical phases. The results show a progressive increase in residual quartz, from 14.31% to 16.37% and a decrease in mullite content from 19.31% to 16.48% in V0 and V12, respectively. These mineralogical changes explain the observed expansion trend, as the higher quartz content directly correlates with the increase in the body thermal expansion coefficient. These preliminary results appear promising for maximizing the content of fired ceramic waste in traditional ceramics, particularly in the sanitary-ware sector. The study demonstrates that introducing 'FCS' at the expense of clay is a strategy to effectively improve the thermal expansion, while keeping the technological properties investigated within industrial tolerances and promoting a more sustainable production.

Bernasconi A. et al. (2025) - Reusing vitreous China fired ceramic scraps in ceramic production: Technological properties and mineralogical insights. Ceram. Int., 51(11), 14358-14372, https://doi.org/10.1016/j.ceramint.2025.01.273.

Gualtieri A.F. (2000) - Accuracy of XRPD QPA using the combined Rietveld-RIR method. J. Appl. Cryst., 33(2), 267-278, https://doi.org/10.1107/S002188989901643X.

Plesingerova B. & Kovalcikova M. (2003) - Influence of the thermal expansion mismatch between body and glaze on the crack density of glazed ceramics. Ceram.-Silikaty, 47(3), 100-107.

Challenges and opportunities of early-stage sustainability assessments for industrial waste valorization processes: Insights from the METALLICO project

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Keywords: waste metals, secondary resources, life cycle assessment.

The EU's clean and digital transition will drive a substantial increase in the demand for Critical Raw Materials (CRMs), further intensifying its heavy import dependency on third countries (Carrara et al., 2023). Reducing this vulnerability requires unlocking domestic supply, not only from primary deposits but also through the recovery of CRMs from currently unexploited industrial waste streams, such as tailings and slags (Steinlechner & Witt, 2024). Beyond reducing criticality, these processes are often presented as strategies to improve circularity, sometimes with co-benefits in terms of environmental performance. However, recovering CRMs from low-grade secondary resources can be energy and reagent-intensive, potentially leading to higher environmental impacts than conventional methods (Adrianto et al., 2023).

To ensure that these innovative processes achieve a desirable balance between supply security, environmental impacts, and circularity performance, quantitative sustainability tools must be adopted from the earliest stages of development. Here, we present the experience from METALLICO, a Horizon Europe project where Life Cycle Assessment (LCA) and circularity assessments were conducted for 5 innovative processes at mid/low Technology Readiness Levels (TRL 4-7), aimed at unlocking the EU's potential to recover and produce CRMs from unexploited resources.

Conducting LCAs at such early stages poses substantial methodological challenges. First, available inventory data derive from lab- or pilot-scale tests rather than industrial operations; furthermore, process configurations evolve continuously throughout the development phase, with several modifications expected upon scale-up. Data obtained at lower TRLs often lack the optimizations typical of mature industries, such as heat recovery systems or closed-loop reagent recycling, which may lead to overestimations of potential impacts. Second, at such scales, the fate, quality, and marketability of waste flows and by-products is often uncertain, making allocation choices and system boundary definition particularly challenging.

Measuring circularity is even more complex, due to additional factors. First, circularity is a multi-faceted concept that no single indicator can fully capture, requiring a careful selection of complementary metrics. Second, no consensus currently exists on how to measure circularity in mining and metallurgical operations, and existing indicators are not widely adopted and offer limited relevance to METALLICO's processes.

Despite these challenges, specific strategies - such as process simulation, or the development of ad-hoc indicators - can help mitigate these limitations. Once addressed, early-stage sustainability tools can then deliver meaningful insights to steer process development towards minimizing environmental impacts and maximizing circularity benefits, while supporting decision-making when trade-offs emerge.

Adrianto L. et al. (2023) - Toward sustainable reprocessing and valorization of sulfidic copper tailings: Scenarios and prospective LCA. Sci. Total Environ., 871, 162038, https://doi.org/10.1016/j.scitotenv.2023.162038.

Carrara S. et al. (2023) - Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU - A foresight study. Publications Office of the European Union, Luxembourg, https://doi.org/10.2760/386650.

Steinlechner S. & Witt K. (2024) - Supply security beyond mines and scrap recycling: valorization potential of metallurgical residues. Philos. Trans. R. Soc. A, 382(2284), 20230237, https://doi.org/10.1098/rsta.2023.0237.

Biosolubility of stone wool obtained from deactivated asbestos cement

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Keywords: deactivated asbestos-cement, stone wool, biosolubility.

Three stone wool samples, two obtained by deactivated asbestos cement (DAC) mixed either with basalt (50%) or quartz sand (22.6%) (Capitani et al. 2024), and a third one, a commercial stone wool taken as reference, have been investigated by static biosolubility tests at pH 4.5 (ALF, artificial lysosome fluid) and pH 7.4 (Gamble's solution). The results have shown that the dissolution behavior is similar to that of modern high-alumina, low-silica wool designed for HT applications (HT wool), which is highly soluble in acidic conditions. As for experiments conducted at near neutral pH 7.4 conditions, precipitation since the first days of treatment of carbonated hydroxyapatite has been observed, suggesting a rapid leaching of Ca that quickly formed a coating on the fibers that impeded further dissolution. Overall, for both DAC-bearing samples, biosolubility is comparable to that of the reference sample, certified as non-carcinogen in accordance with the Note Q of the Regulation No 1272/2008 of the European Parliament and Council, and in-line with those obtained for high-alumina low-silica stone wool fibers tested with an analogous system. Based on the recognized 100 $ng \cdot cm^{-2} \cdot h^{-1}$ biosolubility threshold, none of the studied samples would be expected to result in either fibrosis or tumors.

Capitani G. et al. (2024) - Recycling thermally detoxified asbestos-cement in stone-wool: An end-less-life material! Constr. Build. Mater., 440, 137351, https://doi.org/10.1016/j.conbuildmat.2024.137351.

From construction and demolition waste to high-quality secondary geomaterials: The role of advanced separation and tailored processing

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Keywords: construction and demolition waste, engineered secondary geomaterials, circular economy.

The increasing demand for aggregates is generating growing environmental pressures related to quarrying activities, including landscape alteration and biodiversity loss. In this context, Construction and Demolition Waste (CDW) represents a strategic secondary resource for reducing dependence on primary raw materials. However, many current recycling practices are still based on simple treatments, often producing heterogeneous materials with variable properties and limited added value (Gálvez-Martos et al., 2018). As a result, recycled aggregates (RA) are frequently unable to fully replace natural geomaterials in engineering applications.

This contribution highlights how the transition from conventional waste treatment to resource-oriented approaches, based on advanced separation, selective processing, and targeted material characterization, is essential for the production of high-quality secondary geomaterials. Particular attention is devoted to the influence of material heterogeneity, impurity content, and processing strategies on the engineering performance and potential applications of RA derived from CDW streams.

Recent studies on CDW-derived aggregates for geotechnical and construction applications demonstrate that properly processed RA can achieve mechanical performance comparable, and in some cases superior, to natural aggregates, especially when designed for specific uses (Vieira et al., 2016; Casale et al., 2025). In this framework, CDW should no longer be considered merely as a waste stream to be managed, but as a source of engineered secondary geomaterials for sustainable infrastructure. Emerging evidence from the Regio Insubrica cross-border region between Northern Italy and Southern Switzerland further highlights the importance of improving recycling infrastructures, optimizing logistics, and enhancing local reuse strategies in territories dependent on imported natural aggregates.

The contribution highlights the need to move from quantity-oriented recycling approaches toward quality-oriented circular strategies aimed at producing engineered secondary geomaterials with predictable and application-specific properties. Such approaches may help reduce landfill disposal, transport-related impacts, and environmental pressures associated with extractive activities.

Casale M. et al. (2025) - Performance assessment of recycled aggregates from C&DW plants for road embankments: Influence of composition and treatment methods. Results Eng., 28, 107340, https://doi.org/10.1016/j.rineng.2025.107340.

Gálvez-Martos J.-L. et al. (2018) - Construction and demolition waste best management practice in Europe. Resour. Conserv. Recy., 136, 166-178, https://doi.org/10.1016/j.resconrec.2018.04.016.

Vieira C.S. et al. (2016) - Recycled construction and demolition wastes as filling material for geosynthetic reinforced structures: Interface properties. J. Clean. Prod., 124, 299-311, https://doi.org/10.1016/j.jclepro.2016.02.115.

Textures and crystal-chemistry of phases from tiny to large construction and demolition waste (CDW) grains

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Keywords: CDW, sieving, image analysis.

Construction and Demolition Waste (CDW) accounts for approximately one-third of all solid waste generated from buildings, infrastructures, and civil engineering work. Its volume increases dramatically following natural disasters, generating highly heterogeneous debris. When liberated from organic and metallic fractions, this waste consists of mineral-based or ceramic-like materials, including concrete, mortar, bricks, tiles, and natural stones (Galderisi et al., 2022). At recycling plants, CDW is comminuted and sieved into different grain-size fractions. However, their crystal-chemical and textural attributes are largely lacking. This heterogeneity precludes upcycling and CDWs are often downcycled into low-value applications. Moving from this paradigm, here we focus on textural and crystal-chemical variabilities of CDW from tiny to large size ranges.

Heterogeneous CDW rubble was collected from a recycling plant in Pollenza (Macerata) and sieved from 16 to 0.063 mm; six out of ten representative grain-size fractions were considered: 0.063/0.125, 0.25/0.5, 1/2, 2/4, 4/8 and 8/16 mm. In addition, four representative particle sizes of 0.063/0.125, 0.25/0.5, 1/2, and 4/8 mm were mounted on polished thin sections. In parallel, mesoscopic images of loose CDW clasts were collected using a common smartphone in the 0.25/0.5, 0.5/1, 1/2, 2/4, 4/8, and 8/16 mm ranges. Thin sections of CDW clasts were analysed using Transmitted Optical Microscopy (TOM), Scanning Electron Microscopy (SEM) and Electron Probe Micro-Analysis (EPMA). Textures of CDW clasts in both TOM and mesoscopic photographs were quantified using image analysis (IA), yielding the long and short axes (equal-area ellipse), aspect ratio, perimeter, area, and roundness of individual grains.

Grain sizes were first compared with 2D textural size dimensions from IA, demonstrating that sieving intervals are appropriately measured with 2D IA; fine-grained ranges (≤1/2 mm) can be captured only with TOM, whereas large intervals (≥1/2 mm) can be measured only with digital mesoscopic photographs. At the 1/2 mm interval, both sieving and 2D IA outcomes nearly completely overlap. By contrast, the perimeter and roundness of clasts are adequately captured only by TOM, able to detect fine rim details. Overall, the short and long grain sizes are slightly larger and shorter than the corresponding sieving interval. The average size dimension from 2D IA more accurately reproduces the corresponding sieving interval. EPMA confirmed that calcite, quartz, feldspars, and CSH are the dominant phases, consistent with previous bulk characterizations. This study further defines their specific textures and assemblages per grain size, essential for determining the properties and sorting of heterogeneous CDW.

Galderisi A. et al. (2022) - Petrography of construction and demolition waste (CDW) from Abruzzo region (Central Italy). Waste Manage.,137, 61,71, https://doi.org/10.1016/j.wasman.2021.10.028.

Advancement in Rietveld QPA in understanding and modelling the mineralogy of waste-derived geomaterials

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Keywords: waste-derived geomaterials (WDGs), Rietveld QPA, circular economy.

Waste-derived geomaterials (WDGs), are increasingly recognized as strategic secondary resources for the transition toward a circular economy. However, WDGs are also typically complex, composite products with a broad spectrum of mineralogical assemblage and different crystalline to amorphous fractions. Their intrinsic chemical heterogeneity, complex crystalline phase assemblages, and variable amorphous content pose significant challenges for reliable characterization, classification, and prediction of their engineering and environmental performance. A condition that limits their recycling in new circular materials due to safety, efficiency and performance concerns (Galderisi et al., 2023).

In this context, Quantitative Phase Analysis (QPA) based on the Rietveld refinement of X-ray Powder Diffraction (XRPD) patterns represent a robust, reproducible, and highly informative approach for the detailed mineralogical characterization of WDGs. This contribution presents recent advancements in Rietveld-based QPA of WDGs, focusing on methodological approaches to enhance phase quantification accuracy, speed, and reproducibility. These include optimized sample's preparation, in sequential refinement strategies, selection and adaptation of available structural models, improved background modelling (especially for highly amorphous WDGs), and the integration of internal or external standards for the accurate quantification of amorphous and poorly crystalline phases (Bisciotti et al., 2025a).

Particular emphasis is placed on the integration of XRPD-derived datasets with complementary analytical techniques and methods to validate phase identification and refine mineralogical interpretations at the interface of novel emerging data-driven approaches, including machine learning algorithms, to reduce operator-dependent bias, and improve the prediction of circular materials properties (Bisciotti et al., 2024).

The presentation further demonstrates how high-quality mineralogical datasets obtained through advanced QPA can be directly linked to the modelling of key material properties, including mechanical performance, durability, contaminant leaching behaviour, and long-term environmental stability. These relationships are critical for developing predictive tools that enable the classification of WDGs according to their reuse potential and compliance with regulatory frameworks (Bisciotti et al., 2025b).

By bridging advanced mineralogical characterization with predictive modelling, this work highlights the pivotal role of Rietveld QPA in supporting the sustainable valorisation of WDGs. The proposed integrated approach contributes to reducing uncertainties in material assessment, minimizing reliance on primary raw materials, and promoting safer and more efficient reuse pathways in line with circular economy principles and sustainable development goals.

Bisciotti A. et al. (2024) - Estimating attached mortar paste on the surface of recycled aggregates based on deep learning and mineralogical models. Clean. Mater., 11, 100215, https://doi.org/10.1016/j.clema.2023.100215.

Bisciotti A. et al. (2025a) - Multi-scale X-ray techniques for assessing recycled concrete aggregate: from XRPD analysis of leftover cement in recycled aggregates to micro-CT imaging of concrete microstructure. Dev. Built Environ., 23, 100709, https://doi.org/https://doi.org/10.1016/j.dibe.2025.100709.

Bisciotti A. et al. (2025b) - Classification and predictive leaching risk assessment of construction and demolition waste using multivariate statistical and machine learning analyses. Waste Manage., 196, 60-70, https://doi.org/10.1016/j.wasman.2025.02.033.

Galderisi A. et al. (2023) - Physico-Mechanical Performances of Mortars Prepared with Sorted Earthquake Rubble: The Role of CDW Type and Contained Crystalline Phases. Materials, 16(7), 2855, https://doi.org/10.3390/ma16072855.

Sustainable concrete structures with recycled materials

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Keywords: precast concrete, uniaxial compression tests, three-point bending tests.

Concrete production is essential for the construction sector, but accounts for intensive consumption of raw materials and significant greenhouse gas emissions. This substantial impact is primarily driven by cement, the binder of the concrete mixture. Mitigating these environmental impacts has been a primary research focus in recent years. One approach is the decarbonization of traditional cement through the use of supplementary cementitious materials (SCMs). In most of the cases, SCMs are industrial byproducts, such as slag and fly ash that come from waste stream of other industries. As they can replace a portion of clinker, low carbon concrete can be produced. However, the effect of these substitutions on the overall mechanical performance of concrete structures must be better investigated. In other words, material-level assessments alone are insufficient due to complex interactions between material properties, element geometry, reinforcement ratios, and design code requirements.

Another approach for preserving natural resources is the substitution of natural aggregates with recycled materials. Green Public Procurement (GPP) promoted by the European Union encourages this method, however in a prescriptive way. In Italy, for example, concrete used in public constructions must contain at least 5% of recycled components by mass. Nevertheless, the real ecological benefits of using these materials should be assessed through a comprehensive evaluation like Life Cycle Assessment (LCA). To address these challenges, a set of eco-mechanical analyses in both material and structural levels was carried out on five concrete mixtures. These mixtures, containing from 0% to 45% recycled materials (including slag, recycled concrete aggregates, recycled steel fibers, and rubber aggregate), were used to cast partially precast slabs. The main mechanical properties (i.e., compressive and flexural strength) of the concretes and slabs were measured, and the cradle-to-gate GHG emissions were calculated through LCA. It is crucial to recognize that LCA results are highly variable depending on the place of production, the type of application, manufacturing experience, the availability of local materials, and the reference modules of ISO 21930. However, the obtained results on climate change impacts are meaningful especially when used for comparative analyses within a specific market (in this case, northern Italy). The mechanical and environmental performances were then coupled on a non-dimensional chart, enabling a simultaneous comparison of the sustainability and safety of all the concretes. As a result, despite the environmental benefits, the presence of recycled components negatively affects the compressive and flexural strength of concrete. However, substituting natural materials with those recycled remains a viable solution at the structural level; because concrete slabs not only satisfy GPP requirements and maintain adequate mechanical performances, but also contribute to a significant reduction in CO_2 eq. emissions.

Vibrational spectroscopic fingerprint of heat-treated bottom ashes

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Keywords: bottom ashes, glass structure, Raman-FTIR spectroscopy.

Bottom ash (BA) is a major byproduct of municipal solid waste incineration in waste-to-energy plants and is classified as non-hazardous industrial waste. Generally, BA(s) consist of silicate, carbonate, oxide crystalline and non-crystalline phases, plus metals and organic-derived materials. From a circular economy perspective, the reuse of this waste remains limited and several concerns about the potential dispersion of harmful components from it are well established. In this regard, one of the most promising processes is their treatment at high-T, which transforms them into chemically stable, glass-rich materials capable of immobilizing potentially harmful components. However, the heterogeneous composition of BAs requires a detailed chemical and crystallographic characterisation of the starting and treated waste before re-utilisation (Stabile et al., 2019). Rapid crystal-chemical constraints on BAs-derived materials can be elucidated through studies of natural counterparts, i.e., rocks.

This work thus focuses on the vibrational characterisation of BA-treated samples obtained at 1300°C for durations of 2, 4, 8, and 16 hours. The Raman characterisation of the glass-rich heat-treated BA shows two main regions, between ~300-650 cm^{-1} and stretching ~650-1250 cm^{-1}; they are mainly related to the bending and stretching modes, respectively, of tetrahedral (T) sites occupied by Si and secondarily by Al. Further and finer glass structural details were determined from fitting the Raman components, following previous models that assume these bands are related to the connection of T units (Colomban et al., 2006; Radica et al., 2024; Stabile et al., 2025). Similarly, FTIR spectra were collected in the mid-infrared region; two main multi-component bands were identified and fitted, at ~600-800 cm^{-1} and at ~800-1200 cm^{-1}, in the higher frequency region.

The fitted bands, i.e., their positions, widths, and relative intensities (area%), were then compared with the characteristics of the closest silicate-analogue natural glasses, i.e. basaltic glasses, to definitively derive the short-range order (SRO) of the obtained products (Radica et al., 2024). The adopted approach, combining micro-Raman and FTIR spectroscopies, allows us to interpret the vibrational behaviour of high-temperature-treated BA non-invasively, minimising sample preparation and enabling very short analytical times. This approach might be recommended for rapidly characterising and controlling the glass structure of the BAs-derived new products.

Colomban P. et al. (2006) - Raman identification of glassy silicates used in ceramics, glass and jewellery: a tentative differentiation guide. J. Raman Spectrosc., 37, 841-852, https://doi.org/10.1002/jrs.1515.

Radica F. et al. (2024) - Short-range order and chemical compositions of glasses along the basaltic-rhyolite sub-alkaline join by Raman and FTIR spectroscopies. Chem. Geol., 648, 121938, https://doi.org/10.1016/j.chemgeo.2024.121938.

Stabile P. et al. (2019) - Vitrification treatment of municipal solid waste bottom ash. Waste Manage. 95, 250-258, https://doi.org/10.1016/j.wasman.2019.06.021.

Stabile P. et al. (2025) - Characterization of mixed- waste glasses in the CAS system: insights from differential scanning calorimetry and Raman spectroscopy. Eur. Phys. J. Plus, 140, 739, https://doi.org/10.1140/epjp/s13360-025-06677-3.

Innovative low-clinker limestone cements containing carbonated recycled concrete fines: Hydration and durability issues

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Keywords: low-CO2 cement, CDW fines, durability in aggressive environments.

The cement industry is responsible for approximately 6-8% of global CO_2 emissions (Andrew, 2019). Over the years, the constant effort to mitigate its environmental impact while maintaining high technical performance has led to the partial replacement of clinker with supplementary cementitious materials (SCMs). However, the global decarbonization policy will lead to a decrease in the availability of SCMs, since they are mainly fly ash and blast furnace slag. The trend is shifting towards new 'low-CO_2' cements, such as Portland-limestone and LC3 cements.

At the same time, every year, nearly 700 million tons of construction and demolition wastes (CDWs) are generated globally from end-of-life buildings, accounting for about 30% of all solid waste generated. While the coarse fraction is commonly reused as aggregate, the fine fraction (In this work, industrial cement-based formulations were ground to obtain a fine powder simulating CDWs fines at the laboratory scale. The material was subjected to wet carbonation, producing a powder composed mainly of $CaCO_3$ and reactive silica-alumina gel (Zajac et al., 2020). The obtained material was incorporated as SCM at a replacement level of 15 wt.% in 3 distinct industrial cement formulations and compared with a reference ordinary Portland cement.

The hydration evolution of the cement pastes was investigated through isothermal calorimetry, TGA, FTIR spectroscopy and XRPD. The mechanical performance assessed with uniaxial compressive strength measurements. Since the durability of carbonated CDW-derived cementitious materials has not yet been extensively investigated, the hardened materials were exposed for 3 months to sulphate and chloride rich environments in order to evaluate their behaviour under aggressive conditions (Sotiriadis et al., 2024). The resulting degradation mechanisms and microstructural evolution were further investigated through X-ray tomography. The results provide new insights into the durability of cementitious systems containing carbonated CDW fines and support their potential use as low-carbon supplementary cementitious materials.

Andrew R.M. (2019) - Global CO_2 emissions from cement production, 1928-2018. Earth Sys. Sci. Data, 11, 1675-1710, https://doi.org/10.5281/zenodo.831454.

Silva R.V. et al. (2014) - Properties and composition of recycled aggregates from construction and demolition waste suitable for concrete production. Constr. Build. Mater., 65, 201-217, https://doi.org/10.1016/j.conbuildmat.2014.04.117.

Sotiriadis K. et al. (2024) - External magnesium sulfate attack on hydrated Portland-limestone cements: Effect of the concurrent presence of sodium chloride in the corrosive environment and metakaolin admixture in the binder. Cement Concrete Comp., 151, 105614, https://doi.org/10.1016/j.cemconcomp.2024.105614.

Zajac M. et al. (2020) - Effect of carbonated cement paste on composite cement hydration and performance.Cement Concrete Comp., 134, 106090, https://doi.org/10.1016/j.cemconres.2020.106090.

Reactive pathways of synthetic forsterite and Mg/Ni-serpentine under microwave-assisted carbonation: Insights into incipient dissolution and CO_2 sequestration mechanisms

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Keywords: carbon capture, Ni-serpentine, microwave.

Carbon capture, utilisation and storage represent one of the most promising strategies to mitigate the increasing concentration of atmospheric carbon dioxide. Among the available approaches, mineral carbonation offers a potentially permanent and environmentally safe solution for CO_2 sequestration through the reaction of CO_2 with Ca-Mg-bearing silicates, hydroxides and oxides. However, despite the thermodynamic favourability of these reactions, carbonation kinetics are often limited by mineralogical and structural constraints. Recent studies demonstrated that microwave-assisted carbonation can significantly enhance dissolution and carbonation processes in Mg-bearing phases, improving reaction efficiency under relatively mild conditions (Campione et al., 2024; 2025).

In this work, nanocrystalline synthetic forsterite together with Mg- and Ni-endmember serpentines were investigated as model systems to unravel the role of composition, crystal structure and morphology in early-stage dissolution and carbonation reactions. Particular attention was devoted to the behaviour of Ni-bearing serpentines, considering that natural serpentinites and serpentinite waste materials may incorporate significant amounts of Ni and therefore represent both potential feedstocks for CO_2 sequestration and secondary resources for critical metals (Cavallo, 2018).

A systematic experimental approach was developed to investigate dissolution and carbonation pathways under mild hydrothermal conditions (100°C, $pCO_2 \leq 6$ bar) through microwave-assisted treatments in a controlled environment. The resulting solid and liquid products were characterised by X-ray Powder Diffraction (XRPD), Scanning and Transmission Electron Microscopy (SEM/TEM), micro-Raman spectroscopy and Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES).

The experiments reveal markedly different reactive behaviours among the investigated phases. Synthetic forsterite and Mg-serpentine display significant Mg release into solution, promoting the precipitation of hydrated Mg-carbonates during the early stages of carbonation. Conversely, Ni-serpentine nanocrystals remain comparatively less reactive, retaining Ni within the silicate structure and strongly limiting its mobilisation during treatment. These results suggest that crystal chemistry and structural ordering exert a major control on dissolution kinetics and carbonation efficiency.

Beyond their relevance for CO_2 mineral sequestration, these findings provide new insights into the behaviour of Ni-bearing serpentinite materials during hydrothermal alteration and carbonation processes, with possible implications for the sustainable exploitation and valorisation of serpentinite-derived waste materials and critical metal recovery strategies.

Campione M. et al. (2024) - Microwave-driven carbonation of brucite. J. CO2 Util., 80, 102700, https://doi.org/10.1016/j.jcou.2024.102700.

Campione M. et al. (2025) - Catalytic activity of solution additive anions for magnesite and calcite precipitation in microwave-assisted mineral carbonation experiments. Adv. Energy Sustain. Res., 6, 2500046, https://doi.org/10.1002/aesr.202500046.

Cavallo A. (2018) - Serpentinitic waste materials from the dimension stone industry: serpentinitic waste materials from the dimension stone industry: characterization, possible reuses and critical issues. Resour. Policy 59, 17-23, https://doi.org/ 10.1016/j.resourpol.2018.08.003.

Thermal treatment and vitrification of fine MSWI Bottom Ash: Microstructure, leaching behaviour, and reuse potential

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Keywords: BA-MSWI, leaching test, high temperature treatments.

Fine fractions of municipal solid waste incineration bottom ash (MSWI-BA) are challenging residue streams for circular-economy valorisation because they concentrate soluble salts, secondary Ca-bearing hydrated phases and potentially toxic elements controlling leaching results (Mantovani et al. 2023; Cheng et al., 2024). This study evaluates the thermal upgrading of fine MSWI-BA from the Parma waste-to-energy plant by linking phase evolution, microstructure and environmental performance.

The 0-2 mm fraction and selected finer sub-fractions were characterized by XRF, ICP-MS, quantitative and high-temperature XRD, Raman spectroscopy, SEM-EDS and EN 12457-2 leaching tests. Samples were thermally treated in air up to 1250°C to identify when the heterogeneous ash evolves into a more stable glass-ceramic material.

Untreated fines are dominated by a glassy/amorphous matrix with calcite, AFm/AFt phases, sulfate- and chloride-bearing phases, feldspar, quartz, melilite, larnite and minor Fe oxides. The finest fractions are enriched in Ca-rich secondary phases, alkalis, chlorides, sulfates and selected trace elements. Leaching tests show exceedances for chloride, sulfate, Cr, Cu, Pb, Zn and Sb, indicating that untreated fine BA cannot be directly considered suitable for reuse.

Thermal treatment induces a three-stage transformation. Below about 600°C, dehydration, dehydroxylation and breakdown of secondary weathering phases remove the most labile hosts. Between about 700 and 950°C, the ash recrystallizes, with melilite and larnite becoming major crystalline products and the amorphous fraction decreasing. Above about 1000°C, pyroxene and wollastonite become dominant, while from approximately 1050-1100°C the amorphous fraction increases again, marking the onset of partial vitrification. SEM-EDS documents densification, liquid-phase sintering and chemical partitioning among crystalline phases and residual glass. Combined SEM-EDS and Raman analyses were crucial to recognize micron-scale phase assemblages and distinguish different glassy matrices, including Ca-silicate, aluminosilicate and locally alkali- or sulfur-rich domains. Raman spectroscopy provided structural fingerprints of poorly crystalline and amorphous components not resolved by XRD alone, while identifying minor mineral carriers and heterogeneous reaction products.

This transition is reflected in improved leaching behaviour. Electrical conductivity, chloride and sulfate release, alkali mobility and the leaching of several regulated elements decrease strongly at high temperature, particularly in the 1100-1150°C interval. The results indicate that environmental upgrading is controlled by crossing a structural threshold where fine MSWI-BA changes from a salt-rich, granular residue into a denser, partially vitrified glass-ceramic system. This temperature window supports the potential use of thermally treated fine bottom ash as a secondary raw material, although process feasibility, volatilization effects and end-use performance require assessment.

Cheng Y. et al. (2024) - Physical and mechanical study of municipal solid waste incineration (MSWI) bottom ash with different particle size distribution. Constr. Build. Materi., 416, 135137, https://doi.org/10.1016/J.CONBUILDMAT.2024.135137.

Mantovani L. et al. (2023) - Grain size and mineralogical constraints on leaching in the bottom ashes from municipal solid waste incineration: a comparison of five plants in northern Italy. Front. Environ. Sci., 11, 1179272, https://doi.org/10.3389/fenvs.2023.1179272.

Recycled concrete as a supplementary cementitious material: Clinker substitution and carbon sequestration potential

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Keywords: recycled concrete, clinker substitution, carbon sequestration.

The construction industry's growth has led to significant depletion of natural resources and substantial emissions of greenhouse gases and industrial waste (Shui et al., 2018; Xu et al., 2022). The replacement of clinker with supplementary cementitious materials (SCMs) is considered one of the main strategies to reduce CO_2 emissions in the cement industry (Juenger et al., 2019). This study investigates the potential of thermally reactivated concrete from construction and demolition waste (CDW) as partial clinker substitute in mortar formulations and their capacity for carbon sequestration. Two types of recycled concrete (RC) were examined: material originating from the 2016 Umbria-Marche earthquake (RC-N), and RC from Manini Prefabbricati S.p.A. (RC-M). To analyze the effect of thermal reactivation at 700°C, a mineralogical characterization was conducted on the RCs, to identify and quantify clinker mineral phases. Mortars containing 20 wt.% and 40 wt.% RC (accounting only for clinker phases) were prepared with varying water-to-binder (w/b) ratios: 0.5, 0.6, and 0.7 for the 20 wt.% RC mixtures, and 0.7 and 0.8 for the 40 wt.% RC mixtures. The samples were cured and analyzed at 7, 14 and 28 days using X-ray powder diffraction (XRPD), thermogravimetric analysis (TGA), scanning electron microscopy (SEM) and mechanical compressive tests. The 20 wt.% RC samples generally showed strength values either superior or comparable to the control (CTRL) at low w/b ratios (0.5 and 0.6). However, a sharp reduction in strength was observed at w/b of 0.7. Increasing the RC percentage to 40% leads to a reduction in compressive strength. XRPD and TGA show an increased presence of C-S-H and Aft phases and a notable reduction in Portlandite (CH) content in RC-N compared to the CTRL, while RC-M exhibit similar trends only at 28 days. 20 wt.% RC, both thermally reactivated and non-reactivated, were subjected to accelerated carbonation, at different curing stages (1 and 28 days), by varying reactor internal pressure and carbonation times. At the end of the carbonation process, the specimens were split, and phenolphthalein indicator was applied to the internal surfaces to assess carbonation depth. The phenolphthalein test shows that all specimens containing RC exhibit a thicker carbonation front compared to the CTRL, suggesting that the use of RCs enhances the carbonation process. Carbonation appears to be more effective in samples produced with non-thermally reactivated RC (NR). This behavior may be attributed to differences in microstructure and to the greater availability of hydrated phases that are more readily carbonatable in materials not subjected to thermal treatment. These findings contribute to the development of sustainable cementitious materials, highlighting the role of thermally reactivated RC in clinker substitution and CO_2 sequestration.

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Juenger M.C.G. et al. (2019) - Supplementary Cementitious Materials: New Sources, Characterization, and Performance Insights. Cement Concrete Res., 122, 257-73, https://doi.org/10.1016/j.cemconres.2019.05.008.

Shui Z.H. et al. (2018) - Improvement of Concrete Carbonation Resistance Based on a Structure Modified Layered Double Hydroxides (LDHs): Experiments and Mechanism Analysis. Constr. Build. Mater., 176, 228-40, https://doi.org/10.1016/j.conbuildmat.2018.04.222.

Xu L. et al. (2022) - A Systematic Review of Factors Affecting Properties of Thermal-Activated Recycled Cement. Resour. Conserv. Recy., 185, 106432, https://doi.org/10.1016/j.resconrec.2022.106432.

Circular strategies for valorization of bituminous mixtures in road construction starting from an LCA case study

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Keywords: life cycle assessment (LCA), industrial symbiosis, bituminous conglomerates.

The road construction and paving sector is one of the largest consumers of virgin raw materials and primary contributor to the environmental impacts associated with the built environment. In the framework of the circular economy (CE), the valorization of waste-derived geomaterials, including industrial by-products and end-of-life construction materials, represents a key strategy to reduce dependency on primary resources and minimize waste generation.

This approach is rooted in the concept of Industrial Symbiosis (IS), where the waste or by-products of one process become valuable inputs for another, optimizing resource flows across interconnected networks (Palagonia et al., 2025). Bituminous conglomerates, widely used in road infrastructure, offer a practical context for investigating sustainable material replacement. The technical feasibility of incorporating reclaimed asphalt pavement (RAP) and secondary aggregates into various mixtures enables concrete scenarios for reducing environmental burdens across the entire supply chain (Praticò et al., 2020; Yu et al., 2021).

This study illustrates a Life Cycle Assessment (LCA) from-cradle-to-gate case study conducted in collaboration with an Italian road sector company, following ISO 14040-44 standards and c-PCR to PCR 2019:14. The analysis compares families of bituminous conglomerates differentiated by recycled content percentage, binder types and production technologies. Functional units, system boundaries and inventory data were defined based on real operational conditions, allowing for a robust comparison of environmental impact results. The work doesn't limit itself to examining material recovery within the production cycle of bituminous mixtures, but rather adopts a broader and more systemic perspective on resource use. Attention is also given to incoming and outgoing energy flows, water resource consumption and potential surpluses generated by the process, with the aim of identifying synergies between one company's waste outputs and another company's input needs. In this sense, the analysis aims to identify opportunities for IS that extend beyond traditional LCA boundaries involving adjacent supply chain actors in logics of mutually advantageous exchange of by-products.

The quantified synergies integrated into the LCA framework reinforce the environmental, economic and social arguments for circular procurement strategies. The results want to support the transition toward more sustainable construction practices in the pavement sector, highlighting the value of integrating LCA with a systemic supply chain analysis as a model to guide, on a scientific basis, the selection of materials for circular road infrastructure.

Palagonia C. et al. (2025) - Spanning the industrial symbiosis within the circular economy: Critical issues and future research agenda. J. Ind. Ecol., 29, 746-765, https://doi.org/10.1111/jiec.70005.

Praticò F.G. et al. (2020) - Energy and Environmental Life Cycle Assessment of Sustainable Pavement Materials and Technologies for Urban Roads. Sustainability, 12(2), 704, https://doi.org/10.3390/su12020704.

Yu Y. et al. (2021) - Towards Circular Economy through Industrial Symbiosis in the Dutch construction industry: A case of recycled concrete aggregates. J. Clean. Prod., 293, 126083, https://doi.org/10.1016/j.jclepro.2021.126083.

Recycling waste materials for road subgrade stabilisation: A Portland cement-free approach using biomass ash and thermally activated recycled concrete

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Keywords: supplementary cementitious materials (SCMs), biomass ash, construction and demolition waste.

Finding sustainable alternatives to Portland cement (PC) has become increasingly important, as its production remains one of the major sources of CO_2 emissions and natural resource consumption in the construction sector (Miller et al., 2024). In this context, this work investigates the complete replacement of PC in road subbase stabilisation using locally sourced industrial by-products: wood biomass ash (BA), collected from a commercial biomass heating plant in the Umbria region (Central Italy), and thermally activated recycled concrete (TRC), derived from construction and demolition waste generated during the 2016 Central Italy earthquake. These materials were combined with natural pozzolan (NP) or metakaolin (MK) and hemihydrate (H) to formulate low-carbon ternary binder systems with high recycled content, as sustainable alternatives to PC-based stabilisers in road foundation layers.

The experimental program was organized in three main phases. First, the chemical, mineralogical, and physical properties of all raw materials were characterised using X-ray fluorescence (XRF), X-ray diffraction with Rietveld refinement (XRD-QPA), specific gravity measurements, and dissolved organic carbon analysis. TRC showed a high free lime content (~39 wt.%) and a significant amorphous fraction (~36 wt.%), conferring strong self-cementing potential after thermal activation. BA exhibited moderate calcium phases (lime and portlandite), a high calcite content (~20 wt.%), and an amorphous fraction of ~40 wt.%, suggesting partial pozzolanic activity. In the second phase, the hydration behaviour of four binder systems (MK-BA-H, NP-BA-H, MK-TRC-H, NP-TRC-H) was assessed at 2, 7, 14 and 28 curing days by isothermal calorimetry, thermogravimetric analysis (TGA), and XRD. TRC blends showed significantly higher reactivity, with cumulative heat release near 500 J/g for MK-TRC-H over 7 days and bound water contents up to 22 wt.% at 28 days of curing. XRD confirmed the progressive formation of AFt, AFm, and amorphous C-S-H phases in TRC blends. BA blends displayed more limited hydration kinetics, consistent across all analytical techniques. In the third phase, all binders were combined with standard sand to create mortars and subjected to unconfined compressive strength (UCS) tests at 7, 14, and 28 days. MK-TRC-H reached up to 16 MPa at 28 days. NP-TRC-H blends reached approximately 10 MPa. Mechanical tests on BA blends are currently ongoing. These preliminary results demonstrate that locally sourced industrial by-products and construction waste can be valorised as low-carbon binders for road subbase stabilisation, offering a technically viable and environmentally sustainable alternative to PC and supporting circular economy principles in the construction sector.

Miller S.A. et al. (2024) - Cement and Alternatives in the Anthropocene. Annu. Rev. Env. Resour., 49(1), 309-335, https://doi.org/10.1146/annurev-environ-112621-070104.

A novel protocol for recovering microplastics using the Aqualis device

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Keywords: microplastics, Aqualis, marine pollution.

Microplastics are recognised as environmental contaminants of global significance (GESAMP, 2015). Due to their small size (d $2O_2$), microplastic particles size separation (>100 μm), needed for the final polymer physico-chemical characterisation with FT-IR, Raman and SEM, according to the Commission Delegated Decision (EU) 2024/1441, adopted on March 11, 2024, and published in May 2024 (European Commission, 2024).

The protocol is essential to advance microplastic monitoring programmes in harbour environments using Aqualis or similar floating, semi-stationary collectors, enabling direct comparability of microplastic recovery data.

Abbas G. et al. (2025) - Impact of microplastics on human health: risks, diseases, and affected body systems. Microplastics, 4(2), 23, https://doi.org/10.3390/microplastics4020023.

European Commission (2024) - Commission Delegated Decision (EU) 2024/1441 of 11 March 2024. Off. J. Eur. Union, L Ser., 2024/1441, http://data.europa.eu/eli/dec_del/2024/1441/oj.

GESAMP (2015) - Sources, fate and effects of microplastics in the marine environment (Part 1). GESAMP Reports and Studies No. 90. International Maritime Organization, London.

Oxidation pathways and mineralogical phase evolution of Al_2O_3 in metallic Al combustion

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Keywords: energy carriers, aluminum, mineralogy.

Metal powders are promising carbon-free energy carriers, enabling energy through oxide reduction and release via controlled oxidation (Bergthorson, 2018). Among them, Al stands out due to its exceptionally high volumetric energy density, exceeding that of conventional fuels, such as gasoline, coal and liquid natural gas, and its versatility in both combustion and hydrogen production processes (Trowell et al., 2020). However, its practical implementation as energy carrier is limited by the complexity of its oxidation mechanism, which involves multiscale processes controlling ignition, phase transformations and particles morphology. In particular, the formation and evolution of Al_2O_3 play a critical role in determining combustion efficiency and recyclability within a closed redox cycle. Aluminum particles are covered by a thin oxide layer that forms upon exposure to air, limiting reactivity under ambient conditions. Upon heating, ignition is governed by mechanisms such as the melt-ejection model, in which the molten Al core expands and fractures the oxide shell, triggering rapid oxidation (Feng et al., 2024). These processes produce oxide materials whose mineralogical and morphological features reflect the local thermal and chemical conditions during combustion (Brilhac et al., 2025). Understanding these features is therefore essential to establish clear relationships between operating parameters and energy performance. In this study, Al_2O_3 powders produced under different combustion conditions were systematically characterized to investigate phase and physicochemical transformation of the particles during the oxidation process. Samples were collected from a flame burner under three configurations: excess Al (Palas 5.5), excess Al with water injection (Palas 5.5 + H_2O), and reduced Al availability (Palas 4). For each configuration, the material was sampled from the upper (TOP) and lower (BOTT) parts of the collection chamber to capture spatial variations in the combustor environment. The samples were analyzed using PXRD, SEM-XEDS, and TEM. PXRD analysis highlighted the presence of different alumina phases in the different parts of the burner, with TOP fractions consistently exhibiting more advanced phases than BOTT fractions, indicating nearly complete oxidation. Residual metallic Al was detected by PXRD, under Al-rich conditions, indicating incomplete combustion, while reduced Al availability promoted a nearly complete oxidation, with no residual metal detected in the TOP fraction compared to the Al-rich sample. SEM observations highlighted that BOTT fractions systematically contained larger aggregates compared to TOP fractions, while TEM analysis highlighted comparable particle sizes across all samples.

TEM morphological analysis showed the coexistence of two particle populations: spherical particles, associated with melting and rapid solidification processes, and polygonal particles, indicative of a crystal growth under solid-state oxidation conditions. The fraction of polygonal particles was significantly higher under excess of Al conditions, suggesting that limited O_2 availability favors partial oxidation pathways that preserves features of the original metal particles.

Overall, these results demonstrate that Al availability and local combustion conditions directly control oxidation pathways, phase evolution, and particles morphology. The identification of polygonal particles as a product of solid-state oxidation provides insight into intermediate mechanism that may influence oxide recyclability and energy cycle efficiency. These aspects are essential for optimizing Al-based energy carriers and improving their performance within sustainable energy systems.

Bergthorson J.M. (2018) - Recyclable metal fuels for clean and compact zero-carbon power. Prog. Energ. Combust., 68, 169-196, https://doi.org/10.1016/j.pecs.2018.05.001.

Brilhac J.F. et al. (2025) - Heat generation from swirl-stabilized aluminum-air flames. Fuel, 381, 133494, https://doi.org/10.1016/j.fuel.2024.133494.

Feng S. et al. (2024) - Modeling of micron-sized aluminum particle combustion in hot gas flow. Fuel, 369, 131718, https://doi.org/10.1016/j.fuel.2024.131718.

Trowell K.A. et al. (2020) - Aluminum and its role as a recyclable, sustainable carrier of renewable energy. Appl. Energ., 275, 115112, https://doi.org/10.1016/j.apenergy.2020.115112.

The role of T-XRF in multi-technique metal speciation of incinerator bottom ash

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Keywords: TXRF, heavy metal distribution, density-based fractionation.

The sustainable management of incinerator bottom ash requires characterization that goes beyond bulk chemistry, integrating morphology, mineralogy, and elemental distribution across density fractions. In this study, we present a comparison between T-XRF and ICP-OES analytical data applied to density-separated bottom ash fractions. Previously, a multi-technique complementary protocol was tested: SEM-EDX was used to assess the specific binding structures (oxides, alloys, salts, amorphous glass) of heavy metals such as Zn, Fe, Mn, and Pb; XRPD was used to identify heavy metal-bearing crystalline phases or amorphous structures.

After density separation, bulk elemental composition analysis was performed with ICP-OES. Sample preparation for this type of analysis necessarily requires acid digestion for sample mineralization, since ICP-OES analyzes only liquid samples. Therefore, we applied the T-XRF analytical technique to the same density fractions and solutions. T-XRF sample preparation does not necessarily require acid digestion, as it is possible to analyze fine powders in suspension, as was done in this work. TXRF analyses produced quantitative multi-elemental data in excellent agreement with ICP-OES but requiring minimal sample preparation and being more sensitive to surface and sub-microscopic distribution.

T-XRF confirmed the enrichment of Zn, Fe, and Al in the densest fractions and their scarcity in the light fractions, numerically validating the morphological and mineralogical observations. In this protocol, T-XRF does not replace the other techniques but integrates their results by providing the quantitative bridge between what is observed with SEM-EDS and XRD and what is measured in solution. The convergence of T-XRF and ICP-OES data demonstrates that T-XRF is a reliable and rapid tool for the environmental characterization of complex solid matrices, enabling the overcoming of simple total concentration and supporting a less conservative classification of bottom ash, thereby promoting its recovery as a geomaterial for secondary aggregate applications.

Correlations between physical and crystal-chemical attributes in construction demolition wastes (CDW): Insights into quake rubbles from the 2016/2017 Central Italy seismic crater

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Keywords: CDW, XRPD, XRF.

In 2018, the UE directive n. 851 amended the landmark Waste Framework Directive (EU 98/2008/EC) by significantly strengthening the requirements on waste prevention and fostering "selective demolition… and facilitate re-use and high-quality recycling". However, mixed construction and demolition waste (CDW) poses a significant challenge to achieving high-quality rubble recovery. The high variability in the properties and composition of these materials translates into poor or inadequate performance of the manufactured products (Galderisi et al., 2023). In this context, Galderisi et al. (2022) revealed that CDW from earthquakes strongly conforms to this preposition, as even rubble collected from a small well-defined area shows significant compositional variability. Here, this issue is further explored on rubble from the 2016/2017 seismic event in central Italy, especially the intriguing and poorly explored relation between the crystal-chemistry and physical attributes of CDW.

From a dataset of more than 200 cm-sized samples collected in the crater area, 25 CDW specimens were selected and thoroughly characterized in terms of texture, physical attributes (UNI 11060:2003), mineralogy (XRPD) and chemistry (XRF). Then, they were grouped into six categories: concrete/mortars, natural stones, tiles, bricks, perforated bricks and roof tiles, to evaluate similitudes and differences.

Concrete/mortars, natural stones and tiles are whitish to grey coloured with apparent densities >1900 kg/m^3, masonries are coloured with apparent densities usually 3. The porosity and water absorption of these CDW categories were also quantified; masonries have the largest porosity and water absorption values ($\geq$ 25% and 15% respectively), mortars and natural stones the lowest ones ($\leq$ 10% and 5%), while concretes plus tile intermediate ones, providing further peculiarities for discriminating these wastes. The crystal-chemistry of the concrete, mortars and natural stone is mostly constituted by calcite/dolomite or, equivalently, are CaO- and CO_2-rich, while they are depleted in silicates; the opposite holds for masonries. Tiles are rich in non-crystalline silicate phases.

Therefore, several crystal-chemical aspects correlate with physical features and can be mutually used to identify CDW categories; this is of paramount importance for planning effective sorting procedures (Radica et al., 2024). Light, porous and water-absorbing separated CDW can be recycled for downcycling applications or used for unexplored uses considering their chemical attributes. On the other hand, homogeneous, dense, poorly porous and water-absorbing separated CDW can be used to produce RAC (recycled aggregate concretes) with defined and constant performance. Finally, the damaged area of Central Italy could become a case study to trigger and develop innovative selection procedures.

Galderisi A. et al. (2022) - Petrography of construction and demolition waste (CDW) from Abruzzo region (Central Italy). Waste Manage., 137, 61-71, https://doi.org/10.1016/j.wasman.2021.10.028.

Galderisi A. et al. (2023) - Physico-mechanical performances of mortars prepared with sorted earthquake rubble: The role of CDW type and contained crystalline phases. Materials, 16, 2855, https://doi.org/10.3390/ma16072855.

Radica F. et al. (2024) - Characterization of CDW types by NIR spectroscopy: Towards an automatic selection of recycled aggregates. J. Build. Eng., 88, 109005, https://doi.org/10.1016/j.jobe.2024.109005.

Reusing detoxified asbestos powder in the brick production

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Keywords: ceramic, waste reuse, asbestos.

The reuse of detoxified cement asbestos powder (DCAP) in the production of brick ceramics was evaluated. DCAP was introduced at 10 wt.% in partial replacement of a local clay raw material currently used in a large scale production (Cambiano, Turin). Two versions of DCAP were used: as it is (DCAP-1) and an optimized version to match the granulometric curve of the local clay (DCAP-2). Therefore, three slip compositions were tested: S-REF (only local clay), S-DCAP-1 (90% local clay and 10% DCAP-1) and S-DCAP-2 (90% local clay and 10% DCAP-2).

After granulometric (by sieves) and plasticity (by Atterberg limits) characterizations, all the three slips were dried, pressed and fired following a typical brick firing cycle (i.e. 2 hours soaking time at 850°C).

Technological properties such as water absorption, imbibition test and compressive strenght, were performed, suggesting that the DCAP-bearing bricks (i.e. S-DCAP-1 and S-DCAP-2 compositions) even improved the material behaviour, especially the mechanical performances.

XRD qualitative analysis disclosed that the main crystalline phases are quartz, feldspar, amphiboles, micas, rutile and iron-oxides in the reference brick while in the DCAP-bearing compositions, melilite was also detected.

XRD Rietveld quantitative phase analysis by using internal standard (Gualtieri, 2000) highlighted both compositions are very similar, with larger amorphous in DCAP-bearing materials (~30 wt.% in reference brick and ~ 40 wt.% in DCAP-bearing bricks), quartz as dominant crystalline phase (in the 30-40 wt.% range) and limited amounts of melilite in S-DCAP-1 and S-DCAP-2.

There results are promising and suggest that brick technology is more promising to reuse DCAP compared to other type of traditional ceramics (Bernasconi et al., 2023).

Bernasconi A. et al. (2023) - Recycling detoxified cement asbestos slates in the production of ceramic sanitary wares. Ceram. Int., 49, 1836-1845, https://doi.org/10.1016/j.ceramint.2022.09.147.

Gualtieri A. (2000) - Accuracy of XRPD QPA using the combined Rietveld-RIR method. J. Appl. Cryst., 33, 267-278, https://doi.org/10.1107/S002188989901643X.

Technological evolution for local and low-impact utilization of strategic raw materials for CERamics (TELLUS4CER): Project presentation

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Keywords: waste valorization, sustainability, resilient ceramic industry.

The Italian ceramic sector, while internationally recognized for its excellence, faces growing challenges related to environmental sustainability, resource management, and process efficiency. Its dependence on Critical and Strategic Raw Materials (CRM/SRM) and high energy consumption calls for a transition toward more circular and efficient production models. The TELLUS 4CER project - Technological Evolution for Local and Low-impact Utilization of Strategic Raw Materials for Ceramics - funded by the Italian Ministry of the Environment and Energy Security (MASE)[1], addresses these challenges by developing innovative solutions for the recovery and valorization of Recycled Raw Materials (RRM). The project aims to reduce environmental impact and improve sector efficiency by overcoming technological and operational barriers to RRM integration through advanced separation, purification, and digital traceability strategies. TELLUS 4CER is based on three main pillars: optimization of RRM treatment processes, eco-design of innovative ceramic formulations, and supply chain digitalization using statistical tools and simulation models. These approaches will enhance process efficiency, increase supply security, and reduce the carbon footprint of ceramic production. Through industrial research and pilot-scale validation, the project will develop technologies for selective RRM recovery and impurity removal, alongside optimized ceramic formulations with mechanical and aesthetic performance comparable or superior to conventional materials. A key innovation is the implementation of a digital passport for RRM, ensuring full traceability and certification of origin, quality, and environmental impact. The project also promotes industrial symbiosis with sectors such as construction and metallurgy to maximize waste reuse. Expected outcomes include increased use of RRM, reduced CO_2 emissions, and improved resource efficiency, supporting the transition toward a more sustainable and resilient ceramic industry. Leveraging digital technologies and artificial intelligence, TELLUS 4CER(https://www.tellus4cer-innovability.it/) will accelerate the adoption of circular solutions in line with circular economy and Industry 5.0 objectives.

Progetto di Ricerca Industriale e Sviluppo Sperimentale cofinanziato dal Ministero dell'Ambiente e della Sicurezza Energetica. Avviso pubblico: Progetti di ricerca, sviluppo e innovazione tecnologica sull'intera catena del valore delle Materie Prime Critiche (MPC) e delle Materie Prime Strategiche (MPS). Iniziativa internazionale: Mission Innovation 2.0 | Missioni: Green Powered Future (GPFM) - Clean Hydrogen (CHM). Decreto di riferimento: DM n. 386 - 17/11/2023. Numero progetto: MI_MPC_00023.

XRD monitoring of self-activated binders from steel slags and metakaolin

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Keywords: circular economy, steel slags, self-activated binders.

This study is framed within the Circular Economy approach and proposes the valorization of industrial by-products from the steel sector for the development of innovative low-impact binders. Two different formulations based on metakaolin (MK) and steel slags were investigated: the first consisting of MK and ladle furnace slag, LF (Calcetek), and the second obtained from a combination of MK, Calcetek, and electric arc furnace slag, EAF (Inertex).

The innovative aspect of this work lies in the self-activation capability of the system: the high alkalinity of the LF is sufficient to trigger the activation reactions of MK without the addition of external alkaline activators. This approach differs from both conventional geopolymers and traditional alkali-activated materials (Van Deventer et al., 2010) and can be described as a self-activated system that exploits the intrinsic basicity of an industrial by-product. As a result, both environmental impact and costs are significantly reduced, avoiding the use of energy-intensive compounds that cause global warming (Nikravan et al., 2023). Furthermore, the practical risks associated with the use of conventional alkaline activators are avoided (Adesina, 2018).

Attention was devoted to the mineralogical and microstructural characterization of the developed systems. Phase evolution was monitored up to 28 days by means of X-ray diffraction (XRD), to identify reaction products and follow transformations in crystalline phases. XRD results suggest the possible formation of a C-(A)-S-H gel phase in both formulations. Among the identified mineralogical phases, hydrotalcite was detected in both systems. Hydrogarnet was identified in the formulation containing only Calcetek and MK, likely formed through the reaction between tricalcium aluminate (C_3A), present in Calcetek, and water. Conversely, hydroandradite was observed in the formulation containing Calcetek, Inertex, and MK, typically associated with Fe-rich systems under highly alkaline conditions.

FTIR analysis revealed, for both samples, a shift of the main band toward lower wavenumbers compared to metakaolin, along with the appearance of a shoulder commonly associated with the formation of a short-chain C-(A)-S-H gel phase. SEM analyses showed the development of dense regions, clearly distinguishable from the surrounding matrix. Elemental mapping highlighted the co-localization of calcium, aluminum, and silicon in these areas, further supporting the formation of C-(A)-S-H-type gel phases. Mechanical properties were also evaluated to assess the performance of the obtained binders.

The results highlight the key role of steel slags as reactive secondary raw materials and confirm the feasibility of producing self-activated binders from industrial waste, in line with Circular Economy principles (Ness & Xing, 2017). This study contributes to the development of sustainable geomaterials and promotes advanced waste reuse strategies in the construction materials sector.

Adesina A.D. (2018) - Alkali activated materials: review of current problems and possible solutions. RILEM Publications, 1, 389-394.

Ness D.A. & Xing K. (2017) - Toward a resource-efficient built environment: A literature review and conceptual model. J. Ind. Ecol., 21(3), 572-592, https://doi.org/10.1111/jiec.12586.

Nikravan M. et al. (2023) - Life cycle assessment of alkali-activated materials: a systematic literature review. Low-carbon Mater. Green Constr., 1, 13, https://doi.org/10.1007/s44242-023-00014-6.

Van Deventer J.S. et al. (2010) - Chemical research and climate change as drivers in the commercial adoption of alkali activated materials. Waste Biomass Valori., 1, 145-155, https://doi.org/10.1007/s12649-010-9015-9.

S23.

Geomaterials bridging natural resources, technology and sustainable applications

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Comparative evaluation of pyrophyllite-impregnated woven and non-woven natural plant fibers for sustainable thermal insulation applications

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Keywords: pyrophyllite, insulation, impregnation.

Pyrophyllite has emerged as a promising mineral additive in the development of sustainable insulation geocomposites, owing to its characteristic layered silicate structure, notable thermal stability, and chemical inertness. Refractory, ceramic, fiberglass and cosmetic industries use pyrophyllite as raw material, but it is also used as soil conditioner for fertilizers, as dusting agent for rubber and asphalt industries, and as filler material for other industries (Ali et al., 2021). This study presents a comparative investigation of the thermal behavior and impregnation performance of woven and non-woven natural fiber systems treated with pyrophyllite-rich mineral formulations, with a view toward environmentally friendly thermal insulation applications. Woven jute, cotton, and linen fabrics, along with non-woven jute and sisal yarns, were impregnated with sodium silicate-based binder solutions at varying pyrophyllite concentrations. The raw material, sourced from the Pütürge district of Malatya (Türkiye), was characterized through X-ray diffraction (XRD), which identified pyrophyllite as the dominant mineral phase alongside quartz, muscovite, kaolinite, and illite. Morphological examination revealed platy and fibrous particle morphology, and geochemical analysis confirmed a high silica-alumina composition. Thermal performance was evaluated by thermogravimetric analysis (TGA), while impregnation efficiency was quantified through mass uptake measurements.

Pyrophyllite treatment consistently improved the thermal stability of all fiber systems relative to untreated controls. Woven fabrics demonstrated more uniform impregnation and reproducible thermal degradation profiles, a behavior attributed to their regular weave and balanced fiber structure. Among woven substrates, jute fabrics achieved the highest post-treatment residual mass and thermal performance, reflecting strong mineral retention and enhanced char formation, while cotton fabrics recorded the greatest overall mass uptake. Non-woven yarn systems, by contrast, exhibited substantially higher impregnation capacities, as their open and irregular structures facilitated deeper mineral penetration. Higher pyrophyllite loadings improved residual mass values across both fabric types, though excessive concentrations occasionally led to localized mineral agglomeration. Notably, distinct impregnation thresholds were identified in the non-woven systems: jute yarns maintained relatively stable thermal improvement up to approximately 30% mineral loading, whereas sisal yarns showed a threshold near 35%, beyond which further addition yielded diminishing thermal benefits and increased decomposition variability.

To conclude, woven samples offer reproducible and thermally consistent geocomposite performance, while non-woven configurations provide superior mineral uptake capacity. It is also worth noting that non-woven systems displayed distinct impregnation thresholds, beyond which additional pyrophyllite incorporation provided limited thermal benefit and introduced greater variability in degradation behavior. These observations collectively suggest that both fabric architecture and mineral loading must be carefully optimized to achieve the desired balance between impregnation efficiency and thermal homogeneity. Pyrophyllite-impregnated natural fibers therefore represent viable and sustainable candidates for thermal insulation and flame-retardant composite applications within the broader context of green building materials.

Ali M.A. et al. (2021) - Pyrophyllite: An economic mineral for different industrial applications. Appl. Sci., 11(23), 11357, https://doi.org/10.3390/app112311357.

Evaluating lithium extraction from non-compliant ceramic materials: Potential and sustainability

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Keywords: lithium extraction, Li-rich enamels, LAS glass-ceramics.

Secondary sources of critical metals such as lithium (Li) are receiving increasing attention in the context of the global transition towards low-impact technological processes, waste valorisation, and the reuse of industrial by-products. Given the limited availability of primary Li resources, the development of recycling procedures has become a strategic priority.

Within this framework, the LiCycle project (University of Florence) focuses on the potential of glass-ceramic products that fail to meet technical specifications, i.e. non-compliant, and represent a promising secondary source of Li. A key focus of the project is the study of non-compliant LAS glass-ceramics and Li-rich enamels provided by an industrial partner (Colorobbia Group, Italy). Following a preliminary characterisation by SEM-EDS, XRD, ICP-OES, LIBS and PIGE (results reported in Finto, 2025; Raneri et al., 2025), the work focused on Li extraction procedures. Based on the available literature on LAS glass-ceramics, several strategies for Li recovery have been developed, with a strong emphasis on process sustainability. Following Tao et al. (2024), KOH-based salt roasting treatments were systematically tested on the non-compliant materials. The LAS samples showed effective Li extraction through Li_3PO_4 precipitation, as demonstrated by ICP-OES and XRD analyses. For Li-rich enamels, a preliminary calcination step was employed to remove silicone oil from the formulation, as confirmed by ATR-FTIR, enabling an initial recovery of the materials. Subsequently, the same methodology for Li extraction was applied. Although promising performances were obtained, the process is still under optimisation, requiring a more selective precipitating agent.

This study confirms the potential of non-compliant glass-ceramic industrial materials as secondary sources of Li. An efficient recycling process was achieved for LAS, while the valorisation of enamels remains more challenging due to their chemical complexity. Further optimisation of the procedure will enhance their potential for resource recovery and circular economy strategies.

Finto G. (2025) - Caratterizzazione di sfridi di cava e prodotti industriali non conformi per la valutazione del potenziale estrattivo del litio. Master's thesis, University of Florence.

Raneri S. et al. (2025) - Fast Quantification of Lithium Concentration in Non-Compliant Materials Using Laser-Induced Breakdown Spectroscopy. Appl. Sci., 15(17), 9583, https://doi.org/10.3390/app15179583.

Tao X. et al. (2024) - High-efficiency, environment-friendly extraction of lithium from waste LAS glass-ceramics by roasting with KOH at low temperature. Resour. Conserv. Recy., 209, 107775, https://doi.org/10.1016/j.resconrec.2024.107775.

Mitigation strategies for critical raw materials: New fluxing systems for the porcelain stoneware industry

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Keywords: porcelain stoneware, supply-chain resilience, feldspar substitution.

In the modern ceramic industry, supply-chain resilience for raw materials has become increasingly important in light of geopolitical instability and European policies on critical raw materials. Porcelain stoneware, a key product of the sector, traditionally relies on a feldspathic fraction accounting for about 50 wt.% of the body. This component is essential for glassy phase formation and densification, but it is also strongly dependent on extra-EU mining sources, particularly Turkish albitites.

In this context, it is necessary to identify and evaluate alternatives to feldspar, proposing fluxing materials with lower geographic dependence on single supply areas. To address this need, a review of the scientific literature on feldspar substitution in porcelain stoneware bodies was carried out. The bibliographic contributions were classified according to the chemical composition of the alternative fluxes, in order to make the investigation more systematic and effective.

Based on these references, the experimental work was developed at laboratory scale with the aim of designing and characterizing ceramic bodies containing alkaline-earth silicates as alternative fluxes to feldspar, and of evaluating the effect of this substitution through a series of technological characterizations.

In particular, a benchmark body was defined to assess the progressive replacement of feldspar with wollastonite. The reference composition was selected by considering the critical role of calcium in reducing melt viscosity during firing, so as to balance this effect as the degree of substitution increased. Starting from the benchmark, four formulations were produced by replacing feldspar with wollastonite at 5, 7.5 and 10 wt.% within the body, using a balanced substitution approach.

On the practical side, the selected raw materials, namely clays, feldspar and sands, were wet milled to obtain a homogeneous slip. The slip was then dried, milled and re-wetted to allow manual granulation. The samples were subsequently produced in the form of disks and tiles by hydraulic pressing. As for material characterization this included hot-stage microscopy, density, shrinkage, water absorption, flexural strength, SEM analysis of the most densified samples, and color measurements (L*, a*, b*).

This investigation into feldspar substitution began with wollastonite because it is a useful model for studying the influence of calcium oxides on melt viscosity and on the lowering of the temperature of maximum vitrification. The results show a significant transformation of the post-firing microstructure: the traditional association of mullite and quartz is progressively replaced by a matrix dominated by anorthite and residual silicate phases. This mineralogical change not only responds to the need to diversify supply sources, but also opens new opportunities for optimizing the performance of the final product, outlining possible pathways toward more sustainable ceramic production.

Use of nano ferrites for heavy metals segregation: The case of Pb and Ni incorporation

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Keywords: iron oxides, synchrotron radiation, circular economy.

Iron oxides have been known to have promising adsorption capacities towards heavy metals, especially when in the nano-sized-region. This feature brought interest for potential applications in water remediation and environmental conservation purpose. Despite this, there is a lack of information about the fate of the adsorbed metals once they are inside the crystalline structure. For instance, this study uses nano-sized cubic ferrites (spinel structure) trying to set the bases for a better understanding of the fate of heavy metals when in contact with these structures.

Given the fact that natural ferrites would already have foreign cations attached that would reduce their adsorption capacities, synthesis was the best option. Two main synthesis method were chosen to allow the formation of nanostructured particles and an effective segregation of heavy metals: SOL-GEL and precipitation method. The first one allowed to obtain maghemite pristine nanoparticles used to adsorb heavy metals from water. It was also used to fix the heavy metals directly in the structure by adding them directly to the synthesis reagents. Precipitation used instead a water solution with stoichiometric and non-stoichiometric ratios of iron and heavy metals which were then precipitated by increasing the pH. In both cases, a calcination process (at 200°C for 2 hours) was necessary to induce the formation of the crystalline phases and to better fix the cations in the structure.

The results showed that the adsorption efficiency from water solutions with the SOL-GEL synthetised maghemite was very promising for Pb (more than 80%) while less effective for other cations like Ni. Segregation increased when the cations were directly present among the reagents. Precipitation method was more effective, for both Ni and Pb, but the powders obtained after calcination were not always crystalline given the differences in ionic radius of these two cations.

In order to understand where these cations are located inside the structure, PDF analyses based on both X-ray and Neutron diffraction were used. Moreover, since the results had still left some open question, XAS analyses were performed to try to follow the behaviour of the heavy metals during the synthesis of the spinel nano-powders.

Future studies will investigate the efficiency of heavy metals incorporation under different synthesis conditions and if there is some competition mechanism when the powders are used in more complex heavy metals solutions.

From volcanic eruptions to geopolymers: The resilient use of volcanic materials

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Keywords: geopolymers, pyroclastic materials, natural residue valorisation.

The development of low-environmental-impact binders through the valorisation of natural and residual geomaterials is attracting increasing interest within the circular economy and sustainable construction strategies. Geopolymers offer a promising alternative to traditional binders by reducing environmental impact and being compatible with both natural and waste-derived aluminosilicate precursors.

Following a previous study (Boscia et al., 2025), this work further investigates the use of zeolitized tuff waste (LYT of the Campanian Ignimbrite) as a partial substitute for metakaolin in geopolymeric binders. The study was expanded to include pyroclastic materials from the AD 79 Plinian eruption of Mount Somma-Vesuvius, utilising pumices (VP) and cinerites (VC) obtained from archaeological excavations in Pompeii that were designated for waste.

According to already developed formulations (Boscia et al., 2025), the geopolymeric binder was optimised by reducing the alkaline activator content and L/S, resulting in lower-impact systems ($SiO_2/Al_2O_3 \approx 4$; $Na_2O/A_{22}O_3 \approx 1$; $Na_2O/SiO_2 \approx 0.3$; L/S = 0.4). The same formulations were also applied to systems containing zeolitized tuff, enabling a direct comparison of geomaterials associated with different volcanic events in the Campanian area and the Mediterranean region. Additional formulations containing defoaming and hydrophobic agents provided by BI-QEM SpA were also studied to enhance the performance of the final product.

The experimental activity included mineralogical and microstructural characterisations by ATR-FTIR, TG-DSC, XRPD, and SEM-EDS analyses, integrated with compressive strength, ultrasound, and MIP tests. Moreover, hydric behaviour was evaluated through capillary and free/forced water absorption tests.

Additionally, the potential use of volcanic geomaterials as aggregates in metakaolin-based geopolymeric systems was evaluated, in analogy with studies on other artificial geomaterials (López Gómez & Cultrone, 2025). Materials related to the AD 79 Vesuvius eruption (VP and VC) and the 2021 Tajogaite eruption in La Palma, Canary Islands, Spain (Occhipinti et al., 2024), were compared using coarser grain sizes (0.5 mm < Ø < 2 mm) to assess their contribution to the final properties of geopolymeric composites.

The results obtained highlight the potential of natural and residual volcanic geomaterials as functional components in sustainable geopolymeric formulations, thereby promoting their valorisation within a circular-economy framework.

Boscia S. et al. (2025) - Metakaolin- and zeolite-based geopolymers: mineralogical and mechanical characterizations. In: Geosciences and the Challenges of the 21st Century. Abstract Book, 2025 SIMP-SGI Joint Congress, 790, https://doi.org/10.3301/ABSGI.2025.03.

López Gómez M. & Cultrone G. (2025) - Study of the mineralogical and textural properties of bricks with volcanic ash temper. Appl. Clay Sci., 266, 107690, https://doi.org/10.1016/j.clay.2024.107690.

Occhipinti R. et al. (2024) - Alkali activated materials from Tajogaite volcanic ash (La Palma, Spain): a green recovery after the 2021 eruption. Volcanica, 7(2), 717-731, https://doi.org/10.30909/vol.07.02.717731.

Reactive volcanic geomaterials for sustainable pozzolanic lime mortars: The influence of alkaline activation on mechanical performance

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Keywords: pozzolanic mortars, volcanic geomaterials, sustainability.

The transition toward sustainable and low-impact construction materials is a key challenge within the framework of circular economy strategies and climate-change mitigation policies. In this context, natural volcanic geomaterials represent promising alternative resources for the production of eco-friendly binders and mortars. This study investigates the behaviour of innovative lime-based pozzolanic mortars formulated with two volcanic geomaterials collected from Sardinian volcanic outcrops (Italy): a perlitic rhyolite and a pyroclastic material.

Several mortar formulations were designed by systematically varying three main parameters: pozzolan type, mixing water (tap water and seawater) and the presence or absence of alkaline activation through NaOH. Samples were cured under both standard atmospheric carbonation and limited-carbonation conditions, maintaining high relative humidity (~90%). Mechanical, mineralogical and microstructural properties were investigated after 28 days and six months through flexural and compressive strength tests, X-ray diffraction (XRD), mercury intrusion porosimetry (MIP) and pH analyses.

Preliminary results highlight the strong influence of the volcanic geomaterial type on mortar performance. Mortars produced with the perlitic rhyolite generally exhibited significantly higher compressive and flexural strengths than those formulated with the pyroclastic pozzolan, despite the latter showing a finer grain-size distribution. This behaviour suggests a higher pozzolanic reactivity of the perlitic material toward calcium hydroxide. The addition of NaOH markedly improved the mechanical performance of mortars based on the perlitic rhyolite, while an opposite trend was observed for the pyroclastic formulations.

Carbonation also played a relevant role in the evolution of mechanical properties. Samples cured under atmospheric carbonation generally achieved higher compressive strengths, especially in mortars containing the pyroclastic pozzolan and in NaOH-activated mixtures based on the perlitic rhyolite. Porosimetric analyses revealed an overall inverse relationship between open porosity and compressive strength, whereas pH measurements confirmed the highly alkaline nature of all formulations.

Overall, the findings indicate that the type of alkaline activator and the nature of the pozzolanic geomaterial are the key factors controlling mortar performance. In particular, NaOH activation and the use of perlitic rhyolite proved to be the most effective combination for enhancing mechanical strength and promoting pozzolanic reactivity. The obtained results demonstrate the potential of Sardinian volcanic geomaterials as sustainable secondary resources for innovative pozzolanic mortars, contributing to the development of low-impact construction materials and resource-efficient technological processes.

Feasibility study for the valorisation of basalt sludges and local clays in low-carbon binder systems

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Keywords: alkali-activated materials, local raw materials, multidisciplinary approach.

In order to reduce the carbon footprint of the construction sector, Alkali-Activated Materials (AAMs) represent a viable alternative to Portland cement, allowing for the use of industrial by-products and natural precursors. This study investigates the joint valorisation of sawing sludges from Etnean basalt processing and Sicilian Plio-Pleistocene clays from two different sites: the marly clays of the Monte Narbone Formation (LT, Agrigento-Licata area) and the grey blue clay Formation from Motta Sant'Anastasia (SIL, Catania). The clays were subjected to a calcination process at 750°C in order to make them reactive (Stroscio et al., 2024). The mix design was defined through a preliminary experimental phase aimed at define the suitable ratios between the precursors and the activating solution (KOH 9M; K_2SiO_3 with $SiO_2/K_2O = 1.6$). To validate the performance of local resources, a systematic comparison was conducted with reference mixtures in equal proportions, using commercial metakaolin as a substitute for the clays. Chemical characterization of the clay's raw materials via XRF showed substantial similarity, except for a higher enrichment of Al_2O_3 in SIL, and CaO in LT. The evolution of crystalline phases and amorphous content was monitored via XRD at 7 and 28 days, showing an evident and gradual increase in amorphous content over time. Analysis revealed the presence of unreacted mineral phases such as plagioclase, calcite and muscovite (typical of the precursors), alongside the formation of neo-formed hydrated and silicate phases. FT-IR analysis confirmed the occurrence of geopolymerization, highlighting the bending and stretching vibration bands of hydroxyl groups, carbonates, and Si-O-Al and Al-O bonds. Mechanical performance, evaluated through uniaxial compression tests, indicated average strength value of 17.4 MPa with a standard deviation of 1.4 for LT and a value of 20.2 MPa with a standard deviation of 1.2 for SIL, slightly below the range obtained with mixtures using metakaolin. Finally, setting tests conducted with the Vicat needle allowed for the definition of the mixtures' curing, laying the groundwork for more detailed rheological investigations and their subsequent implementation in extrusion-based 3D printing. The results demonstrate the potential of regional geo-resources to replace commercial precursors, establishing a robust scientific framework for a sustainable, large-scale supply strategy. By transforming local industrial waste and regional clays into high-value technological assets, this study contributes to promote a self-sufficient construction model for Sicily. This approach not only drastically reduces the environmental and economic impact of material transport but also aligns regional production with the most advanced goals of the circular economy.

Stroscio A. et al. (2024) - Sicilian clay sediments as precursor for alkali activated materials. Appl. Clay Sci., 253, 107350, https://doi.org/10.1016/j.clay.2024.107350.

The role of the evaporites in the storage of fluids: A petrophysical characterization of Messinian, Triassic and Permian rocks

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Keywords: evaporites, petrophysics characterization, fluid storage.

Current times are characterized by an increasing demand for subsurface storage sites. Evaporites, owing to their peculiar petrographic and petrophysical properties, are the only rock types capable of acting both as effective seal and reservoir for fluids. However, their properties in relationships of their sedimentological and stratigraphic characteristics remain poorly constrained.

Evaporitic bodies are widespread in the Italian subsurface (both onshore and offshore), ranging in age from the Triassic to the Messinian. The latter have been recently recognized as effective seals for both siliciclastic and carbonate reservoir (Manzi et al.,2024), based on large-scale characteristics, such as overall composition, thickness, geometry, lateral continuity, interbedding of other rocks, facies distribution and stacking pattern. Conversely, poor is known regarding the variability of their petrophysical properties at the medium- and small-scale.

To address this gap, we have undertaken an in-depth revision of the Italian evaporites aimed at their petrographic, mineralogical and petrophysical characterization for storage applications. We have analyzed evaporites with different composition (sulfates and halite) and origin (primary, clastic and secondary) through: i) measurements of effective and relative porosity and permeability (helium porosimeter and air/nitrogen permeameters); ii) facies and compositional analyses (petrography, XRD, tomography); and iii) permeability testing under pure CO_2 injection.

Our work provides key insights for the identification of the most suitable sites for subsurface storage, addressing good seal proprieties to primary and diagenetic evaporites facies and defying as reservoir the non-diagenetic resedimented clastic evaporites.

Manzi V. et al. (2024) - The role of the Messinian evaporites in the identification of potential gas storage sites: A review of the Adriatic foreland basin system (Italy). Basin Res., 36, e70000, https://doi.org/10.1111/bre.70000.

From ore to shield: The structural behaviour of critical borates in neutron-shielding concretes

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Keywords: geomaterials, borates, non-ambient conditions.

Hydrated borates, a group that includes minerals such as colemanite, ulexite, and borax, serve as the primary ore sources for boron. This element is not only a vital geochemical marker used to track and interpret petrogenetic processes, but it also represents a strategic resource essential for high-end technological applications. Highlighting their economic and industrial significance, these minerals have been recently classified as critical raw materials by the European Union (EU Commission, 2017). Consequently, they are being increasingly investigated as specialized aggregates in the development of neutron-shielding concretes. This interest is driven by their exceptional thermal neutron adsorption capacity combined with a characteristically low density, typically measured between 2.3 and 2.5 g/cm^3. From a structural perspective, hydrated borates are characterized by an intricate architecture composed of Bφ_x units, such as tetrahedra and trigonal planes, which are organized into complex polyion clusters. These clusters are interconnected by alkali or alkaline-earth polyhedra, most commonly involving cations such as sodium (Na^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}). Within these crystalline frameworks, H_2O molecules and OH groups establish an extensive and sophisticated hydrogen-bond network. This network is not a secondary feature; rather, it is fundamental to the overall stability and structural integrity of the entire crystalline edifice (Comboni et al., 2022; 2024). A comprehensive characterization of the crystal-chemistry, elastic properties, and long-term stability of these natural borates is essential for modern engineering. Specifically, understanding their structural behaviors at varying temperature (T) and pressure (P) conditions is a fundamental requirement for the accurate modeling and prediction of their performance when adopted as aggregates in technical concretes. The aim of this contribution is to explore the behavior of these minerals at non-ambient conditions, providing a detailed description of their deformation mechanisms at the atomic scale

Comboni D. et al. (2022) - High-pressure behavior and phase transition of jadarite, a promising B and Li mineral commodity. J. Am. Ceram. Soc., 105(11), 6937-6948, https://doi.org/10.1111/jace.18659.

Comboni D. et al. (2024) - Atomic-scale deformation mechanisms at high-pressure in inderborite, $CaMg[B_3O_3(OH)_5]_2(H_2O)_4 \cdot 2H_2O$. Mineral. Mag., 88, 473-481, https://doi.org/10.1180/mgm.2024.29.

EU Commission (2017) - Study on the review of the list of critical raw materials. Brussels, https://doi.org/10.2873/876644.

Industrial upscaling of waste mineral wool valorisation in the Circular Economy perspective: Integrating secondary and local Raw Materials in the european ceramic industry

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Keywords: ceramic, sustainability, scale up.

The transition toward a circular economy requires the ceramic industry to reduce dependence on primary raw materials and integrate secondary resources into established production routes. In this study, the valorisation of waste mineral wool, previously transformed through thermal inertization into a homogeneous glass (Re.Wo.) (Arletti et al., 2023; Conte et al., 2025), is scaled up from laboratory validation to pilot-plant production of porcelain stoneware tiles. Unlike previous investigations based on non-European raw materials and laboratory-scale tests, this work employs locally sourced European clays, sands, and fluxes, strengthening supply-chain resilience and environmental coherence.

Four formulations were designed, including a benchmark and batches containing 2-6 wt.% Re.Wo. as partial replacement of feldspar. After laboratory simulation (TRL 4), selected compositions (0, 2 and 4 wt.% Re.Wo.) were processed at pilot scale (TRL 6) using industrial equipment for milling, spray drying, pressing, and roller-kiln firing, culminating in the production of 60 m^2 of tiles. Technological properties of unfired and fired bodies, gresification behaviour, phase evolution, and thermal stability were systematically evaluated.

Results demonstrate that additions up to 4 wt.% Re.Wo. maintain industrially acceptable forming behaviour and mechanical performance, achieving water absorption below 0.5 wt.% at 1200°C and exhibiting densification trends comparable to the benchmark. Higher additions (6 wt.%) induce overfiring and bloating due to enhanced liquid-phase formation and reduced melt viscosity.

The successful pilot-scale production validates the robustness, reproducibility, and industrial compatibility of the process without requiring modifications to existing equipment. This work demonstrates a concrete pathway for integrating inertized hazardous waste into high-value ceramic products, contributing simultaneously to landfill diversion, reduction of critical raw material use, and decarbonization strategies in the European ceramic sector.

Arletti R. et al. (2023) - Recycling the product of thermal inertization of man-made vitreous fibres for the manufacture of stoneware tiles. Waste Biomass Valor., 14, 1721-1736, https://doi.org/10.1007/s12649-022-01959-8.

Conte S. et al. (2025) - Sintering mechanisms, phase transformations and microstructure of porcelain stoneware containing thermally inertized man-made vitreous fibres. J. Eur. Ceram. So., 45, 117230, https://doi.org/10.1016/j.jeurceramsoc.2025.117230.

The role of chabazite in acid-activated geopolymers for caesium retention in radioactive waste immobilisation

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Keywords: zeolite chabazite, acid geopolymer, radioactive waste management.

Radioactive waste (RW) must be immobilised within stable conditioning matrices to prevent radionuclides release into the environment. Nowadays, Portland cement (PC) is the gold standard for this purpose, yet its retention effectiveness towards anionic species and Cs-137, a highly mobile and abundant radionuclide found in most RWs, is mediocre (Fattori et al., 2025). Geopolymers (GPs), inorganic binders obtained by mixing aluminosilicates with alkaline or acid solutions, exhibit high compatibility with many RW which are otherwise difficult to immobilise in PC. Moreover, GPs are typically effective in immobilising Cs-137 thanks to their zeolite-like microstructure. Phosphate-based GPs (PGPs), activated using H_3PO_4, recently gained attention for their high mechanical strength and anion adsorption properties (Goryunova et al., 2023). However, their Cs retention capability is scarcely investigated in literature.

This work investigated the use of a chabazite-rich zeolitite (about 65% w/w) to enhance Cs retention in PGPs, exploiting the high selectivity of this zeolite for Cs (Baek et al., 2018). The leaching resistance for Cs-137 of a metakaolin-based PGP with 9% w/w zeolitite was assessed and compared to a metakaolin-only reference sample. Unexpectedly, the PGP containing zeolitite exhibited lower retention capabilities: about 11% w/w of the initial Cs was released after four days of leaching, compared to about 4% for the control sample. Confirmed by X-ray diffraction (XRD) analyses, chabazite completely dissolved during the acid geopolymerisation process, determining an unbalance in the P/Al molar ratio and explaining this worsening. Hence, an investigation was conducted to establish the conditions in which chabazite maintains, at least partially, its phase stability in PGPs. Three different H_3PO_4 concentrations (40%, 60%, and 75% w/w) were used to synthesise PGPs with zeolitite as sole precursor. After carrying out a quantitative phase analysis XRD, only the PGP synthesised using the 40% w/w H_3PO_4 solution preserved residual chabazite (33% w/w of the nominal value). Strong correlation between the mineralogical composition of the samples and corresponding Cs retention was highlighted. Finally, XRD analysis on a preliminary multi-precursor PGP (based on metakaolin, zeolitite, and fly ash) activated with 60% w/w H_3PO_4 indicated that chabazite can be stable, to some extent, even when increasing the activator concentration, the main driver for mechanical resistance in PGPs.

In conclusion, PGPs demonstrated to be suitable matrices for Cs retention, though underperforming with respect to their alkaline counterpart. The addition of chabazite can enhance Cs retention, given that its phase stability is preserved if suitable synthesis conditions are adopted. To this scope, two approaches are possible: i) reducing the H_3PO_4 concentration; ii) using a mixture of precursors, in which mineralogical phases less stable than chabazite could be preferentially dissolved.

Baek W. et al. (2018) - Cation Exchange of Cesium and Cation Selectivity of Natural Zeolites: Chabazite, Stilbite, and Heulandite. Micropor. Mesopor. Mat., 264, 159-166, https://doi.org/10.1016/j.micromeso.2018.01.025.

Fattori F. et al. (2025) - Thermal and Chemical Parameters Controlling Phase Stability and Caesium Immobilisation in Phosphate-Based Geopolymers, Using a Chabazite-Rich Volcanic Tuff. Ceram. Int., 51(30), 63441-63452, https://doi.org/10.1016/j.ceramint.2025.11.131.

Goryunova K. et al. (2023) - Phosphate-Activated Geopolymers: Advantages and Application. RSC Adv., 13, 30329-30345, https://doi.org/10.1039/D3RA05131E.

Mineralogical and technological evaluation of Sicilian clays for topical delivery of resveratrol

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Keywords: clay, mineralogy, resveratrol.

Sicily is a geologically diverse region characterized by extensive clay deposits. This study investigates four unexplored Sicilian clay successions representative of the island's tectono-sedimentary evolution: Cretaceous variegated clays (CALT1, green; CALT2, red) from the Caltavuturo Formation; Plio-Pleistocene pelites (SIL); and Tortonian grey clays from the Terravecchia Formation (CEN). While traditionally used in ceramics and construction, these materials remain underutilized for high-value pharmaceutical and cosmetic applications. A multidisciplinary approach was adopted to bridge the gap between mineralogical characterization and functional screening. Bulk materials and their ≤ 2 μm fractions were analyzed using X-ray diffraction (XRD), X-ray fluorescence (XRF), ICP-MS, Fourier-transform infrared spectroscopy (FT-IR), and thermogravimetric analysis (TGA). Model clay-based suspensions were prepared by dispersing the monocationic clay fractions in a hydro-alcoholic medium (50:50 water:ethanol) loaded with 0.6% (w/w) resveratrol (RSV) as a reference bioactive compound. Mineralogical analysis revealed that CALT1 and CALT2 are enriched in interlayered illite/smectite (I/S75R1), with CALT1 also containing chlorite. In contrast, SIL and CEN are richer in pure smectite and kaolinite (I/S80R0). Chemical analysis (XRF and ICP-MS) confirmed that CALT samples have higher alumina and iron contents compared to SIL and CEN. Functional tests demonstrated that the mineralogical assemblage and microstructure are the primary drivers of technological performance. Suspensions based on CALT1 and CALT2 exhibited the highest and most sustained resveratrol release (22.28 ± 0.003% and 17.32 ± 0.005%, respectively) over 24 hours, likely due to their rigid I/S layers and limited swelling. Conversely, the kaolinite-rich SIL and CEN samples showed lower release (16.34 ± 0.245% and 7.52 ± 0.032%). CALT-based suspensions also showed higher occlusion factors (38-40%), suggesting a greater potential for forming protective films on the skin. This study establishes a material-oriented pre-formulation framework for selecting natural clay carriers based on fine-fraction mineralogy. The results highlight that the mineralogical structure and microstructure, rather than simple parameters like particle size or viscosity, play a key role in controlling formulation performance. Specifically, CALT1 and CALT2 combine structural stability and favourable functional performance, making them promising sustainable candidates for future topical delivery systems.

Sustainable radioactive waste management via iRE-SOLVE technology: The pivotal role of chabazite-rich zeolitite in effluent decontamination

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Keywords: chabazite zeolitite, radioactive waste decontamination, inventive solution.

Spent Ion Exchange Resins (SIERs) represent a critical radioactive waste stream, with about 4000 m^3 produced annually worldwide, and more than 1 m^3, that are temporarily stored in facilities. The traditional management route by direct cementation is highly inefficient due to organic-matrix incompatibility, swelling, and chemical interferences from sulfates and borates, which force low waste loadings and skyrocket disposal costs (Broglia A. et al., 2026). Bridging natural resources, technology, and sustainability, iRE-SOLVE is an innovative Italian patented technology (IT202300002082A) that replaces energy-intensive incineration. It integrates SIER treatment through a low-temperature (< 100°C) and ambient-pressure Fenton-like wet oxidation, achieving >95% mineralization, with residue conditioning in geopolymers meeting the Waste Acceptance Criteria (Galluccio et al., 2025a). Embracing circular economy principles, iRE-SOLVE employs industrial waste as catalysts, and precursors of the conditioning matrix (Galluccio et al., 2025b).

A cornerstone of this process is the replacement of energy-intensive evaporation of the Fenton liquor with its rapid, selective decontamination utilizing, after basification, a chabazite-rich zeolitite to concentrate radionuclides into a stable solid residue easy to be conditioned. This study focuses on this decontamination stage, performed using chabazite-rich zeolitic materials. To deeply understand the nature of these porous zeolitite adsorbents, a thorough material characterization was conducted via QPA-XRD. Subsequently, batch adsorption experiments were performed by contacting the zeolitite with Fenton liquor containing stable Cs, Co, Sr, and Ni.

Given the highly promising decontamination yields (>95%) determined via mass spectrometry, further batch tests were carried out by spiking the Fenton effluent with radioactive isotopes (^{137}Cs, ^{63}Ni, ^{226}Ra, ^{241}Am, and ^{99}Tc, though for Tc studies are ongoing for process tuning), where the decontamination yields were determined by means of alpha spectrometry or liquid scintillation counting. To ensure process robustness, the decontamination of ^{137}Cs, one of the most mobile radionuclides in the biosphere, was rigorously investigated across varying zeolitite-to-cesium ratios, temperature, and contact time, and with different chabazite-rich zeolitites. Contact kinetic curves were also derived to determine the velocity and efficiency of these microporous frameworks, precisely defining optimal operational parameters (time, temperature, concentration) for the iRE-SOLVE decontamination stage.

Conclusively, the outstanding decontamination yields achieved for all investigated contaminants backed up the crucial role of zeolitites in treating radioactive effluents (Baek et al., 2018), offering a sustainable, high-performance solution that optimizes repository footprint and effectively addresses the global challenging SIERs backlog.

Baek W. et al. (2018) - Cation Exchange of Cesium and Cation Selectivity of Natural Zeolites: Chabazite, Stilbite, and Heulandite. Micropor. Mesopor. Mat., 264, 159-66, https://doi.org/10.1016/j.micromeso.2018.01.025.

Broglia A. et al. (2026) - Disposal of spent ion-exchange resins with the iRE-SOLVE process: A comparative economic analysis. Nucl. Eng. Technol., 58, 7, https://doi.org/10.1016/j.net.2026.104292.

Galluccio F. et al. (2025a) - iRE-SOLVE Process for the Pre-Disposal Management of Spent Ion-Exchange Resins. Ind. Eng. Chem. Res., 64, 20, https://doi.org/10.1021/acs.iecr.5c01196.

Galluccio F. et al. (2025b) - An Integrated Strategy for Pre-Disposal of Spent Cation-Exchange Resins by Repurposing Industrial By-Products. Sustainability, 17, 8241, https://doi.org/10.3390/su17188241.

Urban mining for sustainable ceramics: Minero-petrographic characterisation of ceramic formulations based on Recycled Raw Materials (RRM)

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Keywords: sustainable ceramic formulations, minero-petrographic analysis, circular economy.

This research aims to develop eco-sustainable ceramic formulations by integrating recycled raw materials (RRM) into ceramic mixtures. Various waste streams - including mining residues, fired ceramic production waste, and construction and demolition waste - have been assessed and characterized with the dual aim of reducing reliance on Critical and Strategic Raw Materials (CRM/CSM) and lowering the high energy demand of the ceramic industry. At the same time, the research seeks to mitigate the environmental impacts associated with conventional raw material extraction by promoting a circular production model inspired by Urban Mining principles. The Italian ceramic sector, recognised nationally and internationally for its industrial excellence, faces increasingly pressing challenges in terms of environmental sustainability, resource management and production process optimisation. In this context, the study emphasizes the preliminary characterization of RRM using optical microscopy (OM), X-ray diffraction (XRD), and portable X-ray fluorescence (p-XRF). These techniques enable a detailed mineralogical, petrographic, and chemical assessment to determine the suitability of RRM as alternative feedstocks for ceramic production. Following this analytical phase, ceramic formulations are developed and experimentally tested, with evaluation of both aesthetic qualities and key technical properties, including linear firing shrinkage and water absorption. The research adopts an eco-design approach based on a threefold sustainability strategy - recovery, recycling, and valorization of RRM - supporting the transition toward a circular and resource-efficient ceramic industry. The proposed approach is expected to enhance material circularity, environmental sustainability, and industrial competitiveness, while ensuring high performance in compliance with European standards (International Organization for Standardization, 2024a; 2024b) and facilitating alignment with Industry 5.0 paradigms.

International Organization for Standardization (2024a) - Circular economy - Vocabulary, principles and guidance for implementation. ISO Standard No. 59004:2024, https://www.iso.org/standard/80648.html.

International Organization for Standardization (2024b) - Circular economy - Measuring and assessing circularity performance. ISO Standard No. 59020:2024, https://www.iso.org/standard/80650.html.

Tuff quarry waste as feldspar substitute in porcelain stoneware: A circular economy perspective

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Keywords: zeolites, secondary raw materials, sustainability.

In recent years, the demand for white-firing clay materials for ceramic tile production has increased, driven by the continued shift toward porcelain stoneware bodies. At the same time, the current geopolitical scenario has exposed the vulnerability of established raw-material supply chains, highlighting the need to evaluate alternative Italian resources for porcelain stoneware production.

In this context, zeolite-bearing tuff waste (ZT) generated by the extraction and processing of *Tufo Giallo della Via Tiberina* from an active quarry in Riano (Lazio, Italy) was investigated as a partial substitute for feldspar in porcelain stoneware formulations (Lombardi & Meucci, 2006). The collected sample was characterized by mineralogical (XRPD), chemical (XRF), microstructural (SEM) and physical analyses, with sanidine as the dominant phase, associated with zeolites (chabazite, analcime and phillipsite), volcanic glass, calcite, and minor phases (Cappelletti et al., 2015). No contamination related to processing operations was detected.

Three replacement levels (2.5, 5, and 10 wt.%) were tested against a reference porcelain stoneware batch and the tile-making process was reproduced at laboratory scale. The addition of ZT increased green and dry bulk density and improved the mechanical properties of the unfired bodies.

All formulations satisfied the ISO 13006 (UNI-EN 14411, 2016) requirements for BIa class porcelain stoneware, showing flexural strength values above 35 MPa and water absorption below 0.5%. Moreover, ZT promoted earlier densification: formulations containing 2.5 and 5 wt.% reached optimal sintering conditions at 1180°C, while the 10 wt.% formulation achieved the target properties already at 1170°C, compared with 1190°C for the reference batch, thus enabling a reduction in thermal energy demand.

These results demonstrate that Riano quarry ZT is suitable across the whole investigated substitution range and represents a technically viable and environmentally responsible strategy for the valorization of volcanic tuff processing waste within a circular economy framework.

Cappelletti P. et al. (2015) - The "Tufo Giallo della Via Tiberina" (Sabatini Volcanic District, Central Italy): a complex system of lithification in a pyroclastic current deposit. Mineral. Petrol., 109, 85-101, https://doi.org/10.1007/s00710-014-0357-z.

Lombardi G. & Meucci C. (2006) - Il Tufo Giallo della Via Tiberina (Roma) utilizzato nei monumenti romani. Rend. Lincei, 17, 263287, https://doi.org/10.1007/BF02904766.

UNI-EN 14411 (2016) - Piastrelle di ceramica - Definizioni, classificazione, caratteristiche, valutazione e verifica della costanza della prestazione e marcatura.

Beyond landfill: Sustainable valorization of *Tufo Giallo della Via Tiberina* processing waste for construction and environmental sectors

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Keywords: zeolite, secondary raw materials, sustainability.

The industrial processing of dimension stones generates large amounts of quarry waste, posing significant logistical and environmental challenges. Within a circular economy framework, the valorization of these residues as secondary raw materials represents a strategy to reduce disposal volumes and decrease demand for primary natural resources.

This study investigates waste generated by the cutting and processing of *Tufo Giallo della Via Tiberina* (TGVT), a pyroclastic tuff from the Sabatini Volcanic District (Conticelli et al., 1997) collected at the active Riano quarry (Lazio, Italy) and evaluates its potential in multiple technological applications. The waste retains the mineralogical composition of the parent material, with sanidine as the dominant phase (41-49 wt.%), followed by zeolites (chabazite, phillipsite and analcime; 16-24 wt.% in total), calcite (15-16 wt.%), mica and pyroxenes.

The collected waste was tested in three application fields: lightweight expanded aggregates (LEAs), pozzolanic additive in cementitious systems and surface-modified sorbent for pharmaceutical molecules. LEAs produced by pelletization and firing at 1250°C fully comply with standards (UNI EN 13055, 2016) requirements, showing a bulk density of 1050 kg/m^3, water absorption of 1.25%, and particle compressive strength of 0.5 MPa.

Pozzolanic activity, assessed by the Fratini test (UNI EN 196-5, 2015), yielded a pozzolanic activity index of about 20% after 15 days, confirming the attitude of the tested waste to participate in hydraulic reactions as a partial cement substitute. Surface modification with cetylpyridinium chloride reversed the zeta potential from -21.11 mV to +7.93 mV and enabled an ibuprofen adsorption capacity of about 11.5 mg/g, with a cation exchange capacity of 1.95 mEq/g.

Given the annual production of approximately 17,000-20,000 m³ of tuff sawdust at the Riano quarry, corresponding to 30-35% of total extraction, tested valorization pathways represent a scalable and replicable model for the sustainable management of zeolite-bearing volcanic waste in central and southern Italy.

Conticelli S. et al. (1997) - Petrology and geochemistry of the ultrapotassic rocks from the Sabatini Volcanic District, Central Italy: The role of evolutionary processes in the genesis of variably enriched alkaline magmas. J. Volcanology and Geoth. Res., 75, 107-136, https://doi.org/10.1016/S0377-0273(96)00062-5.

UNI EN 196-5 (2015) - Cement test methods - part 5: Pozzolanic Test of Pozzolanic Cements.

UNI EN 13055 (2016) - Lightweight aggregates.

Optimized wet leaching of critical raw materials from Portovesme red muds, SW Sardinia

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Keywords: bauxite residues, critical raw materials, acid leaching.

Bauxite residues (BRs), commonly known as red muds (RMs), are produced during alumina extraction by the Bayer process. Although they represent an environmental issue, they may also be considered a secondary source of critical raw materials (CRMs), including scandium, Sc, rare earth elements, REEs, gallium, Ga, and vanadium, V (Samal, 2021). This work focuses on RMs from the Portovesme disposal site, SW Sardinia, and evaluates their potential for CRM recovery through laboratory-scale wet leaching with sulfuric acid.

Ten leaching experiments were performed by changing acid concentration, solid/liquid (pulp) ratio, hydrogen peroxide addition, time, and temperature. Both leachates and solid residues were analysed by inductively coupled plasma optical emission spectrometry (ICP-OES); solid residues were also studied by X-ray powder diffraction (XRPD) to follow the mineralogical changes after leaching. The best extraction was obtained under the following conditions: $[H_2SO_4]$ = 1.6 M, $[H_2O_2]$ = 1.6 M, pulp ratio = 10%, T = 90°C, and t = 240 min. These conditions allowed high recovery of Sc and La, reaching 91% and 90%, respectively. Relevant recoveries were also obtained for Ga (61%), Sr (44%), and V (42%), while Al and Mg reached about 84%. By contrast, Ti, Fe, Ca, Mn, and Cr were less mobilized, with recoveries generally below 35%. XRPD results show that leaching mainly affected aluminosilicate phases, especially sodalite and cancrinite, together with carbonate phases such as calcite. The residues also show partial hematite depletion and the formation of sulphate phases related to the use of H_2SO_4.

Samal S. (2021) - Utilization of red mud as a source for metal ions - A review. Materials, 14(9), 2211, https://doi.org/10.3390/ma14092211.

Low-impact sealing geomaterials for fractured rock mass systems: A case study from a carbonate oil reservoir

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Keywords: metasilicate, calcium, cloride.

Sealing geomaterials play a key role in drilling operations by providing effective and sustainable solutions for well integrity and fluid-loss control in highly fractured rock masses. Their chemical and rheological properties allow the development of gel-forming and cementitious systems capable of reducing rock permeability and sealing complex fracture networks under critical drilling conditions.

This study presents a field case from a carbonate oil reservoir in Cuba affected by severe total circulation losses during drilling operations. The reservoir had been extensively exploited and was characterized by intense historical drilling activity, resulting in highly fractured and depleted formations. The circulation losses generated critical operational risks, including differential pipe sticking, wellbore instability, excessive non-productive time and potential well loss. An integrated workflow based on well-log interpretation and inter-well correlation was applied to identify the loss zone. Caliper, resistivity and drilling data were analyzed together with information from nearby wells, allowing the recognition of a laterally continuous fractured interval within the carbonate reservoir. The interpreted interval corresponded to a loss zone previously identified in an adjacent well, confirming the persistence of a highly permeable fracture system. Based on these results, a sealing treatment composed of cement, sodium metasilicate and calcium chloride was designed and successfully applied. These materials, derived from the processing of natural mineral resources such as limestone, silica-rich minerals and natural brines, generated a low-impact sealing system capable of effectively plugging the fractured interval, restoring circulation and allowing safe continuation of drilling operations.

The results demonstrate how geomaterials derived from natural raw materials can provide efficient and sustainable solutions for fracture sealing and fluid-loss control in fractured rock masses. The study also highlights the importance of integrating geomaterial engineering with geological and petrophysical interpretation to improve operational reliability and reduce environmental impact in petroleum drilling activities.

Kinetic analysis of olivine-based Mg-phosphate cement

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Keywords: low-CO2 cement, kinetic analysis, newberyite.

Due to the high environmental footprint of Portland cement, the research has been focused to alternative low-carbon binders. In this scenario, it has been recently proposed to produce a Mg-phosphate cement by exploiting the reactivity of natural Mg-rich olivine in presence of phosphoric acid (Bernasconi et al., 2024). Compared to common magnesium phosphate cements, the energy-intensive MgO calcination is avoided in the perspective of utilizing olivine resources or olivine-rich wastes. The setting reaction produces a cement comprising residual olivine crystals embedded in a dense matrix of newberyite ($MgHPO_4 \cdot 3H_2O$), with dispersed amorphous silica nanoparticles. These results indicated that that the amount of reaction products is strongly influenced by acid concentration and liquid/solid ratio of the mix. In this work the reaction has been followed in-situ with synchrotron X-ray diffraction to describe the olivine dissolution and the newberyite crystallization, in order to gain further knowledge on the reaction mechanisms in view of optimizing the cement formulation for applications. The results indicate that the increase in liquid content, at same acid concentration, leads to an increased dissolution of olivine and more extensive formation of newberyite, whereas, the overall rates decrease. The newberyite crystallization has been described with an JMAEK kinetic equation with apparent activation energy of 73 kJ/mol for the fastest reacting samples. Conversely, the olivine dissolution kinetics exhibited a multistep behaviour described by first order equations (chemical reaction) in agreement with the literature.

The interplay of dissolution kinetics, acid concentration, and water content governs the balance between crystalline and amorphous phases, which in turn determines the mechanical performance. The information obtained will help in devising strategies for the improvement of microstructure and properties and, at the same time, will provide a framework for recycling olivine-rich wastes, such as volcanic ash or industrial by-products, into sustainable binder systems, offering a pathway to implement circular economy in construction materials.

Bernasconi D. et al. (2024) - Setting reaction of a olivine-based Mg-phosphate cement. Cement Concrete Res., 186, 107694. https://doi.org/10.1016/j.cemconres.2024.107694.

Role of mineralogy in the carbonation behavior of steel slag from northern Italy

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Keywords: steel slag, natural carbonation, lime.

The continuous increase of anthropogenic CO_2 emissions is one of the main drivers of climate change, prompting the development of carbon capture and sequestration (CCS) strategies. Alongside engineered solutions, the natural carbonation of alkaline industrial by-products represents an additional opportunity for permanent CO_2 storage. Steelmaking slag generated in Electric Arc Furnace (EAF) and Ladle Furnace (LF) processes contain reactive calcium-bearing phases (Campo et al., 2021) and may act as effective CO_2 sinks under realistic slag-yard conditions, potentially contributing to emission mitigation across the steel products life cycle.

This work aims to assess and monitor the natural wet carbonation of EAF (black) and LF (white) slag under realistic slag-yard conditions, clarifying the influence of mineralogy and particle size on CO_2 uptake and evaluating potential implications for carbon footprint accounting in steel production at industrial scale.

Representative black and white slag samples were collected from five Italian steel plants. Slag were analyzed in the as-received condition and, where applicable, as fine fractions (< 1 mm). Natural wet carbonation was simulated by outdoor curing in aluminum trays stocked under shelter, with periodic water spraying to reproduce typical slag-yard conditions and storage times. Mineralogical evolution during exposure was investigated by X-ray diffraction at different curing times, while CO_2 uptake was quantified by elemental analysis after up to 180 days of atmospheric exposure. An economic allocation approach was applied to evaluate the impact of slag carbonation on the overall carbon footprint of the EAF steelmaking process.

Black slag showed limited carbonation, mainly due to mineralogical compositions dominated by poorly reactive silicates and oxides. In contrast, white slag exhibited fast and marked carbonation, with calcite and vaterite formation detectable after 14 days of exposure. Calcium aluminates were identified as key phases promoting hydration and subsequent carbonation, whereas calcium silicates played a marginal role under natural wet conditions. Fine particle size significantly enhanced CO_2 uptake. After 180 days, black slag absorbed up to 1 wt.% CO_2, while white slag absorbed up to 5 wt.% CO_2, corresponding to net carbon footprints of -5.2 and -25.2 kgCO_2 eq./ton of slag, respectively. Reallocation of these contributions resulted in a measurable reduction of the EAF steelmaking carbon footprint at system level.

Steelmaking slag, particularly white slag, shows a relevant natural CO_2 sequestration potential under realistic slag-yard conditions. Mineralogy and particle size are critical factors controlling carbonation efficiency. Accounting for slag carbonation can improve the environmental performance of EAF steelmaking and supports circular economy strategies based on optimized slag management, realistic storage scenarios and improved carbon accounting frameworks.

Campo F.P. et al. (2021) - Natural and enhanced carbonation of lime in its different applications: a review. Environ. Technol. Rev., 10, 224, https://doi.org/10.1080/21622515.2021.1982023.

Mineralogical and technological characterization of some Mediterranean and European natural pozzolanic materials

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Keywords: geomaterials, natural pozzolanic materials, Phlegraean Fields.

Pozzolanic geomaterials played a fundamental role in ancient roman maritime infrastructures (e.g., Portus Iulius; Alexandria) (Brandon et al., 2008; Jackson et al., 2012) and monumental thermal complexes (e.g. Baia Thermae) (Rispoli et al., 2019). They were the key component to produce highly durable hydraulic mortars which are the reason why these magnificent constructions can still be admired today. The Romans referred to this geomaterial as *pulvis puteolana*, which was sourced in the Phlegraean Fields Volcanic District, corresponding to the unconsolidated facies of the Neapolitan Yellow Tuff (ca. 15 ka) (Rispoli et al., 2024). Nowadays, the term "pozzolan" suits to fine-grained, glassy volcanic ashes and pumice but it extends, also, to commercial products exhibiting pozzolanic activity.

In the construction market, other natural pozzolans are currently available and sold, each characterized by different geological provenance which influences their mineralogical, chemical and technological characteristics. This study investigates mineralogical, chemical and pozzolanic potential of pozzolana strictu sensu from the Phlegraean Fields (Italy) and natural pozzolans from Xylokeratia (Milos, Greece), Gyali (Nisyros, Greece) and the Trass from the Eifel region (Germany).

A detailed multi-analytical approach was employed, integrating observation with Polarized Optical Microscopy (POM), X-Ray Powder Diffraction (XRPD), X-Ray Fluorescence (XRF) and Field Emission Scanning Electron Microscopy coupled with Energy-Dispersive X-Ray Spectroscopy (FESEM-EDS) to obtain a mineralogical, chemical and microtextural characterization. Additionally, technological and physical properties through pozzolanic activity test and laser diffraction particle size analysis were, also, evaluated.

The results provide a preliminary comparative characterization for mediterranean and European volcanic materials, suggesting insights for both industrial suitability and implementing our knowledge on geomaterials and on ancient construction techniques. This research highlights how the detailed characterization of raw geomaterials can contribute to the development of sustainable, high-performance binders for the modern building industry.

Brandon C.J. et al. (2008) - The concrete construction of the Roman harbours of Baiae and Portus Iulius, Italy: The ROMACONS 2006 field season. Int. J. Naut. Archaeol., 37(2), 374-379, https://doi.org/10.1111/j.1095-9270.2008.00191.x.

Jackson M.D. et al. (2012) - Cement microstructures and durability in ancient Roman seawater concretes. In: Valek J. et al. (Eds.), Historic mortars: characterization, assessment and repair, Springer, 49-76, https://doi.org/10.1007/978-94-007-4635-0_5.

Rispoli C. et al. (2019) - The ancient pozzolanic mortars of the Thermal complex of Baia (Campi Flegrei, Italy). J. Cult. Herit., 40, 143-154, https://doi.org/10.1016/j.culher.2019.05.010.

Rispoli C. et al. (2024) - The key to ancient Roman mortars hydraulicity: Ceramic fragments or volcanic materials? A lesson from the Phlegrean archaeological area (southern Italy). Constr. Build. Mater., 411, 134408, https://doi.org/10.1016/j.conbuildmat.2023.134408.

Data-driven assessment of critical raw material distribution in Porto Vesme red muds, Sardinia

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Keywords: critical raw materials, red mud, machine learning.

Red mud, the main residue produced during alumina extraction by the Bayer process, is increasingly considered a potential secondary source of critical raw materials (CRMs), including rare earth elements (REEs), scandium (Sc), and gallium (Ga). However, their recovery requires a better understanding of how these elements are distributed and which mineralogical or geochemical components control their behaviour. In this study, red mud samples from the Porto Vesme disposal site in Sardinia were investigated through an integrated geochemical and data-driven approach. The chemical dataset was treated using centred log-ratio (clr) transformation, correlation analysis, and principal component analysis (PCA) to identify relationships between major oxides and CRMs (Aitchison, 1982). Extreme gradient boosting (XGBoost) models were then applied to test the prediction of Sc, Ga, and REE groups from bulk composition (Chen & Guestrin, 2016). The results suggest that Sc and heavy rare earth elements (HREEs) are mainly associated with Fe-Ti-P-rich components, likely reflecting the role of Fe- and Ti-oxides and phosphate-bearing phases. These elements also showed the best prediction performance. In contrast, light rare earth elements (LREEs) and Ga displayed more complex behaviour. Ga was not clearly controlled by a single major oxide but appeared diffusely distributed within poorly crystalline aluminosilicate and oxide-rich domains. A nonlinear empirical model was therefore tested for Ga and showed good reproducibility on independent samples.

Aitchison J. (1982) - The statistical analysis of compositional data. J. R. Stat. Soc. B, 44(2), 139-160.

Chen T. & Guestrin C. (2016) - XGBoost: A scalable tree boosting system. Proceedings of the 22nd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining, 785-794, https://doi.org/10.1145/2939672.2939785.

Pozzolanic mortars in Roman architecture of the Phlegraean Fields: A review

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Keywords: Roman mortars, pozzolanic material, Phlegraean Fields.

This work synthesizes about twenty years of minero-petrographic research on Roman bedding, coating mortars and *cocciopesto* from key archaeological sites in the Phlegraean Fields area (Naples, Southern Italy), including Baia Thermal Complex, *Piscina Mirabilis*, *Dragonara* Cave, *Temple of Venus*, and Flavian Amphitheatre (Rispoli et al., 2019; 2024; 2025 and references therein; Montesano et al., 2022). Multi-analytical investigations, including Polarized Optical Microscopy (POM), X-Ray Powder Diffraction (XRPD), Scanning Electron Microscopy coupled with Energy Dispersive X-Ray Spectroscopy (SEM-EDS), Thermal Analysis (TA) and Mercury Intrusion Porosimetry (MIP) allowed to investigate and compare mix designs, binder/aggregate textures, mineral assemblages, hydraulicity indices, pore system, and raw materials provenance. Across sites and functions, mortars comprise slaked lime mixed with volcanic aggregate and recycled fired ceramic. Volcanic aggregates are pumice and scoriae from Phlegraean Fields area, with zeolitic minerals (phillipsite-chabazite-analcime) indicative of local sourcing; specific structures show evidence of Vesuvian imports (leucite-bearing scoriae). Binders exhibit micritic/cryptocrystalline texture and lime lumps; secondary phases include C-A-S-H gel and Al-tobermorite, as well as calcite and gypsum. Binder hydraulicity indices (HI) spans from 0.15 to 0.32, confirming the weakly-to-moderately hydraulic behaviour driven by pozzolanic reactions. Furthermore, porosity tests evidenced a high closed porosity of the binder due to the good pozzolanic reactivity and consistent with long-term durability.

This review highlights how Roman strategies - local sourcing, pozzolanic reaction, and the use of *cocciopesto* - anticipate modern principles of durability and sustainability. By integrating geological knowledge with construction practices, Roman builders developed material solutions to achieve long-term structural performance. The review examines the relevance of their technological choices related to Vitruvian recipe, i.e., raw material selection, aggregate proportions, and pozzolanic reaction. It also explores their alignment with contemporary sustainability paradigms, including reuse, local sourcing and optimization of by-products. Finally, the long-term conservation of the mortars, evidenced by their durability also in complex environments, highlights the lasting impact of Roman technology and their relevance for modern engineering, heritage conservation, and sustainable construction.

Rispoli C. et al. (2019) - The ancient pozzolanic mortars of the Thermal Complex of Baia. J. Cult. Herit., 40, 143-154, https://doi.org/10.1016/j.culher.2019.05.010.

Rispoli C. et al. (2024) - The key to ancient Roman mortars hydraulicity: ceramic fragments or volcanic materials? A lesson from the Phlegraean archaeological area (southern Italy). Constr. Build. Mater., 411, 134408, https://doi.org/10.1016/j.conbuildmat.2023.134408.

Rispoli C. et al. (2025) - Innovative Roman building: geomaterials and construction technology of the Temple of Venus (Phlegraean Fields, Italy). Geoheritage, 17, 163, https://doi.org/10.1007/s12371-025-01208-z.

Montesano G. et al. (2022) - Ancient Roman Mortars from Anfiteatro Flavio (Pozzuoli, Southern Italy): A Mineralogical, Petrographic and Chemical Study. Coating, 12(11), 1712, https://doi.org/10.3390/coatings12111712.

Synthetic Mg-carbonates for Co and Ni removal from contaminated waters: Mechanisms and mineralogical evolution

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Keywords: heavy metal, carbonate, ion exchange.

Heavy Metal (HMs) are persistent inorganic pollutants known for their toxicity and bioaccumulation in water and soil, contaminating ecosystems and posing serious health risks (Jaishankar et al., 2014; Razzak et al., 2022). Sustainability and waste management are keywords in the remediation actions of HMs-wastes for EU policy. This study investigates the efficiency of Co and Ni removal from aqueous solutions using synthetic amorphous Mg-carbonates (AMCs), produced via CO_2 mineralization through the reaction between anthropogenic CO_2 and $MgCl_2$ solutions (Ferrini et al., 2009). Batch experiments were carried out at ambient pressure and temperature by contacting AMCs with Co and Ni solutions (ranging 50-1000 mg/L) over interaction times ranging from 20 minutes to 4 weeks. The residual solutions were analysed by ICP-AES to determine removal efficiency (R%), while solid products were characterised by SEM-EDS, XRPD and synchrotron-based analyses to assess morphological, structural and mineralogical evolution.

The results highlight a dual removal mechanism controlled by adsorption at short times and ion exchange at longer interaction times. For Co experiments, adsorption is well described by Langmuir and Temkin models, indicating homogeneous surface sites and monolayer coverage, with strong agreement between experimental data and the Langmuir qmax (185.18 mg/g). Kinetic modelling (PFO-PSO) confirms a transition from rapid surface adsorption at early stages to ion exchange and chemisorption processes at longer contact times and higher Co concentrations. A critical threshold of ~250 mg/L of Co was identified, marking the transition between two distinct kinetic regimes. At lower concentrations (50-150 mg/L), removal is rapid and highly efficient, reaching up to ~99%, with fast dissolution of AMCs and reprecipitation of Co-bearing hydroxy-carbonates within a few hours. At concentrations ≥ 250 mg/L, removal remains significant (up to ~75%) but proceeds more slowly, with incomplete equilibrium within the experimental timeframe. Overall removal efficiencies (70-90%) are comparable or higher than those reported for conventional Co adsorbents. These findings are consistent with SEM, ICP-AES, XRPD and synchrotron data, which show the progressive transformation of Mg-carbonates into Co-carbonates. Thermal (TG/DTG) and desorption analyses will be carried out to evaluate the stability of the solid products and assess HMs retention. Preliminary results for Ni show comparable behaviour, suggesting similar removal mechanisms and reactivity. Overall, these findings demonstrate that AMCs represent an effective, low-energy and scalable solution for HMs removal.

Ferrini V. et al. (2009) - Synthesis of nesquehonite by reaction of gaseous CO_2 with Mg chloride solution: Its potential role in the sequestration of carbon dioxide. J. Hazard. Mater., 168, 832-837, https://doi.org/10.1016/j.jhazmat.2009.02.103.

Jaishankar M. et al. (2014) - Toxicity, mechanism and health effects of some heavy metals, Interdiscip. Toxicol., 7, 60-72, https://doi.org/10.2478/intox-2014-0009.

Razzak S.A. et al. (2022) - A comprehensive review on conventional and biological-driven heavy metals removal from industrial wastewater. Environ. Adv., 7, 100168, https://doi.org/10.1016/j.envadv.2022.100168.

Bridging natural volcanic resources with sustainable geomaterial technologies: The case study of Monte Arci perlitic rhyolites

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Keywords: sustainable geomaterials, expanded perlite, thermal and acoustic insulation.

Perlitic rhyolites from Monte Arci (Sardinia) represent an important natural geomaterial resource characterized by high technological potential for sustainable construction applications. They are ideally suited for lightweight insulating concrete, structural screeds, and pre-cast blocks, as the tougher cell walls resist mechanical crushing during industrial mixing. Secondarily, this structural integrity makes the raw materials highly effective in metallurgy as a foundry slag coagulant. When applied to molten metal, it expands into a tough, viscous crust that acts as a microscopic sponge to trap and catch floating impurities, allowing them to be cleanly and easily skimmed off. This research integrates geological, petrographic, physical and geochemical investigations in order to characterize the main perlitic-obsidian facies and evaluate their performance in low-impact insulating geomaterials and pozzolanic mortars. Detailed field surveys, petrographic observations and mineralogical and geochemical analyses (XRD, SEM-EDS, major and trace elements) allowed the identification and classification of massive perlite, spherulitic perlite, obsidian and perlitized obsidian facies. The experimental results highlight the strong relationship between pristine glass texture, hydration processes and expansion capability, which directly influence the thermal and acoustic insulating properties of the material. Particular attention is devoted to the potential use of expanded perlite as lightweight aggregate in sustainable geomaterials (also for specialized ceramic products) and low-carbon pozzolanic mortars. Experimental data indicate significant advantages in terms of reduced density, improved thermal insulation, acoustic absorption and enhanced durability, combined with low environmental impact and reduced raw material consumption. The natural vitreous composition and high porosity of the expanded material make Monte Arci perlites particularly suitable for energy-efficient building materials and circular economy approaches in the modern construction sector. Ultimately, the research provides new scientific data for the valorization of Sardinian volcanic geomaterials and highlights the strategic role of natural perlites in the development of sustainable insulating products and eco-compatible building materials.

Durability of pozzolanic mortars for the conservation of built heritage: A sustainable perspective grounded in long-lasting interventions

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Keywords: pozzolanic admixtures, durability tests, built heritage conservation.

The conservation of built heritage is traditionally evaluated in terms of compatibility and effectiveness, while sustainability is often confined to the use of low-impact raw materials or the partial replacement of binders with industrial by-products. However, a third and equally relevant dimension is frequently overlooked: the durability of the intervention itself. Long-lasting restorations reduce the need for repeated maintenance works, thereby decreasing material consumption, embodied energy, and the cumulative economic burden borne by public and private stakeholders responsible for heritage conservation. Within a circular-economy framework, designing for durability complements the use of recycled or waste-derived materials, representing an additional and powerful driver of sustainability (Monaco et al., 2021). Inspired from the exceptional hydro-mechanical performance of Roman pozzolanic mortars, this study investigates the incorporation of reactive geomaterials to improve the resilience of restoration formulations. The millennial durability of Vesuvian and Phlegraean heritage structures demonstrates how the interaction between volcanic ash and lime promotes the formation of hydraulic phases (C-A-S-H) with remarkable resistance to environmental degradation (Jackson et al., 2018).

This preliminary study presents a comparative experimental screening of four pozzolanic admixtures with contrasting mineralogical characteristics and reactivity: metakaolin, nano-silica, silica fume, and commercial volcanic ash. These materials were incorporated into a lime-based binder matrix at replacement levels of 5%, 10%, and 20% by weight. Rather than developing a final commercial formulation, the study aims to establish a scientific benchmark for identifying the most effective admixtures to improve the durability of mortars intended for the restoration of built heritage exposed to outdoor conditions. The performance of the mortars was evaluated through two standardized accelerated ageing protocols simulating the main degradation phenomena affecting historic surfaces: (i) freeze-thaw cycling (UNI-EN 1367-1, 2008), used to evaluate the volumetric and thermohaline stresses within the pore network; and (ii) salt-crystallization induced by $MgSO_4$ saturation (UNI-EN 1367-2, 2010), aimed at evaluating resistance to sub-florescence pressure and sulfate attack. Preliminary results highlight correlations between pozzolanic reactivity of the selected geomaterials and the resulting resistance to frost and salt-induced decay. This contribution provides a data-driven methodology for selecting alternative raw materials that simultaneously support waste valorization and long-term structural resilience, ultimately contributing to more sustainable and climate-change conservation strategies for cultural heritage.

Jackson M.D. et al. (2018) - Extreme durability in ancient Roman concretes. Am. Ceram. Soc. Bull., 97(5), 22-28.

Monaco M. et al. (2021) - Sustainable mortars for application in the cultural heritage field. Materials, 14(3), 1-17, https://doi.org/10.3390/ma14030598.

UNI-EN 1367-1 (2008) - Test for thermal and weathering properties of aggregates. Part 1: Determination of resistance to freezing and thawing. European Committee for Standardization, Brussels, 13 pp.

UNI-EN 1367-2 (2010) - Tests for thermal and weathering properties of aggregates. Part 2: Magnesium sulfate test. European Committee for Standardization, Brussels, 15 pp.

Heavy metals behaviour and stabilization in municipal solid waste bottom ashes and thermally treated products: A multi-analytical study by XRPD, XRF, EPMA and SEM

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Keywords: bottom ashes, metal stabilization, glass-ceramics.

Municipal solid waste (MSW) is commonly treated at high temperatures (T), producing granular bottom ash (BA), a chemically complex and heterogeneous material containing silicates, aluminosilicates, as well as metal oxides sulfates, and carbonates (Astrup et al., 2016). Understanding the distribution and fractions of heavy metals in ash is crucial for assessing the potential environmental impact, and in accordance with emerging environmental standards, developing a safe and effective treatment to enable reuse strategies.

For this purpose, BA sourced from the Rimini facility (Stabile et al., 2019) was chemically and mineralogically investigated to identify both amorphous and crystalline components. This was achieved through a combination of electron probe microanalysis with wavelength-dispersive spectroscopy (EPMA-WDS) and X-ray powder diffraction (XRPD). In addition, scanning electron microscopy (SEM), coupled with energy dispersive X-ray spectroscopy (EDX), was employed to examine the morphology and elemental composition of the starting bottom ash samples, revealing that they share several features with silicate rocks but can directly release harmful components.

To overcome these aspects, new glass-ceramics were prepared by reheating BA at variable high-T (1000, 1100, 1200, and 1300°C) and dwell times (t) (2/16 h). At the lowest T and t, several crystalline phases are observed that progressively disappear as the heat-treatment becomes more intense. The measured glass fraction by image analysis increases as both T and t increase. As T shifts from relatively low to high (also as t increases), the produced glass-ceramics change from crystal- to glass-dominated products; silicate crystalline phases inherited from the starting BA progressively dissolve, while spinel-group minerals persist or newly (chromite) crystallise, acting as key hosts for Fe, Cr, and Zn.

Finally, leaching tests demonstrated that thermal treatment is a robust reference framework for stabilising bottom ash residues, allowing for concentrating metallic elements in spinel structures at $T \geq 1200$°C; they are easily separable after comminution and magnetic sorting from the most abundant silicate glassy matrix.

Astrup T. et al. (2016) - Treatment and Reuse of Incineration Bottom Ash. In: Prasad M.N.V. & Shih K. (Eds.), Environmental Materials and Waste, Academic Press, 24, 607-645, https://doi.org/10.1016/B978-0-12-803837-6.00024-X.

Stabile P. et al. (2019) - Vitrification treatment of municipal solid waste bottom ash. Waste Manage. 95, 250-258, https://doi.org/10.1016/j.wasman.2019.06.021.

Natural pozzolans as supplementary cementitious material: An in-depth crystalline and amorphous phase analysis

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Keywords: natural pozzolans, supplementary cementitious materials, cement.

The global standard of the cement industry, Portland cement, is a mixture of clinker, gypsum, and supplementary cementitious materials (SCMs). Clinker is produced by firing a mixture of limestone and clays, where the former decomposes according to the reaction $CaCO_3 \rightarrow CaO + CO_2$. This step alone accounts for about 50% of total CO_2 emission in the cement industry, with 0.87 kg of CO_2 emitted every kilogram of Portland cement produced (Snellings et al., 2012).

A primary strategy to mitigate this issue is to increase the clinker substitution rate with different SCMs. Among these, natural pozzolans (NPs) are particularly promising due to their abundance, low cost, and minimal processing requirements. These materials, typically consisting of low-Ca silicates or aluminosilicates, are able to react with calcium hydroxide produced during clinker hydration and contribute to the enhancement of mechanical performance and durability of the resulting binder, with their reactivity primarily driven by the amorphous phase content and chemical composition (Snellings et al., 2012; 2023).

A range of analytical techniques was applied in this study to determine the composition of the amorphous fraction of five different NPs. Bulk composition was investigated via X-ray fluorescence (XRF). X-ray powder diffraction (XRPD) data were collected, and Rietveld refinement was performed to determine the mineralogical assemblage. The amorphous content was subsequently calculated by rescaling the crystalline phase weight fractions to the known concentration of corundum used as an internal standard (Gualtieri, 2000). To ensure high analytical precision, the exact chemical composition of each crystalline phase was determined through electron microprobe analysis (EMPA). A mass balance was then performed for each NP - accounting for the abundance of the identified phases, their individual compositions, and the loss on ignition (LOI) - thereby accurately deriving the chemical composition of the amorphous fraction (Chancey et al., 2008). Ultimately, these results were compared with NPs properties when used as SCM (via pozzolanic test and mechanical testing).

Chancey R.T. et al. (2008) - Comprehensive phase characterization of crystalline and amorphous phases of a Class F fly ash. Cement Concrete Res., 40, 146-156, https://doi.org/10.1016/j.cemconres.2009.08.029.

Gualtieri A. (2000) - Accuracy of XRPD QPA using the combined Rietveld-RIR method. J. Appl. Crystallogr., 33, 267-278, https://doi.org/10.1107/S002188989901643X.

Snellings R. et al. (2012) - Supplementary cementitious Materials. Rev. Mineral. Geochem., 74, 211-278, https://doi.org/10.2138/rmg.2012.74.6.

Snellings R. et al. (2023) - Future and emerging supplementary cementitious materials. Cement Concrete Res., 171, 107199, https://doi.org/10.1016/j.cemconres.2023.107199.

Sustainable iron removal from Italian red clay using organic acid leaching for ceramic applications

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Keywords: sustainable clay beneficiation, iron reduction, ceramic applications.

Clay materials are widely used in ceramic and industrial applications because of their fine particle size, chemical stability and suitable physical properties (Arslan, 2021). However, the quality and commercial value of clays can be reduced by the presence of iron impurities, which may produce undesirable colors during firing processes (Martínez-Luévanos et al., 2011). In this study, Italian red clay samples were investigated in order to evaluate a sustainable method for iron removal using organic acid leaching for ceramic applications. For the experimental investigation, the $_2C_2O_4{\cdot}2H_2O$) treatment at 100°C for 120 min with stirring at 700 rpm. The XRF analyses carried out before and after leaching showed that citric acid produced only a limited effect on iron removal, while oxalic acid treatment resulted in a significant reduction of iron content. In the Italian red clay iron reduction values of approximately 57%, 56% and 55% were obtained using 0.35 M, 0.5 M and 1 M oxalic acid solutions, respectively. These results corresponding to lower acid concentrations were still able to achieve high iron removal efficiency, suggesting that lower acid consumption may represent a more sustainable and environmentally friendly beneficiation process. After the leaching treatment, both clay samples showed improved suitability for ceramic applications without significant modifications in their main mineralogical composition. Overall, the obtained results demonstrated that organic acid leaching can be considered an effective low-impact approach for improving natural clay resources and increasing their potential use in ceramic industry applications.

Arslan V. (2021) - A study on the dissolution kinetics of iron oxide leaching from clays by oxalic acid. Physicochem. Probl. Mi., 57(3), 97-111, https://doi.org/10.37190/ppmp/135749.

Martínez-Luévanos A. et al. (2011) - Leaching kinetic of iron from low-grade kaolin by oxalic acid solutions. Appl. Clay Sci., 51(4), 473-477, https://doi.org/10.1016/j.clay.2011.01.011.

Shathi A.S. et al. (2024) - Iron removal from red clay using oxalic acid leaching for enhanced ceramic industry applications. Heliyon, 10(19), e38935, https://doi.org/10.1016/j.heliyon.2024.e38935.

Development and rheological assessment of volcanic ash/waste glass alkali-activated inks for Direct Ink Writing

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Keywords: 3D printing, alkali-activated materials, additive manufacturing.

The escalating environmental impact of the construction industry, currently responsible for approximately 7-8% of global anthropogenic emissions, necessitates the urgent development of sustainable material alternatives. In this context, Alkali-Activated Materials (AAMs) have emerged as a promising solution, utilizing industrial by-products and natural wastes to significantly reduce the carbon footprint associated with traditional binders. This study explores the development and rheological characterization of innovative alkali-activated inks derived from binary mixtures of volcanic ash (V) and waste glass (G) activated with potassium hydroxide (KOH) at molarities of 7M and 9M (Zafarana et al., 2025). The primary focus of this research is the application of these materials within the framework of Direct Ink Writing (DIW), an additive manufacturing technique based on the layer-by-layer extrusion of viscous pastes. The success of DIW is strictly dependent on the precise control over the ink's rheological properties, specifically its viscosity, yield stress and thixotropy, to ensure both extrudability and structural stability upon deposition. Comprehensive rheological evaluations, including flow curves, dynamic strain sweeps and recovery tests, were conducted to assess the time-dependent viscoelastic behavior of the inks. Experimental results identified the formulation characterized by a 60:40 V/G ratio and 9M KOH as the most effective for DIW applications. This specific ink demonstrated superior structural rebuilding capabilities and a high storage modulus (G'), indicating an elastic behaviour of the ink with a rapid recovery of the internal bonds between molecules after the application of shear stress during extrusion. To further enhance the printability, the study investigated the addition of 4 wt.% polyethylene glycol (PEG) as a rheology modifier. Preliminary DIW trials established that the inclusion of PEG significantly improved the thixotropic behaviour and minimized material spreading after the deposition process. Future research will focus on further optimizing these formulations to enhance long-term durability and mechanical performance for a wider range of structural applications.

Zafarana S.E. et al. (2025) - Influence of activator molarity and waste-glass-to-volcanic-ash ratios on the microstructure of potassium-based alkali-activated pastes. J. Sol-Gel Sci. Techn., 116, 1614-1629, https://doi.org/10.1007/s10971-025-06937-9.

From geomaterials science to sustainable “zero-waste” manufacturing: Innovation and industrial symbiosis in the ceramic sector

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Keywords: geomaterials, circular economy, ceramic tiles.

Today, the ceramic tile industry must overcome a historical energy-intensive production model linked to natural raw materials toadopt the principles of the circular economy. The transition to “zero-waste” factories and the activation of synergies with other industrial sectors represent mandatory steps to reduce the environmental impact of the sector. Upstream of the process, the optimization of internal resources isalready at a good point: the recovery of washing wastewater and scraps before firing is now a consolidated practice. As for the fired scrap, it has already undergone a vitrification process andrequires crushing and micronization treatments that involve energy consumption in order to be reused in the mix. Another great opportunity is the integration of waste coming from other supply chains, such as fly ash, foundry slag, and recycled glass. The application on an industrial scale faces three major obstacles: the high chemical variability of external waste, the risk of generating harmful gaseous emissions (such as fluorine and chlorine), and the presence of rigid and fragmented “End of Waste” regulations. Finally, the end-of-life management of the product is heavy. At the time of building demolition, tiles end up among generic construction waste. The lack of reverse logistics and selective demolitions prevents high-value recycling, relegating ceramics to secondary use such as road sub-bases. To overcome these limits, systemic models are needed based on scientific analyses of the life cycle (LCA), capable of mapping material flows and demonstrating the real ecological advantages. Only the synergy between materials science and innovation of production processes will be able to transform these environmental constraints into concrete opportunities for growth and competitiveness.

Sustainability in the extractive sector: Application of the circular economy to the reuse of quarry waste

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Keywords: circular economy, extractive waste valorization, quarry waste.

In recent years, increasing awareness of the limited availability of primary raw materials and the need to reduce the environmental impact of anthropogenic activities have placed the circular economy at the core of global development strategies. Within this framework, the extractive sector of ornamental stones represents both a critical issue and a significant opportunity, due to the large volumes of waste generated during quarrying and processing activities, entailing environmental, economic, and social challenges, while also offering potential pathways for resource recovery and valorization.

This study investigates the generation, characterization, and potential valorization of coarse extractive waste materials, focusing on three representative quarrying districts: the Verbano Cusio Ossola (VCO) basin and the Luserna Stone basin (LSB) in NW Italy (focusing on gneisses), and the Süttö limestone quarrying area in Hungary. The main objective is to identify and quantify the coarse waste produced during quarrying and to evaluate their potential reuse as secondary raw materials.

A multidisciplinary methodological approach was adopted, structured in six phases: (i) volumetric estimation of waste deposits using GIS tools and regional datasets; (ii) selection and analysis of pilot sites; (iii) field sampling; (iv) laboratory characterization, including physical, mechanical, chemical, and mineralogical analyses; (v) experimental treatment processes such as grinding, granulometric and magnetic separation at a laboratory scale; (vi) integrated evaluation of reuse feasibility from both technical and economic perspectives with particular attention given to their role as secondary raw materials and their potential transformation into industrial minerals.

The results highlight that a significant portion of extractive waste exhibits suitable properties for reuse in civil engineering. In particular, carbonate wastes from Hungary show promising performance due to their favourable size distribution, mineralogical composition, and physical-technical characteristics. On the other hand, waste materials from quarrying activities in the VCO and LSB districts were investigated as potential secondary raw materials for the ceramic industry. Beneficiation treatments, including grinding, screening, and selective magnetic separation, enabled the production of quartz-feldspar concentrates. The results highlight the potential for upgrading and valorizing these materials as industrial minerals for higher value-added applications, particularly in the ceramic sector.

Ultimately, this research demonstrates that the integration of scientific characterization with an enabling regulatory framework is essential to promote the transition from a linear to a circular model in the extractive industry. The findings support the feasibility of transforming quarry waste into valuable resources, contributing to both environmental sustainability and economic efficiency.

S24.

Understanding Global Mineral Systems: From Metallogenesis to Discovery for a Sustainable Future

CONVENERS & CHAIRPERSONS:

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Formation of hard-rock lithium ores of anatectic origin: Deterministic controls or probabilistic convergence?

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Keywords: lithium, anatectic crust, hierarchy of processes.

In recent years, renewed interest in the anatectic model for lithium (and tin) mineralization has led to a largely deterministic view of ore formation, in which specific geological processes are assumed to lead directly to predictable outcomes under favourable conditions. While this perspective provides clear links between processes and metal enrichment, it may not fully account for the variability observed in natural systems. More generally, deterministic approaches describe system behavior as the direct consequence of defined processes, assuming that similar conditions lead to similar outcomes, whereas in a probabilistic framework, outcomes are not uniquely determined but instead emerge as a range of possible states resulting from the convergence of multiple contributing factors.

In the context of hard-rock Li ores, the mechanisms governing Li release into anatectic melts, and whether crustal melting alone can concentrate Li to ore-grade levels, remain debated. Here we address these questions by compiling the first database of Li concentrations in anatectic melt inclusions (AMIs). Our results show that the optimization of Li release into anatectic melts is controlled by a set of tightly constrained petrological factors, including (i) the breakdown of biotite, (ii) a narrow temperature window of ~750-800°C, (iii) the absence of cordierite, (iv) the absence of an externally-derived aqueous fluid phase, and (v) equilibrium melting conditions that ensure reproducible Li partitioning between residual minerals and melt. These factors lead to Li concentrations that exceed those of S-type granites, overlap with the range of barren pegmatites, and are therefore insufficient to explain the formation of hard-rock Li ores.

We then combine empirical data with models and experimental constraints to evaluate the likelihood of additional processes capable of enhancing system fertility, including extensive fractionation, multi-stage melting, source pre-enrichment, and melting of staurolite or fluorinated biotite. We conclude that the formation of hard-rock Li ores reflects the probabilistic convergence, in space and time, of several necessary yet individually insufficient processes and conditions - a convergence that, although rare, is preferentially achieved during the waning stages of orogenic cycles.

Silurian heritage in black shales of North Gondwana: Mineralogy and geochemistry of V-hosting SE Sardinia "Graptolite" Shales

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Keywords: vanadium, Silurian, black shales.

Vanadium and other metals concentrations in black shales are potentially significant from the economic point of view. During Silurian, Graptolite-hosting black shales, locally containing variable amounts of V and other trace metals (Boni et al., 2025), were deposited under oxic-dysoxic to anoxic conditions in the North Gondwana realm. Due to their high organic carbon content, these black shales are also considered significant hydrocarbon sources in Northern Africa and Middle East (Le Heron et al., 2009).

Sardinia in the Lower Paleozoic represented a terrane within the assemblage of the north Gondwana margin. During Devono-Carboniferous it became part of the Variscan orogen. In Sardinia, Silurian shales crop out mostly in the SE Gerrei Tectonic Unit, which is characterized firstly by up to 500 m of bimodal volcanic rocks of the Mid-Ordovician Volcanic Complex, interpreted as a marker of subduction of the Rheic Ocean. The Silurian sedimentary sequence is represented by the typical Graptolite-bearing Thuringian facies (Llandovery to Ludlow), which represents a condensed succession deposited in a shelf- to deep-(or deeper) shelf setting under oxic-dysoxic to anoxic conditions. The latter environment is supported by pyrite and abundant organic matter.

The Silurian black shales host potentially economic amounts of V (mean 0.70% V_2O_3), associated with several trace elements. Vanadium is mainly contained in rutile, illite and organic matter. There is a positive relationship between TOC (up to 10 wt.%) and V, similarly to other cases of world-known black shales (Brueckner et al., 2025). Anomalous values of Cr, Ba, Cu, Zn, Se, Mo, As, Mo, F, U, and REEs have been detected in the Gerrei shales. Most V and other elements (Cr, mean 0.26% Cr_2O_3; Cu, mean 0.55% CuO; Ti, mean 2.0% TiO_2; Zr, mean 0.31% ZrO_2) are mainly hosted by organic phases. Vanadium is contained also in illite (max content ca. 2.90 wt.% V_2O_3) and rutile (max content ca. 2 wt.% V_2O_3), but the amounts of both minerals are not significant at a bulk scale. The mineralogy is represented by quartz, illite/muscovite, chlorite, rutile, pyrite, and carbonaceous matter, with subordinate amounts of galena, zircon, monazite and apatite. Mineralogical and geochemical analyses have demonstrated that V may have been originally assimilated in organic matter, and then incorporated into phyllosilicates and Ti-oxides. The hyper-enrichment of V and other metallic elements points to seawater and additional sources, possibly benefiting of the heritage from Ordovician magmatic lithologies.

The content in V and other elements in the Silurian black shales is variable throughout SE Sardinia. Maximum concentrations - up to 2,500 ppm V - occur only in some areas of the Gerrei Tectonic Unit. This variability could be due to the different sedimentologic characteristics of the black shales (less organic-rich and more carbonatic in the V-poor successions), as well as to variable metamorphic grades.

Boni M. et al. (2025) - Vanadium and other critical elements in North Gondwana Silurian Black Shales: the SE Sardinia (Italy) case. J. Geochem. Expl., 275, 107760, https://doi.org/10.1016/j.gexplo.2025.107760.

Brueckner S.M. et al. (2025) - Geochemistry and mineralogy of the shale-hosted vanadium Van Property deposit, Mackenzie Mountains, Northwest Territories. Am. Mineral., 110(3), 337-363, https://doi.org/10.2138/am-2024-9359.

Le Heron et al. (2009) - Ancient glaciations and hydrocarbon accumulations in North Africa and the Middle East. Earth-Sci. Rev., 93, 47-76, https://doi.org/10.1016/j.earscirev.2009.02.001.

PANDOR - IncePtion of lithium AND OtheR critical metal deposits: Deciphering signals from source to sink (FIS starting grant - FIS-2023-00244)

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Keywords: critical metals, crustal processes, ore genesis.

Critical metals such as Li, Be, B, Co, Mn, and P are essential for modern technologies and the energy transition, yet the geological processes controlling their distribution, mobility, and concentration within the Earth's crust remain poorly understood, limiting the development of sustainable exploration strategies for critical raw materials. In this framework, the PANDOR project (FIS2 Starting Grant - *"IncePtion of lithium AND OtheR critical metal deposits: deciphering signals from source to sink"*) addresses this challenge through a multidisciplinary investigation of critical metal behavior and mobility across key geological areas in Italy, including the Sardinia Batholith, the Calabro-Peloritani Arc, and the Ivrea-Verbano Zone.

The project integrates fieldwork, petrology, geochemistry, experimental studies, and modeling to examine metal mobility across a range of spatial scales and physicochemical conditions. Diverse crustal lithologies will be investigated through natural samples, experiments, and microstructural analyses under P-T-X-a(H_2O) conditions relevant to high-temperature crustal processes. Particular emphasis is placed on both mineralized and unmineralized rocks, as the comparison between these systems is essential to understanding the processes that control critical metal concentration and why economically significant enrichment occurs only under relatively rare crustal conditions. Through collaborations with the University of Lausanne, the Università degli Studi di Sassari, and the Università di Pavia, PANDOR combines complementary expertise within an integrated petrological framework.

By investigating the pathways linking metal sources to ore formation, the project aims to identify the crustal conditions that favor critical metal enrichment and accumulation. PANDOR will generate a comprehensive dataset on the distribution of critical metals within major Italian crustal sections and provide new insights into high-temperature crustal processes related to metal mobilization. The results will contribute to a broader understanding of critical metal behavior in the continental crust and provide new constraints for future exploration studies.

Unravelling the timing of granite-pegmatite evolution in the Araçuaí Pegmatite District through multi-mineral U-Pb geochronology

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Keywords: lithium, pegmatite, geochronology.

Establishing the timing of crystallization of lithium-caesium-tantalum (LCT) pegmatites is critical for understanding the evolution of hard-rock lithium deposits, but it is commonly hampered by the scarcity or poor preservation of conventional U-Pb chronometers, the high U contents of accessory minerals, and the possible disturbance of isotopic systems during late-magmatic to hydrothermal processes. In these rocks, the key question is therefore not only "how old is the sample?", but "what geological event is each mineral date actually recording?".

Here we present a multi-mineral LA-ICP-MS U-Pb dataset from the Araçuaí Pegmatite District, Brazil, integrating apatite, monazite, cassiterite and zircon from three associated lithologies: spodumene-rich pegmatite, Li-barren pegmatites and two-mica granite. Zircon and monazite from the two-mica granite yield overlapping U-Pb ages of 525.6±11 Ma and 527.2±9.4 Ma, respectively, consistent with crystallization of the granitic body. Monazite from one Li-barren pegmatite gives a comparable age of 524.4±9.6 Ma. In contrast, apatite from all three lithologies defines a younger and internally consistent U-Pb population, with individual ages between 510±17.4 Ma and 473±17.2 Ma and a combined weighted mean of 487.6±10.7 Ma. Cassiterite from spodumene-rich pegmatite yields a U-Pb age of 495±13 Ma. Textural and compositional evidence supports a magmatic origin for the dated cassiterite, suggesting that this age directly constrains the emplacement and crystallization of the Li mineralized pegmatite.

The comparison among chronometers indicates that zircon and monazite record the older crystallization of the granite and at least part of the Li-barren pegmatite system, whereas cassiterite constrains crystallization of the spodumene-rich pegmatite. The younger apatite U-Pb dates, obtained from magmatic apatite in all three lithologies, are interpreted to record closure of the U-Pb system during cooling or late-magmatic thermal evolution, rather than a separate hydrothermal recrystallization event. This younger time window overlaps with regional evidence for late-orogenic high-temperature/low-pressure metamorphism, emplacement of post-collisional I- to A-type granites, and widespread hydrothermal mineralization along the Araçuaí Orogen. In this framework, Li mineralization in the studied spodumene-rich pegmatites, part of Brazil's most important hard-rock lithium district, is placed within the post-collisional thermal-magmatic evolution of the Araçuaí Orogen and appears temporally distinct from the older two-mica S-type granite crystallization stage. Beyond its regional implications, this case study emphasizes that LCT pegmatite geochronology requires integration of analytical reliability, mineral paragenesis, textural-compositional evidence, and the timing of closure or re-opening of the U-Pb system to define what each mineral date is actually recording.

Tracing sulphide formation and fluid-rock interaction in ophiolite-hosted VMS deposits using Fe isotopes

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Keywords: VMS, CRMs, Fe Isotopes.

Understanding ore-forming processes in Volcanic-hosted Massive Sulphide (VMS) deposits is essential for improving genetic models and for assessing the mineral potential of "fossil" and modern seafloor environments.

VMS deposits represent one of the most significant sources of base metals, playing a strategic role in Zn supply and making a significant contribution to Cu production. Here, we investigate the Fe isotopic composition of Cu-Zn VMS deposits hosted in the Ligurian Ophiolite outcropping in Tuscany (Italy), with the final goal to constrain sulphide precipitation mechanism and fluid-rock interaction during ore formation. Fe isotope compositions were determined for primary stockwork assemblages (chalcopyrite, pyrite, pyrrhotite) as well as for reworked nodular ores dominated by Cu-sulphides (chalcopyrite, bornite, chalcocite) using High-Resolution MC-ICP-MS after chromatographic Fe separation (Di Giuseppe et al., 2025).

Preliminary results show negative δ^{56}Fe values (-0.73 to -0.24‰), comparable to those reported for Cu-sulphide from present-day slow spreading mid-ocean ridge systems. These data are used to assess whether the reworked assemblage (bornite-chalcocite) formed under the same physico-chemical conditions as the primary assemblage (chalcopyrite-pyrite-pyrrhotite), or it may record distinct stages of sulphide formation linked to hydrothermal fluid evolution, with particular emphasis on mixing between hydrothermal fluids and seawater.

Such processes are critical in VMS systems, as they can lead to relative Cu enrichment, up to a factor of ~2 in the reworked assemblage, highlighting their relevance to critical metal supply in the context of the energy transition.

These results highlight the potential of Fe isotopes as tracers of ore-forming processes in ophiolite-hosted VMS deposits and provide new insights into the links between "fossil" hydrothermal systems and active seafloor mineralisation.

Di Giuseppe P. et al. (2025) - Iron Isotope Ratios of IAEA B5 Basalt and Whole-Rock Reference Materials (JB-2, BHVO-2, AGV-1, BE-N and RGM-1) Determined by Multi-Collector Inductively Coupled Plasma-Mass Spectrometry. Geostand. Geoanal. Res., 49, 901-914, https://doi.org/10.1111/ggr.70017.

Structural controls on productive gem-bearing, LCT pegmatites in Minas Gerais (Brazil)

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Keywords: LCT pegmatites, gem tourmaline, tectonic control.

The pegmatite district of Minas Gerais (Brazil) hosts some of the world's most productive gem-bearing pegmatites, historically exploited for mica, gemstones, columbite-tantalite and beryl. Despite more than 80 years of mining activity and extensive studies since the pioneering USGS-DNPM investigations of the 1940s, the structural and mechanical processes controlling the localization of productive pocket-rich volumes remain poorly constrained. Most exploration activities still rely largely on empirical approaches and artisanal knowledge, whereas predictive geological models for gem-bearing pegmatites are still limited.

This contribution presents a district-scale reinterpretation of the Minas Gerais pegmatite field based on the integration of historical geological reports, recent underground observations, structural mapping and comparative analysis of the main productive pegmatite systems, including Golconda, Pederneira, Cruzeiro and Aricanga. The study highlights the existence of two main end-member pegmatite geometries: (i) sub-horizontal, sub-concordant pegmatite sheets emplaced within micaschists, and (ii) sub-vertical discordant pegmatite dykes hosted by quartzites. The contrasting geometries are interpreted as the result of different rheological behaviour of the host rocks during regional deformation within the Araçuaí Orogen.

Three main emplacement processes are recognized: (1) permissive emplacement producing discordant pegmatite dykes in quartzites; (2) forceful emplacement generating large sub-concordant pegmatite sheets in micaschists; and (3) localized permissive emplacement within dilational jogs, tension gashes, folds and structural bridges developed along the larger sheet intrusions. Structural observations indicate that the most productive gem-bearing pockets are systematically associated with these localized dilational domains rather than with the largest pegmatite bodies themselves.

The proposed model suggests that transient underpressure conditions generated during rapid opening of dilational structures played a key role in promoting extreme magmatic-hydrothermal differentiation, pocket formation and gem crystallization. In contrast, many large pegmatite bodies emplaced predominantly under forceful conditions remained barren despite their size and advanced internal differentiation. Consequently, pegmatite "size" alone is not a reliable exploration criterion; the structural mechanisms responsible for magma emplacement and pocket generation are likely more important controls on productivity.

The reinterpretation of the Minas Gerais district also highlights the significant exploration potential of concealed pegmatites beneath lateritic covers and along poorly explored lateral and down-dip extensions of known systems. The proposed structural-mechanical framework may therefore provide new predictive criteria for targeting productive gem-bearing pegmatites in Brazil and comparable Neoproterozoic pegmatite provinces worldwide.

Bismuth melts as gold scavengers in a shallow crustal magmatic-hydrothermal system: The Punta del Fenaio Au-Bi-Te occurrence (Giglio Island, Tuscany)

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Keywords: gold-bismuth ore, bismuth melt, crustal magmatism.

An exceptionally high-grade, yet volumetrically restricted, Au-Bi-Te occurrence has been identified at Punta del Fenaio (Giglio Island, Tuscany), within a hydrothermally altered contact aureole composed of hornfels, skarns and microgranite dykes located near the roof contact of the Early Pliocene Giglio monzogranite pluton (Dini & Orlandi, 2010). Hydrothermal alteration generated a quartz-adularia stockwork affecting a volume of several tens of cubic metres. Native bismuth masses and disseminations, locally reaching fist-sized aggregates, occur together with visible gold, bismuthinite and minor Bi-Te-S phases within cavities and dilational jogs restricted to a very small portion of the stockwork ([3]). Gold occurs as visible grains up to 1 mm in size, commonly concentrated along the rims of native bismuth and associated with late bismuthinite crystallization.

Detailed geochemical sampling reveals an extreme "nugget effect", with gold concentrations reaching up to 7600 µg/g within the Bi-rich dilational jogs and rapidly decreasing to negligible values in the surrounding quartz-adularia veins. The ore is characterized by remarkably consistent Bi/Au, Au/Ag and Bi/S ratios despite the strong local metal enrichment. The spatial distribution of Au and Bi, the ore textures, and the metal ratios strongly support interaction between hydrothermal fluids responsible for the quartz-adularia alteration and an immiscible Bi-rich melt acting as an efficient collector for precious metals. Density contrast and immiscibility between the hydrothermal fluid and the Bi melt likely promoted gravitational accumulation of the latter within larger interconnected cavities and structural traps developed along the main dilational jogs.

This interpretation is consistent with the "liquid bismuth collector model" proposed by Douglas et al. (2000), the low melting temperature of Bi (271°C), and the high partitioning capacity of molten bismuth for gold (up to 19 mol% Au). The observed paragenesis and textures suggest that the Bi-Au-S-(Te) melt remained molten after the formation of the main hydrothermal assemblage and crystallized only during late cooling stages. The Punta del Fenaio occurrence therefore represents a rare natural example of extreme local Au upgrading produced by Bi melt scavenging in a shallow crustal magmatic-hydrothermal system, possibly in the absence of a pre-existing gold ore.

Finally, the geochemical features of this unusual Au-Bi-Te occurrence are compared with Au and Bi concentrations measured in granites, leucogranites, aplites and pegmatites from the wider Tuscan Magmatic Province (Miocene-Quaternary). Preliminary comparisons suggest progressive enrichment of Au and Bi during magmatic differentiation and support a broader genetic relationship between crustal magmatism, evolved felsic melts, metasomatism in contact aureole and late hydrothermal Au-Bi mineralization in southern Tuscany.

Dini A. & Orlandi P. (2010) - A new gold-bismuth occurrence at Punta del Fenaio (Giglio Island, Tuscany). Atti Soc. Tosc. Sci. Nat., Mem., Serie A, 115, 73-82, https://doi.org/10.2424/ASTSN.M.2010.08.

Douglas N. et al. (2000) - The liquid bismuth collector model: an alternative gold deposition mechanism. In: Skilbeck C.G. & Hubble T.C.T. (Eds.), Understanding planet Earth; searching for a sustainable future; on the starting blocks of the third millennium, Abstracts of the 15th Australian Geological Convention, 59, 135.

What drives lithium enrichment in anatectic pegmatites? Evidence from the Adamello contact aureole, Italian Alps

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Keywords: pegmatites, lithium, anatexis.

The mechanisms controlling lithium enrichment during crustal anatexis remain debated, particularly whether economic Li concentrations in LCT pegmatites require inherently enriched sources or multi-stage processes. We investigate compositionally zoned LCT pegmatites within the thermal aureole of the Adamello batholith (Italian Alps), where migmatites and pegmatites exhibit a well-constrained spatial and genetic relationship. Field, petrographic, and new Sr-Nd isotopic data demonstrate that the pegmatites formed by partial melting of Permian metasedimentary rocks (Verrucano Lombardo Formation). We combine phase equilibria and trace element modeling to assess the behavior of Li, Rb, Sr, and Ba during anatexis, and to evaluate the role of cordierite - a phase whose influence on Li partitioning remains contentious. Our results show that cordierite stability, controlled by protolith Fe/Mg ratio, temperature, and water availability, strongly limits Li enrichment in anatectic melts. Under conditions that suppress cordierite crystallization (water content < 2 wt.%, temperature < 750°C), melts achieve Li concentrations up to five times that of the protolith (~320 ppm), closely matching the average composition of the Adamello LCT pegmatites. However, the formation of high-Li miarolitic cores (>1100 ppm Li) requires internal differentiation. This study demonstrates that moderately Li-enriched melts can be generated from common metasedimentary protoliths without multiple melting or large-scale fractionation, but that extreme enrichment to ore grades demands either Li-rich sources or subsequent internal differentiation.

Metallogenesis of As-Sb epithermal deposit of Matra (Corsica, France)

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Keywords: As-Sb ore deposit, epithermal deposit, Alpine Corsica.

The high-grade arsenic orebody that was mined until 1946 at Matra, eastern Corsica (France), made it one of the most-important mines in the country. Despite the notoriety of the mining site, the scientific investigation of the deposit has been developed only in recent times through a multidisciplinary approach that combines structural analysis and mineralogical and geochemical analytical techniques (e.g., Filimon et al., 2025; 2026). Field observations and selective sampling were performed on the host rocks, gossan outcrops, and main structures that lead ore-forming fluids. The As-Sb-Tl-Ni anomalies in bulk ore rock samples are reflected in pyrite and stibnite trace elements (Filimon et al., 2025). The mineral assemblage shows a first Fe-(Zn) stage that is crosscut by a widely developed As-Sb-Fe stage characterized by a dolomite gangue, and minor quartz. Changes in oxidation conditions are evident during the evolution of a multi-stage mineralizing system. The study of ore-forming fluid confirms a multistage event with a wide range of temperatures and salinities of the mineralizing hydrothermal fluids. Boiling conditions during the first stage are suggested by fluid inclusion study and constrains the pressure of formation of mineralization in an epithermal setting (~500-800 m). In contrast, the decrease in temperature is the main mechanism of ore precipitation. Fluid origins were determined using the results of gas analyses in fluid inclusions and C-O stable isotopes. The ratios of gas species highlight mixing of fluids between deep magmatic (mantle) and meteoric sources (Filimon et al., 2026). Moreover, C-O stable isotopes on dolomite support a mantle origin for CO_2 that has a similar signature to other mineralizations in the peri-Tyrrhenian area. The timing of mineralization in the Matra mine is constrained by U-Pb dating of dolomite gangue, which yielded an age of ~9.81 Ma. This established that mineralization occurred within the brittle post-Alpine orogenesis event (Di Rosa et al., 2025), as suggested by the field-based structural analysis. At a regional scale during the Miocene, the Tyrrhenian area experienced crustal thinning and an extensional geological setting related to the emplacement of Tuscany magmatic rocks, formation of extensional faults, and active geothermal fields. As there are Sb±As±Au mineralizations in the Tuscany region, results of the current study allow a direct comparison of mineralization on both sides of the Tyrrhenian Sea.

Di Rosa M. et al. (2025) - U-Pb dating of carbonate gangue with associated As-Sb mineralization in the Matra Fault (Alpine Corsica, France): Constraints for the rifting stage in the Tyrrhenian Sea. J. Geodyn., 165, 102110, https://doi.org/10.1016/j.jog.2025.102110.

Filimon D.I. et al. (2025) - Ore Genesis Based on Microtextural and Geochemical Evidence from the Hydrothermal As-Sb Mineralization of the Matra Deposit (Alpine Corsica, France). Minerals, 15(8), 814, https://doi.org/10.3390/min15080814.

Filimon D.I. et al. (2026) - Fluid sources and evolution in the As (±Sb) epithermal Matra deposit (Alpine Corsica, France): Constraints from fluid inclusions, gas compositions, and stable isotopes (C-O). J. Geochem. Explor., 283, 107996, https://doi.org/10.1016/j.gexplo.2026.107996.

Precious (Au, Ag) and critical (Te, Se) elements enrichment in epithermal deposits of the Chatkal-Kurama region, Uzbekistan

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Keywords: Au-Ag-epithermal deposits, critical elements, Uzbekistan.

Epithermal deposits show complex genetical features that control their metal endowment, which in turn is reflected on their mineralogical assemblages. The epithermal deposits in the Chatkal-Kurama region, in Uzbekistan, are characterized by elevated concentrations of precious, strategic and critical elements like Au, Ag, Te, Se, Cu, Sb, and Bi. Detailed mineralogical, petrographic and geochemical studies on two epithermal deposits, Kochbulak and Kyzylalmasay, reveal metallogenic processes involving different mechanisms of metals enrichment (Filimon et al., 2026). The superposition of successive hydrothermal pulses lead to repeated episodes of metals precipitation, thus resulting in the formation of bonanza-grade Au veins. Furthermore, the strong geochemical affinity of Te and Se with Au and Ag is reflected in a complex mineralogical assemblage composed of Au±Ag-Te- and Ag-Se-bearing phases, which acted as Au-scavengers from the Au-undersaturated ore-forming fluid (Cook et al., 2009). Our results provide new insights into the genesis of the gold-(silver)-telluride-(selenide) deposits in Chatkal-Kurama and note the potential for Te and Se to be used as path-finder elements towards high-grade Au-mineralised domains, thus emerging as useful tools for mineral exploration.

Cook N.J. et al. (2009) - Understanding gold-(silver)-telluride-(selenide) mineral deposits. Episodes, 32(4), 249-263, https://doi.org/10.18814/epiiugs/2009/v32i4/002.

Filimon D.I. et al. (2026) - Ore mineral assemblage, pyrite geochemistry and fluid inclusion data track multi-stage metallogenesis in the Kochbulak Au-Ag-Te deposit (Chatkal-Kurama, Uzbekistan). J. Geochem. Expl., 287, 108097, https://doi.org/10.1016/j.gexplo.2026.108097.

Deep roots of metallogenesis

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Keywords: exploration targeting, metallogenic continuum, mantle metasomatism.

The inventory of strategic metals required to support the development of new technological advances will evolve at unprecedented rates. The list of commodities that are essential to feed the progress of humankind will require exploitation of presently unknown types of ore deposits. However, current exploration strategies are largely based on analogue models, which are clearly not appropriate for finding ore deposit types that have not been encountered yet.

Models underpinning mineral exploration strategies should not be analogue-based, but rather process-based. In this framework, ore deposits may be considered part of a continuum of magmatism and hydrothermal evolution from mantle to upper crust, where processes have continually built up to develop mineralising systems in a sequential and predictable manner. Unveiling commonalities among "deposit types", rather than focussing on their obvious differences, may enhance predictive targeting capability at multiple scales. To unveil the cryptic links that connect different mineral systems, it is necessary to investigate the deep roots of metallogenesis.

Recent work experimentally re-evaluated the role of exotic fluids and melts in triggering metallogenesis in the metasomatised lithospheric mantle. Based on the integration of new isotopic tracers and minero-chemical data, Demmer et al. (2026) put forward the exciting hypothesis that orthomagmatic sulfide mineralisation and orogenic gold systems may tap similar mantle sources and form synchronously in Archean cratons. The work of Cherdantseva et al. (2024) unveiled the role of carbonate melts in the transport and concentration of base and precious metals across the lithosphere, highlighting the role of the lower continental crust as a key metallogenic gateway that is common to a broad range of mineral systems.

The key message is that volatiles may play important physical role in creating mantle fertile sources and in transporting metals from mantle into and across the continental crust. Explorers should map "early fertility" in the lithosphere and understand energy reactivation drivers in space and time. In the future, new search space for commodities will be created through process-based research, which will focus on solving existing knowledge gaps in our understanding of the physical processes that control fluid flux at various pressure-temperature conditions.

Cherdantseva M. et al. (2024) - Carbonated magmatic sulfide systems: Still or sparkling? Sci. Adv., 10, eadl3127, https://doi.org/10.1126/sciadv.adl3127.

Demmer M. et al. (2026) - Unveiling the metallogenic continuum of an Archean craton. Nat. Commun., 17, 1798, https://doi.org/10.1038/s41467-026-68507-z.

Ezad I.S. et al. (2024) - Incipient carbonate melting drives metal and sulfur mobilization in the mantle. Sci. Adv., 10, eadk5979, https://doi.org/10.1126/sciadv.adk5979.

Fault-controlled Fe-Cu-Pb-Zn ore mineralization at Fenice Capanne (southern Tuscany, Italy)

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Keywords: faults, fluid inclusions, base metal mineralization.

The Fenice Capanne mining area, part of the Colline Metallifere mining district (southern Tuscany, Italy), represents a structurally controlled Fe-Cu-Pb-Zn hydrothermal system associated with the extensive hydrothermal activity linked to the Neogene-Quaternary post-orogenic magmatism of the Tuscan Magmatic Province. This study integrates structural analysis, textural characterization, mineral chemistry, fluid inclusion microthermometry, stable isotope data, and mass transfer calculations to constrain fluid evolution and the processes controlling base-metal mineralization. Mineralization is predominantly controlled by high-angle extensional faults striking NW-SE, associated with syntectonic quartz-sulfide veins. Hydrothermal breccias and banded mineralization record repeated cycles of fracture opening and mineral precipitation. Fluid inclusion data from syngenetic quartz yield homogenization temperatures between 177 and 284°C and salinities ranging from 0 to 19.3 wt.% NaCl eq., consistent with values reported for epithermal base-metal and polymetallic hydrothermal systems of Tuscany. Stable isotope and fluid inclusion data suggest mixing between saline hydrothermal fluids, likely of magmatic affinity, and low-salinity meteoric-derived fluids. The combined structural and geochemical dataset indicates that fault reactivation transiently enhanced permeability within the low-permeability sedimentary-derived host rock through fracturing, generating localized pathways for episodic fluid circulation. Local boiling associated with pressure drops during hydraulic fracturing further modified fluid composition and redox conditions. These processes triggered destabilization of metal chloride complexes and episodic sulfide precipitation. The Fenice Capanne system therefore highlights how fault-controlled permeability evolution within sedimentary covers can regulate fluid circulation, metal transport, and base-metal mineralization in shallow hydrothermal systems.

The possible role of the late-Variscan, deep-seated magmatism as a trigger for barium metallogeny across the Southern Alpine domain in Northern Italy

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Keywords: barium, carbonates, Ivrea-Verbano-Zone.

The post-Variscan, rift-related upper crustal sequences of the Southern Alpine domain from Lombardy to the Balkans contain remarkable amounts of baryte associated with the mid-late Triassic regional-scale stratiform and stratabound siderite and Mississippi Valley-type Zn-Pb ore districts and as large hydrothermal, often fluorite-rich vein swarms crosscutting Variscan basement and volcano-sedimentary units not younger than late Triassic. According to the Mineral System Concept, what might be possible souce(s) of Ba supporting such large enrichment in regional-scale ore districts? K-feldspars and muscovite are generally considered sources for Ba. Additional hints come from the Ivrea-Verbano Zone (IVZ) where the exposed lower crustal section of the Southern Alpine basement (Kinzigite Series, KS) bears the effects of late-post-Variscan mantle-related magma underplating causing the emplacement of the large IVZ Layered Complex. The volcano-sedimentary KS shows extensive evidences of original submarine exhalative activity, like amphibolite-hosted sulfide ores, Mn-rich meta-cherts, sulfide-rich calcsilicates as well as widespread Ba-rich marble units (with Ba-K feldspars and baryte), the latter sofar documented for over 20 km between Strona and Ossola valleys. Several carbonatite-like bodies were recently reported in the central and northern sectors of the IVZ: for them a crustal, anatectic rather than mantle origin has been proposed based on geochemical markers. Also the granulite-facies basement in the southern IVZ sector hosts calcite-rich “marble” units with minor Fe-Mn-rich olivine, phlogopite, locally sulfide-bearing cumulitic magnetite layers (historically mined for high-quality Fe ores) and metasomatic antiskarn aureoles. In spite of notable petrographic and geochemical similarities to carbonatites, their radiogenic isotopic signatures and U-Pb ages at 254.3±1.4 Ma of antiskarn titanite suggest a crustal, anatectic origin compatible with the slow cooling history of the nearby IVZ Layered Complex. These southern IVZ anatectic carbonatites stand out for their remarkable Ba-rich character, expressed locally as Ba-Ca + Ba-Mg carbonate facies and especially as overall Ba-bearing calcite rich in sub-m inclusions of Ba-Ca/Mg carbonates and baryte. Compared to the northern Ba marbles, Ba-bearing silicates appear to be subordinate, as Ba-rich micas and, only in antiskarn aureoles, as Ba-K feldspars. These features may arise a few questions. Could the occurrence of these Ba-rich anatectic marbles suggest about a possible southward extension of the IVZ Ba-rich marble horizons? If so, the potential of the deep crustal basement as Ba source would be remarkable. And could anatexis have a possible effect in turning the original marble Ba mineralogy into more easily soluble assemblages for Ba remobilization during the numerous subsequent large-scale events (magmatic, tectonic, hydrothermal) affecting the Southern Alpine terranes during the post-Variscan times?

Lithium clay mineralization in the McDermitt volcano-sedimentary deposit, Oregon, USA

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Keywords: lithium, volcano-sedimentary, hectorite.

The McDermitt caldera (USA) hosts the world's largest volcano-sedimentary (VS) lithium resource and represents the archetypal example of clay-type Li mineralization developed within intracaldera lacustrine basins. This study presents an integrated geological, mineralogical, geochemical, and isotopic investigation of the McDermitt deposit aimed at constraining the processes responsible for Li enrichment in clay-type VS systems. Lithium mineralization occurs within stratiform lacustrine units composed of hectorite-bearing claystones interbedded with siliceous-carbonate beds, altered ash-fall horizons, and zeolitized tuffaceous rocks. Petrographic observations combined with X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), and whole-rock geochemistry demonstrate that Li enrichment is primarily controlled by the formation of Mg-Li smectites (hectorite) associated with hydrous silica and secondary K-feldspar during devitrification of volcanic glass under near-neutral to slightly alkaline conditions.

Bulk-rock and clay-separate geochemistry indicate that Li is predominantly structurally incorporated within the octahedral sheets of hectorite through $Li^{+} \leftrightarrows Mg^{2+}$ substitution rather than adsorbed in interlayer sites. Variations in Li/Mg ratios correlate with changes in the d_{060} spacing of trioctahedral smectites, providing a mineral-chemical proxy for Li incorporation in hectorite-rich assemblages. Textural and paragenetic relationships indicate that Li-smectite formation occurred through a combination of direct precipitation from Li-bearing lake waters and solid-state transformation of volcanic ash and glass mediated by hydrous silica gels generated during devitrification processes.

Paragenetic assemblages include hectorite, calcite, pyrite, analcime, clinoptilolite, hydrous silica, and authigenic K-feldspar, with evidence for microbial activity and reducing lacustrine conditions during mineralization. Chlorite geothermometry from altered volcanic basement rocks yields average temperatures of ~133°C, while hydrogen isotope modelling of Li-smectites indicates equilibrium with fluids having δD values around -107‰, consistent with heated meteoric waters circulating in a geothermal environment associated with caldera cooling, syn-diagenetic volcanism, and circulation of shallow geothermal fluids.

Comparison with the nearby Thacker Pass deposit demonstrates that, unlike Thacker Pass, illitization of smectite did not occur at McDermitt despite comparable thermal conditions. Isotopic modelling and mass-balance calculations suggest that the absence of Li-illite reflects lower Li availability and differences in fluid pH on a caldera scale rather than lower temperatures or fundamentally different fluid reservoirs. These results indicate that geothermal circulation, devitrification of Li-rich volcanic material, and caldera-scale fluid evolution collectively controlled Li enrichment within the McDermitt caldera.

Lithium origin and distribution in sedimentary systems of the Northern Apennines (Italy)

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Keywords: lithium, unconventional resource, Northern Apennines.

Lithium is a strategic element for the global energy transition. In the European Union, its demand is projected to increase up to twelvefold by 2030 due to the rapid expansion of battery production for electric mobility, highlighting the urgency of identifying alternative and sustainable Li sources beyond the imports from conventional hard-rock and salar deposits mainly from Australia, South America and China. Among these, Li-rich fluids circulating in sedimentary basins represent a promising yet still poorly constrained unconventional resource.

This study investigates the origin, distribution, and mobilization mechanisms of lithium within Alpine-cycle sedimentary systems of the Northern Apennines (Italy), where Li-rich groundwaters (up to 164 mg/L; Boschetti et al., 2011) occur in association with thick pelitic-carbonate successions. An integrated geochemical, mineralogical, and multi-isotope approach was applied to investigate sedimentary rocks and waters (springs, SPA wells, mud volcano fluids), providing the first comprehensive Li dataset for this region. Major and trace elements, XRD, SEM-EDS, EPMA, and LA-ICP-MS analyses were combined with $^{87}Sr/^{86}Sr$, $\delta^{11}B$, and $\delta^{7}Li$ isotopes and laboratory leaching experiments to constrain Li sources and water-rock interaction processes.

Data infer to the Cretaceous pelitic formations of the Subligurian and External Ligurian domains the highest Li content (up to 263 mg/kg), with phyllosilicate-rich layers over 500 mg Li/kg. Illite results as the major Li-hosting phase, with systematic associations of Li with B, K, Al, Fe, Rb, and Cs as from micro-scale chemical and mineralogical analyses indicate. Contribution from Permian volcanic of the Eastern Alps, as source of Li-rich detrital material to oceanic basins along the western margin of the Adria plate during the Cretaceous is suggested by strontium isotopes.

Groundwaters circulating in the investigated system display relevant Li contents up to 55 mg/L. Isotopic compositions of B, Sr, and Li are consistent with release from clay minerals during water-rock interaction, with preferential mobilization of ^{7}Li. Leaching experiments reveal rapid Li transfer from clays to water, supporting a model of progressive enrichment of deep groundwaters along the flow path, with minor seawater-derived contributions.

Overall, our results suggest the significant role of clay-rich formations of the Northern Apennines as effective Li reservoirs, supplying lithium to basin groundwaters. These findings highlight the potential of this region as target for sustainable lithium recovery, including Direct Lithium Extraction (DLE) technologies, contributing to European strategies for resource diversification and supply security under the Critical Raw Materials Act and the Italian National Exploration Programme (2025).

Boschetti T. et al. (2011) - Salt Waters of the Northern Apennine Foredeep Basin (Italy): Origin and Evolution. Aquat. Geochem, 17, 71-108, https://doi.org/10.1007/s10498-010-9107-y.

U-Pb dating of carbonate gangues of Southwest Sardinia ores (Italy)

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Keywords: U-Pb dating, ore deposits, Sardinia.

Sardinia is the region of Italy with the most significant metal endowment, being characterized by ore deposits spanning in age from Paleozoic to Cenozoic (Naitza et al., 2024). The basement-hosted Zn-Pb > Ba ores in SW Sardinia have been traditionally subdivided in pre-Variscan and post-Variscan deposits, based solely on the presence or absence of Variscan deformation (Boni et al., 1996). The pre-Variscan ores include sedimentary exhalative (SEDEX), and Mississippi Valley (MVT)/Irish-type deposits (Boni et al., 1996). The post-Variscan ores can be subdivided into vein- and palaeokarst-types, both hosted by Lower Paleozoic rocks (Boni et al., 1996).

The present research aims at identifying distinct metallogenic stages that occurred in SW Sardinia associated with both pre-Variscan and post-Variscan ore deposits. To this end, after detailed petrographic investigation the carbonate gangue of samples from the various mineralization types were analyzed for U-Pb geochronology.

Carbonate gangues of both pre-Variscan SEDEX-type and MVT/Irish-type ores are characterized by Cambrian-Ordovician ages. This indicates that the U-Pb system in gangue carbonate was not significantly affected by the Variscan orogeny in the study area. The cements characterized by post-Variscan ages are well correlated with significant tectonic events that have been rarely recorded across Sardinia. Overall, these new U-Pb ages indicate that gangue carbonates in Southwest Sardinia track a series of mineralization intervals that started during the Cambrian and episodically characterized the area until the Late Cretaceous, during a total timespan of over 400 My. The absolute ages allow to correlate in extreme detail the mineralization processes to major geological events affecting the Variscan basement, thus confirming that large scale ore formation of SW Sardinia is primarily controlled by global tectonic events.

Boni M. et al. (1996) - Base metal ores in the lower Palaeozoic of South-Western Sardinia. In: Carbonate-Hosted Lead-Zinc Deposits: 75th Anniversary Volume, Sangster D.F. et al. (Eds.), Society of Economic Geologists, 4, 18-28, https://doi.org/10.5382/SP.04.03.

Naitza S. et al. (2024) - Post-collisional tectonomagmatic evolution, crustal reworking and ore genesis along a section of the Southern Variscan Belt: the Variscan mineral system of Sardinia (Italy). Minerals, 14(1), 65, https://doi.org/10.3390/min14010065.

Mineralogical and geochemical studies of pegmatites from Ladakh Batholith: Implications for melt evolution and critical metal exploration in Trans-Himalaya

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WITHDRAWN

Vanadium and other metallic elements in Silurian Black Shale of Morocco

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Keywords: vanadium, Silurian, Morocco.

Vanadium is increasingly regarded as a critical metal, owing to its strategic importance in low-carbon energy technologies, particularly in vanadium redox flow batteries. Black shale-hosted deposits represent nearly 80% of the global V resources, although less than 2% are economically viable. Several types of V-containing black shales are characterized by high TOC and an enrichment in metals, including Ni, Se, Mo, Ag, Zn, Cu, Pb, V, As, Sb, Au, P, Ba and U ± PGE. Due to their elevated TOC, many of them are also considered important hydrocarbon source rocks.

During Silurian, widespread anoxic basins developed along the North Gondwana margin, leading to the deposition of graptolite-bearing black shale successions enriched in V and associated metals. These successions extend from NW Africa to S Europe and the Middle East. Lower Rhuddanian black shales are recorded in Morocco, where TOC locally reaches up to 10.5%. This study integrates whole-rock geochemical and mineralogical data on Silurian black shales from several Moroccan districts, to constrain their major and trace element compositions, as well as to V deportment. The results are compared with other Silurian black shale successions along Gondwana margin.

The Oumjrane Cu mine is located in the eastern Anti-Atlas (Drâa-Tafilalet). Mineralization occurs as a network of hydrothermal veins hosted within Ordovician-Silurian sandstone and organic-rich black shales. The Silurian succession comprises shallow-marine, graptolite-bearing shales, interbedded with sandstone, siltstone, carbonate and argillite layers (Idbaroud et al., 2026). The district hosts a polymetallic mineralization formed during two distinct mineralizing events (Cu ores at 175.6 ± 1.1 Ma; Pb-Zn ores at 151.3 ± 3.1 Ma) (Idbaroud et al., 2026).

The El Hammam (Western Meseta) REE-rich fluorite ± barite ± sulphides vein system, is hosted in sedimentary and volcanic rocks of Cambrian-Ordovician to late Carboniferous. The polymetallic ores at Tighza (Central Meseta) are considered magmatic-hydrothermal, hosted in Palaeozoic rocks surrounding late-Variscan granites. In both cases the Silurian sequence consists of a shallow marine succession dominated by organic-rich graptolite-bearing black shales (Bouabdellah et al., 2016).

Whole-rock geochemical analyses of black shales indicate variable V concentrations ranging from 160 to 860 ppm and TOC up to 3 wt.%. Compared with coeval Silurian successions developed along the North Gondwana margin, the Moroccan black shales display elevated concentrations of several trace elements, including Sb, Ba, Se, Mo, As, Mo, F, Cu, Ni, U and REEs (average ~330 ppm including Y and Sc). Mineralogical investigation reveals a mineral assemblage dominated by quartz, illite/muscovite, chlorite, pyrite, Fe-Mg-Mn carbonates and carbonaceous matter, with subordinate feldspar, galena, chalcopyrite, gypsum, zircon, monazite and apatite. Vanadium is mainly hosted in rutile, with concentrations reaching up to ~2 wt.% V_2O_3.

Bouabdellah M. et al. (2016) - Geology and Mineralogy of the El Hammam REE-Rich Fluorite Deposit (Central Morocco): A Product of Transtensional Pangean Rifting and Central Atlantic Opening. In: Bouabdellah M. & Slack J.F. (Eds.), Mineral Deposits of North Africa, Springer, 307-324, https://doi.org/10.1007/978-3-319-31733-5.

Idbaroud M. et al. (2026) - Timing of the telescoped sediment-hosted Cu-(Ni) and Pb-Zn-Ba mineralization at the Oumjrane vein system (Eastern Anti-Atlas, Morocco) and its relevance to Pre-Cretaceous Central Atlantic and Maghrebian Tethys geodynamics. Gondwana Res., 149, 351-372, https://doi.org/10.1016/j.gr.2025.08.022.

Integration of EnMAP spaceborne imaging and laboratory spectroscopy for mineral characterization of the Skorpion - Rosh Pinah (Namibia) Zn orebodies

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Keywords: hyperspectral imaging, reflectance spectroscopy, Zn mineralization.

High-grade deposits of oxidized Zn mineralization (nonsulfides or in mixtures with sulfides) represent attractive targets for mineral exploration. While these deposits exhibit large alteration footprints at the surface, spaceborne spectral imaging has seen limited use for their exploration. In this study, we investigate the spectral behavior of alteration and Zn-bearing minerals collected from the supergene oxidized mineralization at Skorpion and the hypogene Zn-Pb deposit at Rosh Pinah (Namibia) (Arfe et al., 2017).

A total of forty-three hand samples were collected from mineralized zones and country rocks. High-resolution spectral reflectance imaging and point spectroscopy, acquired over the Visible Near-Infrared (VNIR) to Shortwave Infrared (SWIR) range, were coupled with analytical geochemistry (i.e., XRPD and FESEM-EDS) and spaceborne imaging spectroscopy. A large suite of ore and alteration minerals, exhibiting well-developed absorption features, was detected, including Fe oxy-hydroxides (hematite, goethite), carbonates (dolomite, calcite, smithsonite), and silicates (hemimorphite, Zn-smectites, micas, kaolinite).

Upscaling to the district scale was achieved using EnMAP hyperspectral satellite data, covering the VNIR-SWIR wavelength range, between 420 and 2450 nm, with 224 contiguous spectral bands at 30 m spatial resolution (Chabrillat et al., 2024). The abundance, composition, and crystallinity of the target minerals were estimated by applying a multiple-feature extraction workflow based on polynomial fitting and band ratio methods to the reflectance data (Rodger et al., 2012; Sorrentino et al., 2026).

The EnMAP-derived products enabled the mapping of the spatial distribution of hydrothermal and supergene alteration minerals, revealing key spectral features that may serve as exploration vectors. In particular, the 2160 nm absorption feature is spatially constrained to the Skorpion mine area and to a smaller occurrence approximately 20 km to the northeast, suggesting similar alteration processes. Variations in carbonate composition, together with anomalies in Fe-oxyhydroxide abundance, delineate the occurrence of known mineralized zones. Notably, the calcite-dolomite boundary appears to define structurally-controlled pathways that may have acted as conduits for hydrothermal fluid flow and ore deposition.

These results highlight the significance of reflectance spectroscopy for defining diagnostic absorption features for regional upscaling and demonstrate the capability of EnMAP data to identify distinct alteration footprints associated with oxidized Zn deposits, providing district-scale vectors to support mineral exploration.

Arfe G. et al. (2017) - New CO isotopic data on supergene minerals from the Skorpion and Rosh Pinah ore deposits (Namibia): Genetic and paleoclimatic constraints. J. Afr. Earth Sci., 126, 148-158, https://doi.org/10.1016/j.jafrearsci.2016.11.022.

Chabrillat S. et al. (2024) - The EnMAP spaceborne imaging spectroscopy mission: Initial scientific results two years after launch. Remote Sens. Environ., 315, 114379, https://doi.org/10.1016/j.rse.2024.114379.

Rodger A. et al. (2012) - A simple quadratic method of absorption feature wavelength estimation in continuum removed spectra. Remote Sens. Environ., 118, 273-283, http://dx.doi.org/10.1016/j.rse.2011.11.025.

Sorrentino A. et al. (2026) - Hyperspectral remote sensing study of the structurally-controlled Zn mineralization in the Flinders Ranges, South Australia. Miner. Deposita, 61, 699-726, https://doi.org/10.1007/s00126-025-01407-2.

The essential contribution of sedimentary petrology to understand sedimentary rocks-hosted ore deposits

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Keywords: sedimentary petrology, MVT deposits, multidisciplinary study.

In ore geology, syngenetic deposits, formed at the same time as the enclosing rocks, are commonly distinguished from epigenetic deposits, in turn formed later than their host rocks. Sediment-hosted epigenetic deposits may range from those formed very early and at shallow burial depths to others formed much later, under a considerable burial, and possibly in a completely different geotectonic context compared to the one where host rocks were deposited. Diagenetic processes in carbonate sediments may operate before, during, and after ore mineral precipitation. These processes may change significantly the features of the original sediment and in particular porosity and permeability which influence the possibility of the rock to be crossed by a fluid flow and thus to become a mineral or hydrocarbon reservoir.

We present here data of a research carried out on Upper Triassic shallow platform limestones and dolostones (Bergamo Prealps, Lombardy) which host sphalerite, galena, fluorite and barite mineralizations which have been the object of historical extraction and modern exploration. We show that a multidisciplinary study (stable isotope geochemistry, fluid inclusion microthermometry, radiometric dating) can provide useful data for interpreting ore formation, only if it is preceded by careful standard and cathodoluminescence petrographic analyses, aimed to infer the properties of the sediments/rocks at the time of mineralization.

Fluid inclusion microthermometry in sphalerite, fluorite and associated dolomite shows that precipitation temperatures were in the range of 70 to 140°C. However, some petrographic characteristics (e.g.: a dolomite-cemented ash layer with a minus-cement porosity of about 75%; micron-sized calcite and dolomite inclusions in quartz and sphalerite crystals; the high degree of mineralization of shale layers) document that ore minerals and the associated quartz and dolomite grew early in the diagenetic evolution, within a sediment which had not been significantly compacted i.e. deeply buried. Calcareous sediments which had already been locally cemented in a very early diagenetic stage, were not affected by replacement phenomena by e.g. dolomite and sphalerite confirming that permeability was a strong controlling factor on mineralization. A high permeability is not expected at considerable burial depths in fine-grained sediments which are known to suffer rapid porosity reduction by compaction during the earliest burial stages. This places a strong constraint on the time of mineralization, even more precise, albeit qualitative, than the direct radiometric dating of ore or gangue minerals, which often have wide error margins.

Only with this approach can a chronology of events be reconstructed and correlated with tectonic and/or magmatic events, which in turn determine fluid composition and circulation. Furthermore, the risk of equating temperature with depth of ore formation, based solely on geothermal gradients, can be avoided.

Mineralogy and geochemistry of the Toojerdi nickel-laterite deposit, Neo-Tethyan ophiolite, Iran

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Keywords: nickel, laterite, mineralogy.

Nickel-laterite deposits in Iran are associated with the ophiolitic complexes emplaced by the Late Cretaceous collision between Afro-Arabian and Iranian plates. The Toojerdi nickel-laterite deposit was formed by intense weathering of serpentinized peridotite in the Neyriz ophiolite in the Zagros fold-and-thrust belt. The profile has the typical saprolite, limonite, and ferricrete zones from bottom to top. Petrographic observations and X-ray powder diffraction (XRPD) indicate that saprolite contains olivine, chromite and quartz, together with chlorite and montmorillonite, whereas limonite and ferricrete are mostly composed by hematite and goethite. In the latest, nodular calcite and dolomite were also detected. The geochemical analyses revealed that Ni and Co increase from the bedrock towards ferricrete. Positive correlations between Ni, Co and Fe concentrations suggest their co-occurrence in Fe-oxy-hydroxides, thus allowing to classify the depost as oxide-type. The positive correlation between REEs and Fe_2O_3 suggests that REEs were adsorbed and/or incorporated into newly formed Fe-oxide minerals within the weathering profile. The results suggest that the deposit was formed by intense chemical weathering under warm and humid climatic conditions, possibly during the Late Cretaceous-Late Paleocene period. This study provides valuable insights into the geological setting, mineralogical composition and geochemical characteristics of the Toojerdi Ni-laterite deposit and contributes to the understanding of Ni-laterite formation and Ni-laterite potential of the region.

From leaching to enrichment: Controls on critical element (REY, Ga, Sc, Co, PGE) distribution in surficial mineral systems

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Keywords: bauxite, laterite, REY deposits.

In the past decade, the raw materials needed for the energy transition to low carbon emission sources (so-called "critical" or "strategic" by different countries) have appeared in a plethora of multidisciplinary scientific papers as well as in mass media. The ones with higher demand and/or higher supply risk are the rare earth elements (REY), Ga, Sc, Co and the platinum group elements (PGE), which are commonly concentrated to economic levels by supergene processes.

On one hand, karst bauxites, the main sources of Al and Ga, are significant, potential non-conventional REY deposits, with total REY tenors (hundreds to a few thousand ppm) comparable to those of ion adsorption deposits (IAD), with low Th and U contents, and the additional advantage of being a loose material with likely easy processing. The REY-bearing mineralogy in this setting includes relictic and authigenic phosphates (e.g., monazite, xenotime), and authigenic carbonates (e.g., bastnäsite-synchysite polysomatic series) and oxides (cerianite), as reported in the numerous deposits across the Tethyan belt (Barremian-Miocene), and in the Dominican Republic (Pleistocene-Holocene; Villanova-de-Benavent et al., 2023, and references therein). In addition, REY may be adsorbed onto Al oxyhydroxides (especially gibbsite, up to ~2500 ppm La, ~1900 ppm Ce, ~1700 ppm Nd, ~2200 ppm Y; Domínguez-Carretero et al., 2026), in the same way as clay minerals (e.g., kaolinite) in IAD. The Al oxyhydroxides are the main Al ores and may account for the majority of the total REY content in some karst bauxites. Each mineral has a different REY signature (i.e., monazites tend to concentrate light REY, whereas other phosphates are Y-dominant, and carbonates may contain remarkable medium REY), and require different beneficiation methods, being the secondary minerals and the adsorbed ores the easiest.

On the other hand, Ni-Co laterite deposits (derived from tropical weathering of ultramafic rocks), like the ones located in Cuba, are important targets for Co (median 0.1 wt.% Co), Sc (median 77 ppm; lower than in the oxide-rich laterites formed from weathering of Ural-Alaskan complexes, ~300-600 ppm) and PGE (~200-300 ppb; Aiglsperger et al., 2016; Domínguez-Carretero et al., 2024). All of them are more concentrated in the upper, oxide-rich horizon, and less in the lower, silicate-rich saprolite horizon. The most abundant minerals in the oxide zone, Fe oxyhydroxides (especially goethite) yield remarkable Co and Sc contents (< 0.3 wt.% CoO, < 117 ppm Sc), while lesser maghemite (< 1.8 wt.% CoO) and lithiophorite-asbolane (< 12.8 wt.% CoO, < 94 ppm Sc) must also be considered (Domínguez-Carretero et al., 2024). Finally, PGE minerals may be primary, altered (by serpentinisation or weathering), and authigenic (neoformed).

Nevertheless, accurate knowledge on the mode of occurrence of CM in the hosting minerals in each deposit is fundamental to determine the viability and sustainability of exploration and exploitation projects.

Aiglsperger T. et al. (2016) - Critical metals (REE, Sc, PGE) in Ni laterites from Cuba and the Dominican Republic. Ore Geol. Rev., 73, 127-148, https://doi.org/10.1016/j.oregeorev.2015.10.010.

Domínguez-Carretero D. et al. (2024) - The Geology, Geochemistry, and Mineralogy of the Moa Bay Ni Laterite Mining District, Cuba. Econ. Geol., 119, 1685-1706, https://doi.org/10.5382/econgeo.5101.

Domínguez-Carretero D. et al. (2026) - The hyper-enriched rare earth elements karst bauxites of the Sierra de Bahoruco, SW Dominican Republic. Econ. Geol., https://doi.org/10.5382/econgeo.5214.

Villanova-de-Benavent C. et al. (2023) - REE ultra-rich karst bauxite deposits in the Pedernales Peninsula, Dominican Republic: Mineralogy of REE phosphates and carbonates. Ore Geol. Rev., 157, 105422, https://doi.org/10.1016/j.oregeorev.2023.105422.

S25.

Developing different uses of geothermal energy: from fundamental research to non-conventional applications

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Advancing geothermal district heating networks through the strategic repurposing of hydrocarbon infrastructure in the framework of EU energy policies

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Keywords: district heating, repurposing, hydrocarbon well.

Climate change and the global energy crisis have placed District Heating (DH) at the forefront of the transition toward a sustainable energy landscape. Given that heating and cooling systems accounted for 48% of the final energy consumption in EU20 countries, the development of zero-emission DH networks is essential for meeting European climate objectives. This transition is now further catalysed by the recent 2026 EU Geothermal Action Plan and the Accelerate EU strategy, which prioritise the deployment of geothermal energy to ensure energy sovereignty and price stability across the Union.

This study investigates the implementation of geothermal district heating as a transformative solution for residential energy demand, aligning with the EU's new directives to reduce financial and geological risks. The research compares the feasibility of systems in documented geothermal areas with those utilising the repurposing of existing hydrocarbon infrastructure. In Italy, the potential for such systems is anchored in the country's extensive hydrocarbon legacy, comprising 847 active wells across 111 onshore concessions. By converting these industrial assets into primary heat sources for DH grids, the study demonstrates a practical application of circular economy principles that directly addresses the EU's call for "de-risking" strategies and the reduction of Capital Expenditure (CAPEX).

Through comparative case studies in Romentino (Northern Italy) and Tuscania (Central Italy), the research evaluates technical and economic performance. The results show that these projects are highly competitive, with a Levelized Cost of Heat (LCOH) remaining below the reference tariff of 100 €/MWh, a result that supports the EU's objective of making renewable heating affordable for households. Furthermore, the study explores optimisation through binary systems for simultaneous heat and power production, maximising global efficiency. In conclusion, the strategic reuse of oil and gas wells for geothermal-sourced district heating represents a scalable and resilient solution that significantly contributes to the Net-Zero Industry Act goals, transforming existing liabilities into strategic assets for the European energy transition.

Groundwater Heat Pumps in densely urbanized areas: The benefits of dynamic ATES systems

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Keywords: heat transport, thermal storage, groundwater.

The use of aquifers for low-enthalpy geothermal energy production represents an effective response to the increasing demand of renewable and low-carbon energy sources, especially in densely urban areas. Groundwater can serve as a renewable thermal resource for building heating and cooling, contributing to the decarbonization of air-conditioning systems and to the sustainable use of the subsurface. However, its exploitation should minimize anthropogenic stress and guarantee long-term preservation of the resource.

Conventional open-loop geothermal systems, commonly referred to as GWHP (Groundwater Heat Pump) systems, typically consist of extraction wells located upstream of the building and reinjection wells downstream. Groundwater is extracted under undisturbed conditions, thermally exploited within the heat pump system, and reinjected at an altered temperature. However, these systems may suffer from several limitations, including thermal interference from nearby installations, thermal short-circuiting caused by hydraulic gradient reduction, and downgradient migration of thermal plumes. These issues are particularly relevant in densely urban areas (e.g. Milano), where more than 700 GWHP systems are installed, often without coordinated planning, increasing the risk of thermal and hydraulic interference.

In this context, Dynamic Aquifer Thermal Energy Storage (D-ATES) systems represent an innovative alternative for hydrogeological settings characterized by medium to high groundwater flow. In D-ATES configurations, extraction and reinjection wells are reversed compared to conventional GWHP layouts. The system stores thermal energy within the flowing aquifer and exploits the temperature variations induced during the previous season for heating and cooling purposes. This approach reduces the environmental and operational limitations of conventional systems, mainly by limiting downgradient thermal plume propagation through the hydraulic barrier effect generated by pumping wells. Furthermore, groundwater can be extracted at more favorable temperatures, improving heat pump performance in terms of COP and EER.

A detailed reconstruction of the hydrogeological setting, coupled with numerical modeling, is essential to ensure the correct operation and efficiency of D-ATES systems. In this study, the MODFLOW-USG code was used for coupled groundwater flow and heat transport simulations in the shallow aquifer of the Milan metropolitan area. The simulations show the ability of the system to effectively capture the maximum thermal perturbation during winter and the minimum perturbation during summer, leading to an improvement in energy performance of approximately 10%. Furthermore, the analysis of optimal well spacing, operating schedules, and pumping rates highlights how system design and management can maximize thermal energy recovery while minimizing induced thermal disturbances within the Milano aquifer.

An integrated geological and geophysical approach for the evaluation of the geothermal energy potential of the Romagna and Ferrara Folds and surrounding areas

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Keywords: geothermal energy, geological model, cluster analysis.

To contribute to a secure and low energy carbon future, the InGEO project (Innovation in GEOthermal resources and reserves potential assessment for the decarbonization of power/thermal sectors) developed an innovative exploration workflow for combining multi-parameter datasets that will help reduce the risks associated with geothermal energy exploitation. The chosen area for the application is the Northern Apennine buried - structures belonging to the Romagna and Ferrara Folds (RFF), Eastern Po Plain, and the Northern Adriatic Sea (Italy). There, a heat flow anomaly was detected and interpreted to be the effect of deep fluid circulation within the deep-seated Mesozoic carbonate sequences (e.g., Pasquale et al., 2013). As part of the workflow, we first developed a consistent geological model of the RFF region, which integrated data from over 200 seismic surveys from the ViDEPI database (www.videpi.com), 700 deep (>1500 m) boreholes (CNR database, www.geothopica.igg.cnr.it), 160 borehole logs (sonic and lithological logs) (Livani et al., 2023). The deep subsurface was characterized by applying unsupervised clustering algorithms (K-means and Fuzzy c-means) to jointly interpret seismic tomography and gravity datasets (e.g., Zahorec et al., 2021; Kästle et al., 2025). By utilizing thermo-physical measurements on rock samples, collected in the field and results obtained from previous laboratory experiments, the cluster model was further validated. The results consist of a 3D architecture of shallow and deep geological features of the study region. Shallow features (up to a depth of ~15 km) included eight horizons ranging in age from the Quaternary to the Permian, while deep features (between ~15 and 50 km depth) included the basement, the upper crust, and the Moho depths. The results are the main input for a thermal model of the region and the assessment of the deep geothermal resource potential. Lastly, the described workflow is intended to be part of a decision support system for developing geothermal projects in Italy.

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Kästle E.D. et al. (2025) - Alpine Crust and Mantle Structure From 3D Monte Carlo Surface and Body-Wave Tomography. J. Geophys. Res.: Solid Earth, 130(2), e2024JB030101, https://doi.org/10.1029/2024JB030101.

Livani M. et al. (2023) - Subsurface geological and geophysical data from the Po Plain and the northern Adriatic Sea (north Italy). Earth Syst. Sci. Data, 15, 4261-4293, https://doi.org/10.5194/essd-15-4261-2023.

Pasquale V. et al. (2013) - Evidence for thermal convection in the deep carbonate aquifer of the eastern sector of the Po Plain, Italy. Tectonophysics, 594, 1-12, https://doi.org/10.1016/j.tecto.2013.03.011.

Zahorec P. et al. (2021) - The first pan-Alpine surface-gravity database, a modern compilation that crosses frontiers. Earth Syst. Sci. Data, 13, 2165-2209, https://doi.org/10.1029/2024JB030101.

Integrated geothermal and hydrogeological study for the implementation of a low-temperature energy system in an urban public building

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Keywords: geothermal, hydrogeology, heating-cooling.

The increasing spread of low-temperature geothermal systems in urban environments requires increasingly accurate hydrogeological characterization, with the aim to ensure proper system sizing, optimization of energy performance, and the long-term sustainability of the resource. In this context, the present study aims to evaluate the potential use of low-temperature geothermal fluids to meet the energy demands of a secondary school located in the urban center of Pisa. The city of Pisa lies within an alluvial-coastal plain characterized by significant sediment thickness and high vertical and lateral variability in lithological and hydrogeological properties.

The analysis focuses on defining the main hydrogeological and thermal parameters of the reference aquifer, such as hydraulic conductivity, transmissivity, physico-chemical characteristics of the fluids, and temperature, which are considered fundamental elements for the design of efficient geothermal systems. In an urban environment like Pisa's, the stratigraphic complexity and anthropogenic interferences make detailed knowledge of local hydrogeological conditions essential, both for the correct selection of the plant configuration and for evaluating the thermal and hydraulic effects on the subsurface.

The geothermal system was modeled using the software GHE Analysis, a tool specifically developed for the design of geothermal heat pump systems. This model made it possible to simulate the thermal behavior of the geothermal field and assess different design scenarios.

The study confirms the fundamental role of integrated hydrogeological-geothermal studies for the energy transition of public buildings and the spread of geothermal technologies in high-density urban environments.

HOrizontal CLosed loOP (HOCLOOP) system for Sustainable Energy Applications: Fracture distribution as basic dataset for evaluating possible energy supply

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Keywords: geothermal energy, closed-loop systems, hocloop project.

Geothermal energy offers a promising opportunity for sustainable and low-emission power generation. Current geothermal systems mainly rely on extracting heat from naturally occurring hot and permeable aquifers. However, these geological conditions are relatively rare, which limits deployment and often leads to high investment costs and operational uncertainty.

The HOrizontal CLosed loOP(HOCLOOP) project addresses these limitations through the development of a horizontal closed-loop system designed to recover heat from both deep and shallow rock formations. The concept builds on advanced drilling methods that simplify several of the technical difficulties associated with traditional geothermal well construction.

By using extended-reach horizontal drilling with larger well diameters, the system is expected to increase heat recovery and improve overall energy output. Additional performance gains may also come from replacing water with alternative working fluids, including CO_2-based fluids, for heat circulation. In this view, several experiments were performed using testing fluids circulating in a closed system characterised by an inner and an outer pipe, the latter being in contact with the surrounding rock.

In addition, the technology is designed to ensure reliable long-term operation, with an expected lifespan of up to 50 years, and can be combined with other renewable energy systems.

To test this technology, several pilot sites across Europe were selected, covering different geological environmental, together with the preparation of full-scale testing activities and assessments of environmental impact and public acceptance. A participatory approach will be adopted to promote both community engagement and market uptake of the technology.

In Italy, three pilot sites were selected for simulation of heat extraction, based on their different rock composition, thermal gradient, and assumption of heat extraction from depths of about 1 km. In each area, a detailed fracture networks study was performed, to develop different scenarios to simulate the heat extraction, contributing to the evaluation of the thermal energy exchange between the geothermal reservoir and the working fluid (water or supercritical CO_2), as well as the cooling of the reservoir over time.

Overall, HOCLOOP represents a promising pathway for expanding the use of geothermal energy by making it viable even in geological settings that are unsuitable for conventional systems, thereby supporting the transition toward sustainable renewable energy sources and potentially lowering the Levelized Cost of Energy (LCOE) compared with conventional geothermal technologies.

Hydrodynamic and thermo-physical characterisation of the underground aimed at using geothermal energy for space heating and cooling: A detailed study in Marche Region (Central Italy)

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Keywords: geothermal energy, space heating and cooling, thermal energy production.

Differently from what occurred immediately after the geopolitical crisis of 2022, the International Energy Agency's Global Energy Review (IEA) reports that overall global energy demand growth slowed to 1.3% in 2025 slightly below the previous decade's average of 1.4% and significantly lower than in 2024. The main reasons for this slowdown include lower global economic growth, less extreme temperatures in some regions, but overall rapid uptake of more efficient technologies. As widely discussed, the thermal sector remains responsible for 49% of final energy consumption in Europe. Among renewable energy sources, geothermal energy may play an important role in supporting the green energy transition, although it is still overlooked, covering only around 2% of heating and cooling demand (Goetzl et al., 2022).

In this context, the present study aims to improve current knowledge on the underground characterisation, a mandatory step for defining the geothermal potential suitability, , of the Marche region (Central Italy).

A thermophysical and mineralogical analysis of the main lithologies of the Umbria-Marche succession together with hydrogeological investigations (Chicco et al., 2019a, b) has been implemented with new data, encompassing geognostic drillings, geophysical data (e.g., MASW, HVSR), climatic information, and Thermal Response Tests, to provide a more accurate estimate of underground thermal properties, especially in the first 150/200 m, to test their impact on thermal energy production. This study mainly focuses close to the urban areas where the use of efficient systems integrated with geothermal energy could significantly reduce energy costs and CO_2 emissions.

Goetzl G. et al. (2022) - Pathways to better integrate geothermal energy at its full technological scale in European heating and cooling networks. Eur. Geol., 54, 44-50, https://doi.org/10.5281/zenodo.7882918.

Chicco J.M. et al. (2019a) - Plio-Quaternary tectonics and possible implications for geothermal fluids in the Marche Region (Italy). Tectonophysics, 755, 21-34, https://doi.org/10.1016/j.tecto.2019.02.005.

Chicco J.M. et al. (2019b) - Thermophysical properties and mineralogical chicomposition of the Umbria-Marche carbonate Succession (Central Italy). In: Koeberl C. & Bice D.(Eds), 250 Million Years of the Earth History in Central Italy: Celebrating 25 Years of the Geological Observatory of Coldigioco. Geological Society of America Special Paper, 542, 59-67, https://doi.org./10.1130/2019.2542(02), ISBN: 9780813795423.

Urban heat islands and possible use of waste heat: hydrogeological investigation in the city of Turin (NW Italy) through a physical-chemical one-year piezometers monitoring

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Keywords: groundwater monitoring, urban heat islands, waste heat.

Water management in urban cities also deals with pollution coming from both chemicals and anomalous temperatures due to industrial activities and space heating and cooling systems, may determining the urban heat island effect.

This work deals with a constant monitoring of the groundwater quality in the urban centre of Turin (NW Italy) aimed at defining possible urban heat islands and a use of this waste heat for space heating and cooling.

Thanks to the partnership with the Municipality of Turin, some piezometers mainly located in the central and southern part of the city, are being monitored. Sensors measuring in continuous groundwater temperature and pressure has been placed at different depths in piezometers. The different position of the sensors depends on the piezometer depth and on the water level from the ground. During one year-monitoring, a series of field surveys to each of the piezometers has been also conducted and they are still ongoing. These consist of detecting important hydrogeological and chemical parameters such as electrical conductivity, pH, and Total Dissolved Solids though the use of a multiparametric device.

Results after one-year monitoring highlight a seasonal increasing of the temperature value of at least 1°C from autumn to summer, for all the investigated piezometers; except for one of the examined cases, these increasing values are not directly related with the electrical conductivity how should it be; this inverse could be explained considering a complex scenario including chemical pollution. To this regard, piezometers located in the most populated parts of the city, in which more public activities as well as more apartments and vehicular traffic are present, display higher groundwater temperature (e.g., 17.15 - 18.9°C) than those recorded in more peripheral areas or with fewer buildings and activities nearby (e.g., 14.2 - 14.7°C). These results can confirm how urban activities can have an impact on groundwater quality especially for the temperature value, leading also to evaluate how this residual heat can be used for space heating and cooling.

The Tertiary Piedmont Basin thermal district: new insights from geophysical exploration and thermal modelling

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Keywords: gravity and seismic surveys, thermal modelling, geothermal resources.

The Tertiary Piedmont Basin (TPB), located at the boundary between the Alpine and Apennine belts and characterised by an Oligocene-Miocene sedimentary sequence mainly composed of marls interbedded with sandstone layers, is the most important thermal district in northwestern Italy. It hosts the Acqui Terme hydrothermal system, characterised by numerous thermal springs and a total thermal discharge of about 3 MW. Previous studies suggested that groundwater warming can be caused by a normal regional geothermal gradient (~ 30°C/km). However, the thermal gradients determined from well logs define a relatively large area with gradients > 120°C/km. The TPB sediments constitute the impermeable cover of the system, while the pre-Oligocene crystalline basement of Valosio, outcropping south of the TPB and characterised by NW-SE-oriented faults, can connect the deep groundwater reservoir to the surface. In this paper, we present results from new geophysical investigations, namely gravity and passive-seismic ambient-noise measurements, together with a reinterpretation of previously acquired thermal, geoelectrical, and seismo-stratigraphic data, which refine the underground structural model of the Acqui Terme system. The integrated interpretation of geophysical and stratigraphic data indicates a horst structure beneath the hot spring area, where the crystalline basement top reaches a minimum depth of about 200 m. To the north, the top of the basement, inferred from seismic reflection data to be more than 1 km deep, is associated with a structural lineament likely corresponding to an overthrust. The inferred geological model was used to develop a thermo-hydraulic numerical model. A more permeable zone within the structural high below Acqui Terme was assumed, consistent with the occurrence of thermal springs and a discharge of about 10^{-5} m^3/s, corresponding to the total natural discharge. Two permeability scenarios have been explored: (i) permeability values of 10^{-15} m^2 in the deepest parts and of 10^{-14} m^2 in correspondence with the structural crystalline high; (ii) an even higher permeability (10^{-13} m^2) in the shallower portion of the horst of Acqui Terme. In the second scenario, in addition to forced convection, thermal convection may occur in the higher-permeability portion of the basement. In both cases, the fluid warms to depths of 3-5 km and moves towards the most permeable zone, producing an isotherm upwarping beneath Acqui Terme. Both thermo-hydraulic simulations show excellent correspondence between the temperature gradients observed in the wells and the calculated thermal gradients. These findings support our initial geological and hydrogeological hypotheses, which envisage a groundwater flow path originating in the Valosio recharge area, about 15 km south of the thermal area. The results provide a new interpretative framework for evaluating the geothermal potential of Acqui Terme.

Assessment of low-enthalpy geothermal potential in the Sibari Plain

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Keywords: shallow geothermal energy, coastal basins, Calabria.

Low-enthalpy geothermal systems are typically associated with alluvial and coastal basins, where shallow groundwater circulation and highly permeable unconsolidated sediments enhance heat-transfer efficiency and favour the exploitation of shallow geothermal resources. In these environments, saturated gravel- and sand-dominated deposits provide suitable conditions for both closed-loop Borehole Heat Exchangers (BHE) and open-loop Groundwater Heat Exchange (GWHE) systems, while the shallow depth of the water table generally reduces drilling requirements and installation costs.

The Sibari Plain, located in northeastern Calabria (southern Italy), represents one of the largest Quaternary coastal basins of the central Mediterranean and constitutes a suitable case study for the assessment of shallow geothermal resources. Within the framework of the STICE project (Soluzioni Tecnologiche Innovative per Comunità Energetiche), developed under the Tech4You innovation ecosystem, an integrated geological, hydrogeological, thermal and geochemical investigation was carried out to evaluate the low-enthalpy geothermal potential of the basin and identify the principal environmental and operational constraints associated with geothermal development.

To achieve these objectives, historical datasets (Vespasiano et al., 2015; 2019; Cianflone et al., 2018) were integrated into a comprehensive geo-database, supporting the development of thematic maps and conceptual models of the subsurface. Thermal conductivity, volumetric heat capacity and geothermal potential were subsequently assessed through spatial interpolation and GPOT-based modelling approaches (Casasso & Sethi, 2016). The results identified the central sector of the plain as the most suitable area for BHE installations, with estimated geothermal potential values of up to 11.6 MWh/year for a standard borehole. Overall, the findings indicate that closed-loop systems constitute the most reliable and sustainable option for large-scale geothermal exploitation in the Sibari Plain.

Casasso A. & Sethi R. (2016) - G. POT: A quantitative method for the assessment and mapping of the shallow geothermal potential. Energy, 106, 765-773, https://doi.org/10.1016/j.energy.2016.03.091.

Cianflone G. et al. (2018) - Late quaternary stratigraphic setting of the Sibari Plain (southern Italy): hydrogeological implications. Mar. Pet. Geol., 97, 422-436, https://doi.org/10.1016/j.marpetgeo.2018.07.027.

Vespasiano G. et al. (2015) - The Small Spring Method (SSM) for the definition of stable isotope-elevation relationships in Northern Calabria (Southern Italy). Appl. Geochem., 63, 333-346, https://doi.org/10.1016/j.apgeochem.2015.10.001.

Vespasiano G. et al. (2019) - A multidisciplinary approach for sustainable management of a complex coastal plain: The case of Sibari Plain (Southern Italy). Mar. Pet. Geol., 109, 740-759, https://doi.org/10.1016/j.marpetgeo.2019.06.031.

Evaluation of the impact of closed-loop ground-source heat exchangers on subsurface temperature through numerical modelling: Two case studies

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Keywords: ground-source heat exchangers, numerical modelling, thermal impact.

Closed-loop ground-source heat exchangers (geoexchange) coupled with heat pumps represent a reliable solution for indoor climate control, providing a continuous energy supply throughout the year with low emissions. These systems exploit the relatively stable temperature of the subsurface at shallow depths, which remains nearly constant at approximately the local yearly mean atmospheric temperature. Consequently, heat can be extracted from the ground for winter heating and re-injected to the ground for summer cooling.

To minimize subsurface temperature variations that may reduce system efficiency, it is essential, whenever possible, to operate these systems under balanced thermal loads, meaning that the energy injected into the ground is comparable to the energy extracted (e.g. Hałaj et al., 2020). In contrast, unbalanced thermal loads can generate thermal plumes, potentially affecting long-term system performance. To predict these temperature changes, regulatory authorities increasingly require the use of numerical models capable of simulating system operation over long periods (at least 20-30 years). In this context, the present study introduces two FEFLOW models simulating closed-loop ground-source heat pump systems located in the Marche Region (Central Italy).

The first case study concerns a recently installed system, just started to work, located in the city of Fano. The system consists of six double-U Borehole Heat Exchangers (BHEs), each reaching a depth of 80 m. The local stratigraphy is characterized by unconsolidated alluvial sediments overlying the Argille Azzurre Formation. A shallow groundwater table is present at a depth of 4 ± 1 m below ground level at the study site, enhancing the ground's heat exchange capacity (Hecht-Méndez et al., 2012).

The second case study deals with a 5-years operational system located near the city of Urbino. This installation comprises nine double-U BHEs extending to a depth of 200 m within the Marnoso-Arenacea Formation.

For both sites, thermal conductivity profiles obtained from Enhanced Ground Response Tests (EGRT) were available. Thermal and hydraulic properties were derived from the literature and implemented in the models, together with the specific characteristics of the BHEs. The thermal loads (heat extraction and injection) were estimated based on the building design loads. Results of 20-year simulations highlight how the systems impact on subsurface temperature evolution, with marked differences mainly related to the thermal properties of the subsoil, and, above all, to the presence of groundwater.

Hałaj E. et al. (2020) - Finite Element Modeling of Geothermal Source of Heat Pump in Long-Term Operation. Energies, 13(6), 1341, https://doi.org/10.3390/en13061341.

Hecht-Méndez J. et al. (2012) - Optimization of Energy Extraction for Vertical Closed-Loop Geothermal Systems Considering Groundwater Flow. Energy Convers. Manag., 66, 1-10, https://doi.org/10.1016/j.enconman.2012.09.019.

Geothermal resources in stable shield domains - constraints on reservoir depths

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Keywords: hot springs, low enthalpy, well bore simulations.

Most continental regions of the Earth comprise Precambrian shields that are not tectonically active, and have little or no volcanic activity. In such regions, geothermal resources are limited to low enthalpy hot springs that are inadequately explored. In the Indian Precambrian shield, the eastern fringe of the cratons is rimmed by the Proterozoic Eastern Ghats Belt. This intensely deformed granulite facies terrane was a key domain that is considered to have been adjacent to East Antarctica in the Neoproterozoic time. The terrane underwent ultrahigh temperature metamorphism ~ 1100 Ma, and cooled slowly through the Neoproterozoic. The last major thermal anomaly in the terrane is recorded at ~500 Ma. The present study investigates the geothermal potential of hot springs at four selected sites within the belt. Geothermometric studies constrain reservoir temperatures of the hot springs to ~150°C. However, there is no existing method that can accurately constrain the depth of the reservoir, which is generally estimated based on an assumed or measured geothermal gradient. In this study, Monte-Carlo simulations were performed to assess the geothermal heat-in-place at the hot spring sites and reveal a probabilistic resource of P10 ($1.47*10^{13}$ kJ), P50 ($1.92*10^{13}$ kJ), and P90 ($2.48*10^{13}$ kJ). The depth of the reservoirs was constrained using single-phase wellbore simulations integrated with the geothermometric results. These constrain the reservoirs to depths shallower than 1.60 km and 2.60 km, that were estimated from earlier studies. Wellbore simulations on the producing-fluid temperature suggest that the extraction can be enhanced by ~35% when the flow rate is increased from 4.5 m^3/hr (the highest measured natural discharge rate) to 11.3 m^3/hr using a downhole pump. Sensitivity analysis indicates that flow rate and geothermal gradient have the highest impact on the outlet temperature. Preliminary estimates indicate that ~0.6 MW geothermal plants can be developed for these shallow reservoir scenarios. This study demonstrates the feasibility of utilizing geothermal energy from hot springs in the Indian shield by integrating geo-thermometric analyses with wellbore simulations, and suggests applicability globally to other terranes with similar geological setting. The well bore simulations also provide constraints on the maximum depth of the geothermal reservoirs, thereby facilitating estimation of the energy resource.

Numerical assessment of phase change materials in underground thermal energy storage systems

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Keywords: underground thermal energy storage, phase change materials.

Underground thermal energy storage (UTES) is a promising strategy for improving the seasonal management of renewable and low-grade thermal energy in the built environment. However, the efficiency of conventional UTES systems is strongly controlled by the thermo-physical properties of the subsurface, including thermal conductivity, volumetric heat capacity, density, porosity, moisture conditions, and storage volume layout. The integration of phase change materials (PCMs) into underground storage systems offers a potential solution to increase energy storage density by combining sensible and latent heat storage within a limited underground volume.

This study presents a numerical framework for evaluating PCM-enhanced underground thermal energy storage under seasonal charging and discharging conditions. The model considers heat transfer between the heat carrier fluid, the PCM-based storage domain, and the surrounding ground. The phase transition of the PCM is included to account for latent heat absorption during charging and heat release during discharging. Different PCM configurations, thermo-physical properties and carrier fluid types and flowrates are considered to investigate their influence on storage capacity, temperature stabilization, charging/discharging phases duration, and thermal energy amount recovery capabilities and efficiencies. Particular attention is given to the interaction between PCM behaviour and geological conditions, since the effectiveness of latent heat storage depends not only on the phase-change temperature of the PCM, but also on the thermal response of the host ground.

The numerical assessment highlights that PCM integration can improve the thermal buffering capacity of UTES systems, reduce temperature fluctuations, and extend the useful heat-release period during the discharging phase. The results also emphasize the importance of selecting PCMs with phase-change temperatures tailored on the operating range of heat pump and end-user thermal loads requests. This approach provides a geoscience-based contribution to the design of advanced underground thermal storage systems and supports the development of more efficient and sustainable solutions for daily thermal energy storage.

An open-source workflow from public Italian subsurface data to improve techno-economic assessment of direct use of geothermal energy: PRISM, PULSE, CRAFT, Waiwera and GEOPHIRES-X softwares

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Keywords: direct use of geothermal energy, subsurface modelling.

In Italy, the direct use of geothermal energy potential and scoping (e.g. District Heating, Ground Source Heat Exchangers coupled with Heat Pumps) is hampered by the fragmentation of public subsurface data and by the difficulty of integrating passive-seismic archives with stratigraphic and petrophysical logs. Here we present a modular open-source workflow, orchestrated by the new PRISM (.NET 8, OpenGL/IMGUI) software, that joins data ingestion, passive imaging, reservoir segmentation and physics-based flow simulation in one pipeline.

PRISM (Physics-informed Ranking and Integrated Subsurface Modeler) automates ingestion from nine Italian public portals: SGI WFS (about 55k boreholes), ISPRA hydrogeology, CARG geological maps, MOSAICO contaminated sites, ITHACA capable faults, WebMS geotechnics, ViDEPI hydrocarbon wells, UNMIG mining concessions and GeoThopica geothermal archives, with Copernicus DEM GLO-30 (30 m) topography, harmonised into one data model. Lithologies follow USCS; fault kinematics are honored with offsets on 3D Delaunay surfaces. Tops and bottoms are interpolated by a discontinuity-constrained ordinary kriging that masks cross-fault weights after the LU solve. LAS import and a petrophysical-points editor merge Vp, Vs, density, porosity, permeability and thermal conductivity. Candidate areas are then ranked by a geothermal-potential index combining temperature, permeability and a drilling-cost depth penalty.

PULSE (Passive sUb-surface Lsqr Seismic Engine) reconstructs high-resolution Vp/Vs volumes via a hybrid pipeline: a region-aware 1-D seed (Apennines/Alps/Po Plain, auto-selected from the dataset centroid) is preconditioned by iterative back-projection of station-quality anomalies through a depth-dampened lateral kernel, Laplacian-smoothed between passes, over cells supported by ITACA strong-motion and INGV broadband (EIDA/FDSN) stations. A damped LSQR travel-time inversion (Paige & Saunders, 1982) is then run on auto-picked P and S arrivals with bent-ray tracing through FDSN event hypocenters; outer non-linear iterations re-trace rays under Tikhonov-plus-Laplacian regularisation.

CRAFT (Cross-investigation Reservoir Architect with Fault-aware Tessellation) segments the volumes into Reservoir, Aquifer, Caprock and Fault domains: faults are imported from ITHACA/CARG and refined by velocity-discontinuity analysis, while Reservoir/Aquifer/Caprock are auto-classified by threshold bands on Vp, Vs, acoustic impedance and field reliability (a 0-1 composite of ray coverage, station-support coherence and artifact risk), then curated with interactive 3D tools. A data-driven thermal estimate calibrated on regional gradients supplies initial conditions for Waiwera (Croucher et al., 2020), a non-isothermal multiphase flow simulator, and GEOPHIRES-X (Beckers & McCabe, 2019) for techno-economic closure. The workflow accelerates exploration and potential assessment, giving stakeholders a user-friendly tool that maximizes open-source data.

Beckers K.F. & McCabe K. (2019) - GEOPHIRES v2.0: updated geothermal techno-economic simulation tool. Geotherm. Energy, 7, 5, https://doi.org/10.1186/s40517-019-0119-6.

Croucher A.E. et al. (2020) - Waiwera: A parallel open-source geothermal flow simulator. Comput. Geosci., 141, 104529, https://doi.org/10.1016/j.cageo.2020.104529.

Paige C.C. & Saunders M.A. (1982) - LSQR: An algorithm for sparse linear equations and sparse least squares. ACM Trans. Math. Softw., 8(1), 43-71, https://doi.org/10.1145/355984.355989.

Updating the conceptual model of the high-enthalpy Karthala geothermal system (Grande Comore, Union of the Comoros)

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Keywords: volcanic geothermal systems, geothermal exploration, Comoros.

High-enthalpy geothermal systems are typically associated with active volcanic regions, where shallow magmatic heat sources and fracture-controlled permeability sustain vigorous hydrothermal circulation underneath an impervious cap-rock with a steep geothermal gradient. Grande Comore, the youngest island of the Comorian archipelago, located within the central Mozambique Channel, is dominated by the long-lived and active Karthala shield volcano (2,361 m a.s.l.), which provides a suitable context for the occurrence of a high-enthalpy geothermal system. Indeed, it is one of the most favorable volcanic settings for geothermal development in the whole western Indian Ocean. Two decades of surface exploration undertaken by KenGen (2008), Jacobs (2014-2016), GNS Science (2015), STEAM (2024) and government-led campaigns have consistently highlighted the northern and north-western flanks of Karthala as the primary upflow zone of a high-enthalpy geothermal system. This interpretation is supported by persistent fumarolic activity, widespread hydrothermal alteration, and favorable MT-derived resistivity distribution and structural setting. As part of the UNDP-implemented Karthala Geothermal Assessment and Development Programme, a new integrated investigation is being conducted in collaboration with the Bureau Géologique des Comores (BGC) to consolidate existing datasets and acquire additional targeted observations. Field activities are carried out jointly with BGC staff, thereby providing practical, on-the-job training and strengthening national technical capacity. The study comprises: (i) gravity surveying aimed at refining subsurface density distribution and identifying major permeability-controlling fault systems; (ii) systematic sampling and analysis of fumarolic gases and condensates to characterize the composition of the rising fluid and estimate reservoir temperatures by gas-geothermometric techniques; (iii) comprehensive reassessment and harmonization of all historical geological, geochemical and geophysical datasets. These efforts support the development of an internally consistent conceptual model that constrains reservoir geometry, heat-source configuration and principal fluid pathways with improved confidence and identifies priority well targets for the forthcoming drilling exploration phase.

Comparative thermal performance and long-term sustainability of closed-loop geothermal systems in high-temperature volcanic environments

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Keywords: closed-loop geothermal systems, volcanic environments, multilateral wells.

Closed-loop geothermal systems represent a promising alternative for exploiting high-temperature geothermal resources in volcanic environments while avoiding the environmental and operational risks commonly associated with conventional hydrothermal systems (Renaud et al., 2019; Doran et al., 2021; Mohaman et al., 2025). This study investigates the thermal performance and long-term sustainability of different closed-loop borehole heat exchanger (CBHE) configurations under shallow high-enthalpy conditions representative of Vulcano Island (Italy). A coupled thermo-hydraulic numerical framework integrating one-dimensional wellbore flow with three-dimensional conductive heat transfer in the surrounding geological formation was developed using finite-element modelling. Simulations were performed over a 25-year operational period to evaluate the influence of borehole geometry, trajectory, spacing, operational strategy, injection temperature, flow rate, and insulation on system performance. Five single-well configurations were first analysed, including vertical coaxial, deviated coaxial, horizontal coaxial, U-loop, and single-lateral systems. Results demonstrate that borehole geometry exerts the dominant control on long-term thermal performance. Lateral and horizontal configurations significantly outperform conventional vertical systems by increasing the effective heat-exchange length within high-temperature formations and extending fluid residence time. After 25 years of continuous operation, horizontal, U-loop, and single-lateral systems maintained production temperatures of approximately 147-165°C, whereas vertical and deviated systems stabilised near 96-106°C. The study further investigated vertical coaxial arrays, mixed vertical-deviated arrays, and advanced multilateral closed-loop systems. Multilateral and deviated configurations improved heat extraction and estimated electrical power generation by approximately 40-60% compared with purely vertical arrays. However, thermal interference between neighbouring boreholes and laterals progressively reduced performance gains, indicating optimal spacing thresholds of about 50 m for borehole arrays and 150 m for multilateral laterals. Operational analyses further showed that high circulation rates maximise short-term power production but accelerate reservoir cooling, whereas moderate flow rates and higher injection temperatures favour long-term thermal sustainability. Periodic operation with alternating production and recovery phases proved effective in stabilising outlet temperatures and mitigating thermal depletion. Overall, the results highlight the critical role of trajectory design and operational optimisation in enhancing the feasibility of closed-loop geothermal systems in shallow volcanic environments. The proposed configurations provide a technically viable and environmentally sustainable pathway for geothermal heat and power production in high-temperature island settings.

Doran H.R. et al. (2021) - Modelling an unconventional closed-loop deep borehole heat exchanger (DBHE): sensitivity analysis on the Newberry volcanic setting. Geotherm. Energy, 9(1), https://doi.org/10.1186/s40517-021-00185-0.

Mohaman D.A. et al. (2025) - Evaluation of a Closed-Loop coaxial borehole heat exchanger in High-Temperature volcanic environment. Energy Convers. Manag.: X, 28, 101388, https://doi.org/10.1016/j.ecmx.2025.101388.

Renaud T. et al. (2019) - Numerical simulation of a Deep Borehole Heat Exchanger in the Krafla geothermal system. Int. J. Heat Mass Transf., 143, 118496, https://doi.org/10.1016/j.ijheatmasstransfer.2019.118496.

Advanced thermophysical monitoring and AI-oriented predictive analysis of a hybrid closed-loop geothermal heat pump system at the Beato Pellegrino Humanities Campus of the University of Padua

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Keywords: heat pump, thermophysical monitoring, closed-loop.

This work presents the design, implementation, and first operational outcomes of an advanced thermophysical monitoring framework applied to the hybrid geothermal HVAC system serving the Beato Pellegrino Humanities Campus of the University of Padua. The plant consists of a closed-loop geothermal heat pump system coupled with a borehole heat exchanger (BHE) field and integrated with air-source heat pumps operating in dynamic switching mode according to indoor thermal demand, outdoor climatic conditions, and subsurface thermal response. The monitoring architecture is based on a multi-scale and multi-sensor approach integrating MUMS (Multi-Utility Monitoring Systems), composed of vertical chains of distributed temperature sensors installed within selected geothermal boreholes, together with Distributed Temperature Sensing (DTS) systems based on fiber optic technology. The combined deployment enables high-resolution spatial and temporal reconstruction of subsurface thermal fields, allowing continuous characterization of heat transfer processes within the geothermal field and surrounding geological formations. Particular attention is devoted to innovative data acquisition, organization, and interpretation methodologies. Large heterogeneous datasets generated by the monitoring network are processed through advanced deconvolution algorithms and signal analysis procedures aimed at isolating transient thermal behaviors, identifying thermal interference phenomena among boreholes, and detecting operating anomalies in real time. The proposed framework supports the extraction of physically meaningful indicators describing the thermo-energetic performance of the geothermal storage volume under variable seasonal operating conditions. The study further explores the integration of the monitoring platform with AI-oriented predictive models for subsurface temperature trend forecasting and adaptive plant management. By combining thermophysical measurements, climatic variables, operational parameters, and historical datasets, the system enables predictive analyses capable of optimizing the switching logic between geothermal and air-source heat pumps. This approach contributes to improving seasonal energy efficiency, reducing thermal imbalance within the ground, enhancing long-term sustainability of the geothermal resource, and supporting predictive maintenance strategies. The presented methodology demonstrates how high-density thermal monitoring combined with advanced data analytics and artificial intelligence can represent a key enabling technology for next-generation hybrid geothermal systems in complex urban buildings and university campuses.

Integrated geothermal assessment of the Aeolian Archipelago within the IRGIE Project

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Keywords: volcanic islands, energy transition, geothermal energy.

Small islands face significant energy challenges due to geographic isolation and limited infrastructure. This is especially relevant for the Aeolian Islands, located in the Southern Tyrrhenian Sea (Italy), an archipelago not connected to the mainland electrical grid and relying primarily on diesel-based power generation. The annual diesel consumption across the archipelago to meet energy demand is approximately 13,000 tonnes, highlighting the urgent need to harness local renewable energy sources. The IRGIE project (Inventory of Geothermal Resources of the Aeolian Islands, 2023-2026), led by INGV and funded by Regione Siciliana, aims to identify and characterise geothermal resources within the Aeolian Archipelago and to estimate their theoretical and technical potential. IRGIE represents the first stage of a broader geothermal exploration program and adopts a multidisciplinary approach, integrating new geochemical and geophysical data to support numerical modelling, technological development, and data infrastructure, alongside the analysis of social aspects related to the geothermal resource. The results highlight a clear west-east contrast across the archipelago. Vulcano, Lipari, and Panarea show the most evident hydrothermal manifestations, including fumaroles, thermal springs and wells, and diffuse onshore and offshore degassing. Estimated geothermal reservoir temperatures at Vulcano and Lipari reach approximately 180-220°C and 150-180°C, respectively. Low-resistivity anomalies imaged by audio-magnetotelluric data suggest the occurrence of hydrothermally altered zones overlying potential shallow geothermal reservoirs (<600 m below sea level). The moderate resistivity contrasts, together with the relatively low discharge rates of the hydrothermal manifestations in all the active islands, suggest limited circulation within the shallow geothermal reservoirs. These constraints can limit the feasibility of conventional geothermal exploitation approaches shifting technological interest toward non-conventional solutions, such as closed-loop systems, total reinjection strategies and zero emission plants. In addition to scientific-technical investigations, the project integrates communication and social engagement components to increase geothermal awareness through educational activities and interactive tools. Citizen and stakeholder engagement assessments, utilizing mixed-method approaches such as surveys and focus groups, reveal a generally positive perception of geothermal energy. Findings highlight a significant demand for transparency and high trust in scientific institutions, contrasted by a pronounced scepticism toward decision-makers. The IRGIE project thus provides a replicable framework for the early-stage geothermal assessment in small volcanic islands, integrating resource characterization, technological screening and social engagement to support the path towards energy autonomy and valorisation of local renewable resources.

3D seismic tomography of the Acquasanta Terme geothermal system: insights from LSQR inversion and PRISM processing

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Keywords: Acquasanta Terme, geothermal system, recharge area.

The Acquasanta Terme anticline, located in the Central Apennines (Italy), is an east-verging structure extending N-S for about 30 km, at the centre of which, near the town of Acquasanta Terme, sulphate-chlorinated thermal waters with temperatures above 30°C are discharged (Boni et al., 1986). The characterization of deep fluid circulation in the Acquasanta Terme hydrothermal system remains an outstanding issue, as its complex hydrogeological conceptual model is not fully defined yet. This study presents a high-resolution 3D seismic tomography of the area, aimed at defining the geometry of the carbonate reservoir and its recharge mechanisms.

The model was reconstructed using a comprehensive dataset of waveforms and arrival times sourced from the ITACA and INGV networks. We applied a 3D tomographic inversion based on the LSQR (Least Squares QR-factorization) algorithm, an iterative method particularly efficient for solving large, sparse systems of linear equations typical of crustal seismology. Data processing and ray tracing were performed using the PULSE (Passive sUb-surface LSqr sEismic tomography) module of the PRISM (Physics-informed Ranking and Integrated Subsurface Modeler) software (Mangiagalli et al., 2026), enabling robust integration of topography and complex geological interfaces.

The resulting Vp and Vs models provide an unprecedented view of the subsurface velocity structure down to 6 km beneath *Acquasanta Terme*. The analysis of velocity anomalies and Vp/Vs ratios highlights significant lateral heterogeneities. In particular, the inversion reveals two low-wave-velocity-ratio corridors: a western sector, interpreted as a deep-seated flow path connected to the fractured Mesozoic carbonates of the Sibillini Mountains, and a south-eastern sector, where fluid infiltration appears facilitated by the *Valle Castellana* thrust.

These results demonstrate the effectiveness of the LSQR-PULSE workflow in imaging complex geothermal systems and provide a revised conceptual model for the *Acquasanta Terme* hydrothermal circulation.

Boni C. et al. (1986) - Schema idrogeologico dell'Italia centrale. Mem. Soc. Geol. It., 35, 991-1012.

Mangiagalli M. et al. (2026) - An open-source workflow from public Italian subsurface data to improve techno-economic assessment of direct use of geothermal energy: PRISM, PULSE, CRAFT, Waiwera and GEOPHIRES-X softwares. In: Congresso Congiunto SGI-SIMP, Abstract book, Padova, 15-17 settembre 2026.

Unlocking closed-loop technologies: Navigating constraints and disruptive potential

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Keywords: closed-loop, technology, innovation.

The geothermal industry stands at a decisive crossroads. The next decade will determine its role as a cornerstone of the global energy transition. While traditional geothermal systems face hurdles—ranging from public opposition due to seismic risks to financial barriers like high upfront costs and slow returns—Closed-Loop Geothermal (CLG) systems emerge as a potential game-changer.

By circulating working fluids through sealed, rock-insulated systems, CLG technology bypasses the environmental and social "friction" of standard production. This work explores the shift from theoretical promise to technical reality, analyzing the surge in research and the strategic opportunity to repurpose unproductive or abandoned oil and gas wells.

However, disruption comes with constraints. Our findings indicate that CLG systems, when coupled with Organic Rankine Cycle (ORC) conversion, reach economic and technical viability primarily in high-enthalpy environments: specifically, where temperatures exceed 150°C. This necessitates deep drilling in high-gradient areas (>45°C/km) or targeting "hot spots" like *Campi Flegrei* (>100°C/km). While innovative designs are rapidly evolving, the transition from "promising" to "market-ready" hinges on large-scale demonstration tests. This keynote will navigate these technical boundaries, evaluating whether CLG is the definitive solution to bridge the gap between geothermal potential and a sustainable, bankable future.

Coupled geothermal wellbore-reservoir simulation using T2Well-EWASG: Insights from the Alaşehir case study

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Keywords: geothermal energy, wellbore modelling, non-condensable gases.

Geothermal systems are inherently dynamic, and their sustainable development requires a detailed understanding of fluid and heat transport processes occurring across multiple spatial and temporal scales. While reservoir-scale numerical models are widely used, the representation of wellbore processes under transient conditions remains a critical knowledge gap, particularly in systems containing non-condensable gases.

In this study, we present a fully coupled wellbore-reservoir numerical model applied to the Alaşehir geothermal field, a reference case extensively documented in the literature (Aydin & Akin, 2020). The model is constructed using publicly available geological, thermal, and fluid data and a three-dimensional computational grid generated using VORO2MESH (Bonduà et al., 2017), a pre-processing tool developed at the University of Bologna. The methodological novelty lies in the explicit coupling of the wellbore with the reservoir domain using T2Well-EWASG (Vasini et al., 2018), an enhanced coupled wellbore-reservoir simulator of the TOUGH-family of codes (LBNL), developed at the University of Bologna in collaboration with Saipem S.p.A.. T2Well-EWASG allows for a consistent treatment of multiphase flow, heat transfer, and saline brine containing non-condensable gases in both production and reinjection wells.

The model is used to analyze pressure, temperature, and two-phase flow evolution along the production well, including opening and shut-in transients, highlighting the role of wellbore dynamics in controlling system response. Special attention is devoted to the presence of CO_2, examining its influence on pressure transients, flow regimes, and wellbore deliverability. Numerical results are visualized and analyzed using TOUGH2Viewer (Bonduà & Bortolotti, 2020), a post-processing tool developed at the University of Bologna. Results indicate that gas exsolution processes upon fluid boiling significantly affect wellbore transients and deliverability.

These findings demonstrate that coupled wellbore-reservoir processes constitute a key component of the behavior of geothermal fields under exploitation and should be explicitly considered when assessing resource performance and sustainability. The proposed approach provides a geoscience-based framework for interpreting coupled wellbore-reservoir dynamics at the field scale and supports the use of advanced wellbore modelling tools to improve the understanding and management of geothermal resources, including systems characterized by a complex fluid composition.

The authors gratefully acknowledge Eni S.p.A. for the fruitful collaboration that contributed to the results presented in this paper.

Aydin H. & Akin S. (2020) - Numerical Reservoir Simulation of Alaşehir Geothermal Field. In: Proceedings of the 45th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, February 10-12, 2020, SGP-TR-216.

Bonduà S. & Bortolotti V. (2020) - TOUGH2Viewer 2.0: A multiplatform tool for fully 3D Voronoi TOUGH grids. SoftwareX, 12, https://doi.org/10.1016/j.softx.2020.100596.

Bonduà S. et al. (2017) - 3D Voronoi pre- and post-processing tools for using the TOUGH2 family of numerical simulators for hydrocarbon gas migration. In: Offshore Mediterranean Conference and Exhibition 2017 (OMC 2017), March 29-31, 2017.

Vasini E.M. et al. (2018) - Interpretation of production tests in geothermal wells with T2Well-EWASG. Geothermics, *73*, 158-167, https://doi.org/10.1016/j.geothermics.2017.06.005.

Fast tracking geothermal exploration while reducing costs and subsurface uncertainty

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Keywords: geothermal exploration subsurface uncertainty, multiphysics modelling.

Accelerating geothermal deployment requires exploration strategies that can rapidly screen large areas, focus investments on the most prospective targets, and continuously refine subsurface models as new data become available. We present a multiscale, multiphysics workflow inspired by recent integrations in machine learning and AI-enhanced subsurface imaging. At the regional scale, probabilistic geological modelling is compared against well-established methods such as gravity and magneto-telluric. At the local scale, geophysical inversions are compared against geological data. We discuss applications to geothermal systems and expand on their impact on the blooming of the geothermal market. Such an approach shows how financially-affordable and environmentally non-invasive methods can help reducing subsurface uncertainty during the exploration phase and save costs to support the growth of the geothermal sector.

A geochemical web portal for geothermal fluids to support geothermal exploration in Italy

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Keywords: geochemistry, geochemical data, web-portal.

Fluid geochemistry is a cost-effective and reliable tool for gaining insights into several characteristics of low-to-high enthalpy geothermal systems. Although a vast amount of geochemical and isotopic data on fluids of (potential) geothermal interest has been collected worldwide, these data appeared scattered and fragmented in the available published literature and databases. In addition, these data exhibit inconsistencies due to the intrinsic heterogeneity in format and provenance of geochemical data. These limitations make the exploration and examination of such datasets challenging and cumbersome.

A free-access web portal offering detailed and coherent published and newly geochemical data of geothermal fluids (thermal springs, mineral waters, gas-rich waters and gas vents) can play a key role in simplifying and accelerating preliminary reconnaissance stages of geothermal exploration and, simultaneously, boosting and fostering the exploitation of geothermal resources. To address this challenge, we have created, in the framework of the Emotion Project funded by the research program *Pianeta Dinamico* INGV-MUR (*Istituto Nazionale di Geofisica e Vulcanologia - Ministero dell'Università e della Ricerca*), an innovative free-access national web portal designed to centralise, standardise, visualise and distribute geochemical and isotopic data of geothermal manifestations in Italy: The Geochemical web portal for geothermal fluids in Italy.

This web portal, upholding the FAIR principles -Findable, Accessible, Interoperable, and Reusable-, is specifically designed to: 1) collect and harmonise existing and newly acquired geochemical and isotopic data on central-northern Italy, through dedicated data and metadata structures; 2) standardise and homogenise both geochemical and isotopic data with geospatial parameters; 3) store data and metadata in a centralised, structured and dedicated database; 4) issue interactive maps for intuitive spatial data visualisation and customisable geochemical plots. The web portal assembles about 4,500 samples of geothermal fluids that can be geographically visualised based on type categories and compositional information, as the user prefers.

The web portal has been developed using the Free Open Source Software (FOSS) R project for statistical computing and specific modules for interactive exploratory data analysis, such as "Shiny", "Plotly" and "Leaflet". To encourage accessibility, openness and repeatability, all source codes as well as (meta)data are publicly available, and access to the web-portal is free-of-charge. (Meta)data use a language that promotes interoperability and reusability with any applications for storing, analysing and processing.

This web portal aspires to serve as a scalable model for analogous initiatives and an essential component of monitoring to ensure efficient and sustainable energy extraction, also encouraging stakeholders and researchers to create increasingly holistic infrastructures and platforms to achieve shared goals.

S26.

Innovative materials and processes: From the laboratory to the real world application

CONVENERS & CHAIRPERSONS:

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Alkali activated slag binders: Examples of real industrial applications

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Keywords: blast furnace slag, restoration, pollutant immobilization.

Alkali activated binders using granulated and ground blast furnace slag (GGBS) as the precursor alumino-silicate material (AAS) are well known and have been proposed since the early twentieth century. However, the examples of clinker-free industrial applications of AAS are scarce. This is the result of the coupled effect of availability and price of GGBS. Yet AAS has some specific characteristics which make it apt to be used in applications which make it the material of choice. In the following we present our experience through three case studies.

The first example is the realization of outdoor paving systems. One part AAS has been used to realize both pervious and non-pervious floors for outdoor parks and gardens. The specifications to be met were flexural strength > 5MPa, chemical stability in aggressive and oxidizing environment and aesthetic qualities matching or surpassing resin-bonded pavements. A a blend of normal and ultrafine slag activated with Na_2CO_3 and $Ca(OH)_2$ was used, with the surface being deactivated to expose the selected aesthetic aggregates. The advantage over Portland cement is a wider open window for water-jet cleaning of the deactivated surface, a critical necessity for the working site.

The second example is the production of materials for the restoration of heritage artworks. The demand was to have a compatible material, capable of being used as an aerated low-density compound. These requirements were met using ultrafine slag only, activated with the minimum possible quantity of the Na_2CO_3 and $Ca(OH)_2$ activator. A system with an extremely low amount of soluble mobile salts was obtained, which was used to restore the terracotta statue of St. Januarius and St. Procolus from the Flavius amphitheater of Pozzuoli. The same material will now be tested for the restoration of the statues of the Dornava castle in Slovenia. Where necessary the rheology and plasticity of the material was controlled with the addition of precipitated silica, while lightweight foams were prepared by air entraining using a selected blend of surfactants.

The third case is the immobilization of potentially toxic materials. This application concerns both the reclaim of polluted soils or of industrial wastes, where the pollutant immobilization occurs during the AAS hydration, and the capture of heavy metals from contaminated waters by the use of hardened granulated AAS. The immobilization of the pollutants occurs by the joint mechanisms of adsorption onto the hydrated phases and of hydrate precipitation onto the highly alkaline surfaces. For this application Na_2CO_3 and $Ca(OH)_2$ were used as activators in some instances, while calcium aluminates were used in others. The calcium aluminates used were constituted by Al killed ladle steel slag, thus further contributing to the implementation of circular economy.

Synergistic thermo-mechanical activation of low-grade polymineralic clays for sustainable alkali-activated binders

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Keywords: geopolymers, polymineralic clays, thermo-mechanical activation.

The modern construction industry is urgently called upon to address the need for decarbonization by seeking sustainable alternatives to ordinary Portland cement (OPC), whose production is responsible for a significant share of global CO_2 emissions. Within this scenario, alkali-activated binders (AABs) derived from widely available clays represent a strategic alternative, especially when integrated into circular economy frameworks that involve the recovery of industrial waste. This study focuses on optimizing activation protocols for low-grade polymineralic clays, both natural and as waste residue. The research involved a fundamental characterization phase of two heterogeneous clayey precursors: a natural clay from the Italian Apennines (Campomaggiore, CC) and tunnel excavation spoils from the London area (London Clay, LC). Both materials are dominated by 2:1 phyllosilicate, which are notoriously refractory to conventional thermal treatments due to their structural stability. Through a systematic evaluation of thermal (T), mechanical (M), and combined (T-M and M-T) pre-treatments, an optimal synergistic protocol was identified. The experimental results, obtained via X-ray diffraction with Rietveld refinement, laser diffraction particle size analysis (PSD), and dissolution tests in 8 M NaOH analyzed by ICP-MS, demonstrate that a moderate calcination at 600°C followed by just 10 minutes of high-energy ring-milling unlocks a reactive fraction of approximately 65 wt.%. This T-M approach minimizes the thermal input compared to standard high-temperature calcination, leveraging mechanical comminution as the driving force for both the amorphization of the residual illitic fraction and the refinement of the particle size distribution, achieving an optimal d50 of ~2 μm. Conversely, thermal treatments (up to 900°C) and the M-T sequence yielded high structural disorder (up to ~70 wt.% amorphous phase) but severely compromised chemical solubility due to particle sintering and loss of specific surface area (yielding a maximum reactive fraction of 45 wt.% for the solely calcined clay and 55 wt.% for the M-T protocol). The optimization of the precursor pre-treatment is aimed at the formulation of alkali-activated binders for the stabilization of marine dredged sediments within a framework of environmental and economic sustainability.

Mechanical stabilization of marine dredged sediments using alkali-activated clay binders

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Keywords: geopolymers, polymineralic clays, soil stabilization.

The management and disposal of marine dredged sediments present a significant environmental and logistical challenge for coastal infrastructure. Although these materials are highly complex from a geotechnical perspective, they can become a valuable resource if treated using appropriate stabilisation methods. Traditional methods make extensive use of ordinary Portland cement (OPC), a practice that conflicts with the growing need for low-environmental-impact solutions aimed at reducing carbon emissions. In this scenario, alkali-activated materials (AAMs) synthesized from widely available or waste-derived clays offer a highly sustainable alternative for soil improvement, enabling the transition toward a circular economy. To evaluate the potential of these materials in geotechnical applications, a thermally activated illitic clay was utilized as a standard reference precursor for the mechanical stabilization of marine dredged sediments. This geopolymeric binder was incorporated into the sediments at various dosages (8, 16 and 32 wt.% of the dry mass of the sediments) to assess its impact on the material's geomechanical behavior. Specifically, the chemical activation was triggered by the direct addition of solid sodium hydroxide (NaOH), which reacted with the seawater naturally present within the dredged spoils to initiate the geopolymerization process. Experimental data show a notable improvement in the treated soil's consistency indices (reaching a value of 0.7 after 60 days of curing in the 32 wt.% mix), with the liquid limit increasing from 45% to 64% at the highest dosage, and a significant enhancement of its overall mechanical performance. Preliminary uniaxial compressive strength (UCS) tests performed after 28 daysshowed promising results, with the stabilized mixtures exhibiting mechanical properties comparable to those prepared using conventional OPC-based treatments. Alongside mechanical improvements, experimental monitoring revealed volumetric shrinkage dynamics when samples were cured in unconfined air. These phenomena provide interesting insights into the early-age behavior of the geopolymeric matrix, prompting ongoing investigations into targeted curing protocols to optimize long-term dimensional stability. Overall, these encouraging findings suggest that the tested clay-based binders can be effectively used to improve the mechanical properties of dredged sediments.

Organic petrography for optimization of biochar production and performance for wastewater treatment

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Keywords: carbon, water remediation, sustainability.

Biochar is the carbonaceous material resulting from thermochemical degradation of waste biomass in oxygen-limited environment. Its production process concentrates carbon in a stable, inertinite-like structure, making it a compelling candidate for global-scale carbon sequestration. Its current main application is soil amendment, however, widespread adoption requires proven viability also for high-added value applications, such as water treatment. In fact, biochar bears potential for environmental remediation owing to its physical-chemical properties but applicability using commercially available materials remains largely unexplored (Animali et al., 2025).

Nine commercial biochar have been employed to carry out adsorption experiments to remove harmful heavy-metal contaminants (Pb^{2+} and Cr^{3+}) from aqueous solutions. Recorded performance is either on-par or better than that obtained with purpose-made biochar produced in laboratory settings. Nevertheless, key removal mechanisms and performance reproducibility are strictly tied to biochar properties. In turn, such properties largely depend on the kind of employed biomass and carbonization level achieved throughout biochar production (Weber & Quicker, 2018). In this context, reflectance analysis and micro-Raman spectroscopy have been employed as novel characterization techniques to survey commercial biochar's carbonization level and gather insight for production optimization. In fact, they allow the detection of biochar's internal variability providing evaluation of property uniformity across batches and of environmental recalcitrance for carbon sequestration purposes (Mitillo et al., 2026). Results underscore the need for overarching standardization efforts for biochar materials.

Testing performance constraints of commercial biochar constitutes a necessary stepping stone for its use in global-scale carbon removal strategies. Subsequently, performed work directly supports efforts put towards Objectives 6 and 13 of the 2030 Agenda for sustainable development and circular economy frameworks.

Animali L. et al. (2025) - Characterization and evaluation of commercial biochar for surface water purification. Sustain. Horiz., 15, 100145.

Mitillo N. et al. (2026) - Assessment of commercial biochar's stability: Insights from organic petrography and micro-Raman Spectroscopy. Int. J. Coal Geol., 104978.

Weber K. & Quicker P. (2018) - Properties of biochar. Fuel, 217, 240-261.

K and Na zeolite synthesis from mixtures of agricultural and industrial alumina wastes

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Keywords: K and Na zeolite, biomass, industrial alumina wastes.

Rice husk (RH) is an abundant by-product of rice processing. Most rice husks are incinerated, producing a solid waste known as rice husk ash (RHA). RHA contains organic components (cellulose and lignin) and both crystalline and amorphous inorganic silica.

Among industrial aluminum wastes, those derived from bauxite processing (red mud - RM) and aluminum alloy production are the most prevalent. In this study, we used a sample of RM and a metallurgical by-product (ARG). In detail, Italian RHA+RM and RHA+ARG were used as sources of silica and alumina for the synthesis of potassium-sodium zeolites. The synthesis involved a hydrothermal process following pre-fusion with KOH or NaOH, using either distilled water or seawater.

The results demonstrate how the chemical composition of these industrial wastes influences the synthesis outcomes. Specifically, after KOH pre-fusion, the hydrothermal process led to the formation of merlinoite instead of chabazite. In contrast, NaOH pre-fusion treatment resulted in the formation of LTA and zeolite X instead of katoite. In detail, the data indicate the crystallization of two types of K-zeolite: merlinoite from the RHA+RM mixture and chabazite from the RHA+ARG mixture, regardless of the solution type used. However, the NaOH pre-fusion method yielded LTA and zeolite X only when using the RHA+ARG mixture, while katoite formed from the RHA+RM mixture. All synthesized products can be effectively utilized to remove toxic elements from contaminated water.

In conclusion, these findings demonstrate the feasibility of synthesizing potassium and sodium zeolites using rice husk ash as a silicon source and industrial aluminum wastes as alumina source. This integrated waste management approach offers a sustainable strategy for increasing the recycling of diverse industrial by-products, consistent with circular economy principles. Furthermore, using seawater as an alternative aqueous medium for synthesis promotes efficient use of water resources.

Water strategy to control EDI and CHA-type zeolite synthesis from kaolinite and bentonite

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Keywords: clay minerals, KOH-pre-fused hydrothermal process.

Due to their chemical composition, clay minerals have been used as raw materials for zeolite synthesis. However, although numerous data have documented the crystallization of sodium zeolites, to our knowledge, very few studies have investigated and compared the synthesis of zeolite from kaolinite and bentonite by hydrothermal processing after KOH pre-fusion. This study addresses this gap. The Clay Mineral Society kaolinite standard (KGa-1) and a commercial bentonite sample (C-Bent-1) were used as raw materials for zeolite synthesis using distilled water or seawater, with the volume doubled from 2.5 to 40 ml in each run, maintaining the same solid mass.

The results indicate that at very low water contents, N-type zeolite (EDI type) forms from both raw materials and both solutions. By doubling the water content, the EDI-type zeolite predominates in KGa-1; the use of seawater enhances the crystallization of CHA in C-Bent-1. A larger amount of solution (20, 40 ml) controls the formation of chabazite along with the chabazite-merlinoite intergrowth (CHA-MER) using commercial bentonite. Interestingly, CHA crystals also form from kaolinite via a hydrothermal process with 20 ml of seawater.

These laboratory data confirm the crucial role of water in controlling the crystallization process, specifically regarding its effect on Si and Al dissolution and the variation in alkalinity. Improving our understanding of the processes is a fundamental prerequisite for developing reliable and practically applicable synthetic processes for these minerals (zeolites), which can be used in a variety of contexts. The goal is to form specific types of zeolite while minimizing the use of a precious resource like water and using low-cost and widely available natural sources such as clay minerals.

Management and upcycling of waste-to-energy side-streams

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Keywords: MSWI residues, alkali-activated materials, circular economy.

This research evaluates the physicochemical characteristics and resource recovery potential of Municipal Solid Waste Incineration (MSWI) residues, addressing the technical and regulatory challenges that hinder their integration into a circular economy and their valorization as potential low-carbon building materials when used as Supplementary Cementitious Materials (SCMs).

The rapid global increase in Municipal Solid Waste production has promoted the adoption of Waste-to-Energy (WtE) systems, which reduce waste volume while producing heat and energy (Chen et al., 2024). However, these processes produce large quantities of solid by-products: non-hazardous bottom ash (BA) and hazardous fly ash (FA), the latter enriched in heavy metals and toxic organic pollutants (Liang et al., 2024; Aghabeyk et al., 2025).

This study investigates bottom ash (BA) batches supplied by NOAH (Norway) and fly ash (FA) from Italian WtE facilities. Both BA and FA are characterized through a multi-analytical approach, including X-Ray Fluorescence (XRF), X-Ray Powder Diffraction (XRPD) with qualitative and quantitative analysis, and Scanning Electron Microscopy (SEM). The amorphous glassy fraction, representing the reactive part in alkaline solution, is quantified by XRPD using an internal standard, and its composition is estimated by mass balance calculations.

Bottom ash samples (BA 205 and BA 209) show a silica-rich composition (≈50 wt.% SiO_2) with significant sodium content. The presence of metallic Al and heavy metals poses a challenge for the management of possible expansion phenomena and leaching. Laboratory-scale alkaline activation of bottom ash is performed, using sodium aluminate ($NaAlO_4$), sodium hydroxide (NaOH) and sodium silicate solution, with metakaolin ($Al_2Si_2O_7$) as co-precursor. Specific formulations are selected based on target molar ratios (Na/Al ≈ 1.1, Si/Al ≈ 2.2), consistent with average N-A-S-H composition. Thermodynamic modeling is used to simulate chemical equilibria under alkaline conditions and to optimize mix design.

A key objective is to identify formulations that mitigate aluminum-related reactions, such as hydrogen gas formation and bubbling, which generate porosity and compromise mechanical integrity. Mechanical strength of molded samples is evaluated using a hydraulic press after two weeks of curing at ambient temperature or 60°C.

The same procedures are applied to fly ash, with the additional goal of evaluating leachability of hazardous elements. Fly ash presents greater challenges due to its heterogeneous morphology, high chloride concentrations (≈280,000 ppm) and hazardous levels of lead, zinc, and chromium. Chemical mapping and digital image analysis (DIA) provide further insights into this complexity.

By stabilizing leachable elements and controlling expansive reactions, this study contributes to ongoing efforts to improve the safe management and reuse of MSWI residues, e.g. in construction applications.

Aghabeyk F. et al. (2025) - Physicochemical characterization and resource recovery potential of hazardous municipal solid waste incineration (MSWI) fly ash and air pollution control (APC) residues in the Netherlands. J. Environ. Manag., 384, 125579, https://doi.org/10.1016/j.jenvman.2025.125579.

Chen B. et al. (2024) - Advances in using municipal solid waste incineration (MSWI) bottom ash as precursor for alkali-activated materials: A critical review. Resour. Conserv. Recycl., 204, 107516, https://doi.org/10.1016/j.resconrec.2024.107516.

Liang D. et al. (2024) - The Resource Utilization and Environmental Assessment of MSWI Fly Ash with Solidification and Stabilization: A Review. Waste Biomass Valoriz., 15(1), 37-56, https://doi.org/10.1007/s12649-023-02275-5

On-field exploration of natural pozzolans for sustainable cement production integrating LIBS and machine learning approaches

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Keywords: LIBS, natural pozzolans, cement.

The replacement of Portland clinker with supplementary cementitious materials (SCMs) is one of the most effective strategies for reducing CO_2 emissions associated with cement production (Habert et al., 2020). Among SCMs, natural pozzolans (NPs) represent a widely available volcanic resource, although their industrial exploitation is often limited by strong compositional heterogeneity and by the absence of rapid field-based characterization methods. Conventional laboratory analyses, such as XRF and XRD, provide accurate compositional information but remain time-consuming, expensive, and unsuitable for real-time geological exploration. This work investigates the use of portable Laser-Induced Breakdown Spectroscopy (LIBS) combined with multivariate statistics and machine learning techniques as an innovative approach for rapid on-field classification of NPs for cement applications. A dataset composed of raw LIBS spectral emission lines from NPs of different Mediterranean provinces was analyzed using Principal Component Analysis (PCA), t-distributed Stochastic Neighbor Embedding (t-SNE), unsupervised and supervised machine learning autoencoder architectures. The results demonstrate that raw LIBS spectra alone are sufficient to identify distinct geochemical clusters corresponding to different magmatic affinities. Materials characterized by low SiO_2 and high Fe-Mg contents, associated with basic to ultrabasic volcanic compositions, are clearly separated from silica-rich acid pozzolans. Among the tested approaches, supervised machine learning achieved the highest classification accuracy in cross-validation tests and significantly outperforming conventional linear dimensionality-reduction methods. Mechanical testing through Activity Index measurements at 90 days further revealed a consistent relationship between silica-rich clusters and improved pozzolanic performance. Although the observed trend is linked to total silica rather than directly measured reactive silica, high-SiO_2 materials generally exhibited superior mechanical behavior, while low-silica compositions showed lower reactivity. The proposed LIBS-machine learning framework represents a fast, non-destructive, and field-deployable exploratory methodology capable of providing immediate compositional screening of volcanic deposits. This approach can support rapid decision-making during geological exploration, optimize sampling strategies, and accelerate the identification of promising SCM resources for low-carbon cement production.

Habert G. et al. (2020) - Environmental impacts and decarbonization strategies in the cement and concrete industries. Nat. Rev. Earth Environ., 1(11), 559-573, https://doi.org/10.1038/s43017-020-0093-3.

Influence of nano MgAl-NO_3 and MgAl-HCOO layered double hydroxide on the hydration and microstructure of cement paste

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Keywords: layered double hydroxide, cement hydration, durability.

Improving the durability of cement-based materials through functional additives is a strategy for reducing the environmental impact of cement production (Raghav et al., 2021). Among emerging additives, Layered Double Hydroxides (LDHs) have attracted growing interest due to their tunable composition, high specific surface area, and anion-exchange capability (Zhai et al., 2022; Wang & O'Hare, 2012). Despite increasing research activity, gaps remain in understanding how LDHs interact with the cement matrix at the chemical and microstructural level. In this work, nano-sized Mg-Al-NO_3/HCOO LDHs were synthesised via an ultrasound-assisted co-precipitation method and comprehensively characterised in terms of structure, morphology, and chemical composition. The effect of two nano-LDHs with different intercalated anions (MgAl-NO_3 and MgAl-HCOO) on Portland cement (CEM I) hydration kinetics, hydration product formation, and pore structure evolution was then investigated. To this end, in situ X-ray diffraction (XRD) with Rietveld quantification, isothermal calorimetry, and 3D X-ray microtomography (μ-CT) were combined to correlate chemical behaviour with microstructural changes at different curing stages. In situ XRD and calorimetry show that, during early hydration, LDHs capture SO_4^{2-} ions, inhibiting early ettringite precipitation and promoting portlandite formation after the first 24 hours. MgAl-HCOO reduces Ca^{2+} availability in solution, limiting the precipitation of calcium-rich phases and slowing alite (C_3S) dissolution. μ-CT data are currently being processed to quantify the 3D pore network geometry and spatially resolve LDHs distribution within the cement matrix, providing microstructural evidence of their possible nucleation and pore-filling role. The results presented here contribute to a deeper understanding of the role of selected nanomaterials in early cement hydration, microstructure and durability. They also highlight possible adverse effects and support the development of effective incorporation strategies for cement systems. The integrated approach further enables the rational design of engineered cements with a reduced environmental footprint and improved mechanical performance.

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Raghav M. et al. (2021) - Review of the Effects of Supplementary Cementitious Materials and Chemical Additives on the Physical, Mechanical and Durability Properties of Hydraulic Concrete. Materials, 14, 7270.

Wang Q. & O'Hare D. (2012) - Recent advances in the synthesis and application of layered double hydroxide (LDH) nanosheets. Chem. Rev., 112(7), 4124-4155.

Zhai M. et al. (2022) - Layered double hydroxides (LDHs) modified cement-based materials: A systematic review. Nanotechnol. Rev., 11(1), 2857-2874.

Additive Manufacturing of geopolymers across scales: From functional architectures to extra-terrestrial construction

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Keywords: additive manufacturing, geopolymers, IRSU.

Additive manufacturing is opening new opportunities for the processing of alkali-activated materials and geopolymers, enabling the fabrication of architected porous structures with controlled geometry, hierarchical porosity and tailored transport properties. In particular, extrusion-based techniques such as Direct Ink Writing (DIW) are especially suitable for geopolymer processing, thanks to the intrinsic shear-thinning rheology of the slurries and their ability to consolidate at near-ambient temperature without sintering.

Our research has demonstrated how the combination of material design and additive manufacturing allows the development of multifunctional structures for environmental and catalytic applications. The intrinsic mesoporosity and ion-exchange capability of geopolymers make them promising adsorbents for water treatment and gas capture, while their processability enables the fabrication of highly permeable lattices and monoliths with optimized fluid-dynamic behavior. Moreover, geopolymer matrices can act as versatile binders for active phases such as zeolites, activated carbons, hydrotalcites, preserving accessibility to the functional sites while providing mechanical integrity and shape control. Zeolite-geopolymer composites produced by DIW have demonstrated excellent performances in CO_2 capture and catalytic processes. The possibility of tailoring the binder microstructure and of integrating catalytic or adsorptive phases within these printable matrices also enables the fabrication of structured heterogeneous catalysts, combining high accessibility of active sites with low pressure drop and improved mass transfer. Examples include geopolymer lattices for biodiesel production, Cu/ZSM5-geopolymer monoliths for NH_3-SCR deNOx reactions, and structured zeolite A monoliths for carbon capture.

Beyond laboratory-scale functional materials, extrusion-based additive manufacturing of geopolymeric systems is also emerging as a strategic technology for large-scale sustainable construction. The scalability of DIW, from centimetre-sized functional components to architectural elements, together with the possibility of exploiting local raw materials and low-energy consolidation routes, makes these materials particularly attractive for extra-terrestrial applications. Recent activities within the ASI-funded GLAMS (Geopolymers for Lunar Additive Manufacturing and Sensing) project demonstrated the feasibility of additive manufacturing of alkali-activated lunar regolith simulants, highlighting both the opportunities and challenges associated with processing under reduced-pressure and lunar-like conditions. These developments suggest that additive manufacturing of alkali-activated materials may represent a key enabling technology for future in-situ resource utilization (ISRU) strategies for lunar infrastructures, where local regolith could be transformed into functional and structural components directly on the Moon.

Fault-controlled heavy-metal mineralization in the Southern Alpine Basement: Toward the valorization of excavation materials

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Keywords: critical raw materials, excavation waste, heavy metal mineralization.

The study area is located in southern Switzerland and belongs to the pre-Alpine basement of the Southern Alps. It is bounded by the south-verging thrust of the Upper Orobic Nappe over the Varesotto slices (S), the Val Colla Fault (W) and the Lugano Fault (E), a Jurassic extensional structure reactivated during Alpine compression. The exposed lithologies are dominated by paragneisses, schists, and orthogneisses affected by Variscan amphibolite-facies metamorphism, locally preserving mafic relics recording eclogite-facies conditions. During the Alpine cycle, including Jurassic extension and Cenozoic collision, these rocks likely remained at temperatures below ca. 180°C. Heavy-metal mineralization, including gold, is associated with the Val Colla Fault, but its timing remains poorly constrained (Permian-Cenozoic).

The study delineates heavy-metal enrichments along the planned route of a new motorway tunnel, located between the Val Colla and Lugano faults, by using geological mapping, geochemical analyses, and petrological investigations. The main finding is that heavy-metal enrichment is not uniformly distributed, but rather localised, structurally controlled and linked to two fault systems: (i) NE-SW-striking faults with left-lateral strike-slip kinematics and a normal component, and (ii) NW-SE-striking normal faults. Enrichment is located within ductile-brittle fault zones, especially in dark cataclasites (locally graphite-rich) and mylonitic gneisses. In contrast, light-coloured gneisses and porphyrites are barren.

Elevated concentrations of As, Sb, and Zn are linked to fine-grained sulfides (<100-200 μm), including arsenopyrite, bournonite, boulangerite, and sphalerite, hosted within intensely deformed rocks and carbonate veins formed during the circulation of alkaline, carbonate-rich fluids. Microprobe analyses indicate that vein carbonates mainly consist of Fe-rich dolomite-ankerite and, locally, Mg-rich siderite. Overall, our findings highlight deformation zones as the primary pathways and traps for heavy metals. Finally, although heavy-metal enrichment may represent a challenge for excavated material management, some of the identified elements, particularly Sb and As, are currently classified as Critical Raw Materials by the EU, highlighting the potential for selective treatment and valorisation of tunnel spoil as a secondary raw-material resource.

Biomass fly ash as an alternative solid activator for One-Part Alkaline Activated Materials production

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Keywords: AAMs, biomass fly ash, one-part alkaline activation.

Alkali-activated materials (AAMs) are amorphous aluminosilicate materials produced through the chemical activation of aluminosilicate-rich precursors. Despite they have emerged as promising eco-friendly materials for various applications, including construction, waste immobilization, fire-resistant systems, and environmental remediation, their environmental advantage is still constrained by the use of conventional chemical activators, typically sodium/potassium hydroxides and silicates, whose production is associated with high costs, embodied energy and CO_2 emissions. Biomass fly ash, a solid residue generated from the combustion of lignocellulosic biomass in energy cogeneration plants, represents a potential alternative solid activating source due to its intrinsic content of alkali and alkali-earth elements. This study investigates the use of biomass fly ash as a solid alkali activator for metakaolin in the preparation of one-part AAMs, in which the solid precursor and activator are only mixed with water. Two biomass fly ash samples with different chemical compositions, designated FaF and FaFm, were used for sample preparation. Both ashes were characterized by high contents of CaO and K_2O (CaO = 21.28-51.00 wt.% and K_2O = 9.50-16.05 wt.%, respectively), along with lower amounts of Na_2O and SiO_2 (Na_2O =1.47-5.51 wt.% and SiO_2 =2.59-2.26 wt.%, respectively). These oxides were predominantly present as soluble crystalline phases such as portlandite [$Ca(OH)_2$], sylvite [KCl], and aphthitalite [$(K,Na)_3Na(SO_4)_2$]. Mix design optimization was performed by varying the $(Na_2O+K_2O)/Al_2O_3$ molar ratio, liquid-to-solid ratio, and curing conditions. Samples were prepared using two processing routes: conventional mold casting and granulation using an Eirich EL1 multifunctional mixer to produce granules with controlled morphology and particle size distribution. Characterization techniques included compressive strength tests, XRD, FTIR, SEM-EDS, density measurements, water stability and water absorption analyses to investigate the physical, mechanical and microstructural properties of the synthesized materials. The developed AAMs exhibited satisfactory structural integrity and compressive strength values up to approximately 21 MPa. Mineralogical characterization of the hardened pastes revealed the formation of calcium-aluminate hydrate phases, indicating the development of a hybrid binder matrix in which geopolymeric gel coexists with cementitious reaction products typical of high-calcium alkali-activated systems. Granulated samples exhibited a slight formation of secondary salts, suggesting a reduced extent of reaction during the granulation process compared to their mold-cast counterparts. The results demonstrate the feasibility of using biomass fly ash as an alternative solid activator in one-part alkali-activated systems, highlighting its valorization potential for producing multifunctional AAMs within circular economy approaches.

Reducing mercury and antimony mobility in legacy mining soils through in situ magnesium hydroxide stabilization: The LIFE HERMES project

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Keywords: mercury, life hermes, remediation.

Mercury (Hg) is a naturally occurring element that has been mined and utilized by humans for millennia. Only in recent decades, however, have its severe risks to human health and the environment been fully recognized, leading to stringent international, European, and national regulations. To address this legacy pollution, the LIFE HERMES project introduces an innovative and highly scalable solution for the decontamination of soils primarily affected by Hg. Two historic mining sites were selected to apply this technology: the *Cerco de Almadenejos* site (CDA, 30,000 m^2) near the Almadén mine in Spain, and a pilot site (1,000 m^2) within the Le Lame dump at the *Abbadia San Salvatore* mine (ABSS) in Italy. Notably, this 1,000 m^2 pilot plot covers only a small fraction of the vast Le Lame area, which spans 120,000 m^2. The ABSS site presents a unique dual-contaminant challenge, as it is co-contaminated with Antimony (Sb), with soil leachates revealing critically high Sb concentrations exceeding 1,500 µg/L. The LIFE HERMES strategy relies on the in situ chemical stabilization of these heavy metals. The process involves amending the contaminated soils with a low-grade magnesium hydroxide, a sustainable by-product derived from the calcination of natural magnesite. Field operations are scheduled to commence at the end of June and conclude by September 2026, ensuring a swift and efficient application of the stabilizing matrix. Unlike disruptive ex situ methods, this approach is minimally invasive and highly cost-effective, adequately preserving the site's physical integrity and reducing negative impacts on the surrounding ecosystem. By stabilizing the contaminants directly on-site, the risk of dispersion during excavation or transport will be mitigated, ensuring a safer overall remediation process. Furthermore, the amendment provides long-term geochemical stability by converting the metals into less mobile forms. To rigorously verify the effectiveness of the stabilization and observe the reduction of metal mobility, a comprehensive geochemical monitoring program will be launched immediately after the soil mixing in September. This scheduled monitoring plan will span up to five years, periodically analyzing air, water, vegetation, and soil leachates. The inherent flexibility of the LIFE HERMES solution allows it to be tailored to specific site conditions and varying contamination gradients. Beyond chemical remediation, the project integrates ecological restoration through area revegetation and aims to repurpose the land.

Micro-tomography for the structural characterization of geopolymer consolidation interventions on siliceous and calcareous sand

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Keywords: micro-tomography, geopolymers, 3D quantitative analysis.

The consolidation of damaged mortars is a critical challenge in restoration, aiming to preserve both structural integrity and the authenticity of materials. Injection methods are commonly used but pose technical difficulties, as the consolidating mixtures must be fluid enough to penetrate deteriorated masonry while ensuring stability and preventing phase separation. The chemical-physical properties of the consolidant must also ensure compatibility and long-term durability. Geopolymers offer a sustainable solution with high mechanical performance and low environmental impact, adaptable to specific restoration needs. This study focuses on investigating the 3D microstructural properties of geopolymeric binders used as consolidation products, particularly how they distribute within the voids in tubes filled with sand, which mimic fractures in damaged mortar, and whether this distribution varies based on the type of sand used. Particularly, this study investigates the internal microstructure of ten geopolymer samples using three-dimensional X-ray computed microtomography (μCT). Each sample was scanned in three different sections (bottom, middle, and top) at a spatial resolution of 10 μm. Quantitative image analysis enabled the evaluation of total matrix volume, overall porosity, and the distribution of pore volumes, injection-induced air bubbles, and fractures, while excluding the intrinsic porosity of the grains. The analysis was carried out using the software Dragonfly, where several U-Net-based deep learning models were trained and optimized for the different classes of samples. These models allowed accurate segmentation of the geopolymer matrix, effectively excluding fractures and grain porosity from the analysis. Furthermore, quantitative analyses based on sphericity and volume enabled the separate identification of pores and injection air bubbles. The latter were often interconnected and characterized by significantly larger dimensions compared to the pores. The different sample classes exhibited highly variable microstructural features in terms of fracture distribution, pore size, and air-bubble content. Some samples showed a complete absence of fractures but a high concentration of injection bubbles, whereas others were dominated by extensive and wide fracture networks. This approach provides detailed three-dimensional information on the internal organization and heterogeneity of geopolymer matrices: the results demonstrate that the intrinsic properties of the different geopolymer matrices strongly influence the formation and distribution of fractures and air bubbles, which in turn play a critical role in determining the technical properties of the investigated geopolymers.

Fly ash-based alkali activated mortars for restauration: An example of application in the Benedettini Monastery of Catania (Italy)

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Keywords: alkaline activated materials, fly ash, mortars.

As the demand for sustainable and environmentally responsible practices in heritage conservation grows, the use of alternative materials such as alkali-activated fly ash has emerged as a promising solution. Fly ash, a pozzolanic byproduct of coal combustion, can be chemically activated with alkaline solutions to form durable binders suitable for restoration. These alkali-activated materials exhibit high mechanical strength, chemical stability, and resistance to environmental degradation, making them viable for the repair of historic structures. A key advantage of these systems lies in their high tunability: by adjusting parameters such as the SiO_2/Al_2O_3 ratio, alkali concentration, curing conditions, and incorporating additional precursors like metakaolin, it is possible to tailor the physical and hygric properties of the binder to closely match those of traditional materials. Moreover, their lower thermal conductivity and reduced carbonation rates present additional benefits in specific conservation contexts.

This work explores the application of alkali-activated fly ash mortars in the restoration of the Benedettini Monastery in Catania, a multi-layered cultural heritage sited in Sicily. As part of the PNRR CHANGES project -Spoke 6- (CUP-E63C22001960006), which promotes sustainable conservation strategies, various mortar formulations were developed using fly ash alone or blended with metakaolin and calcium-based additives. In parallel, the performance of different alkaline activators, namely sodium and potassium solutions, was assed.

The objective is to understand how these compositional parameters influence the mechanical, hygric, and chemical behavior of the resulting materials, with an emphasis on compatibility with historic substrates and long-term durability in conservation contexts.

Benedettini Monastery serves as a practical case study showing the effectiveness of these innovative binders in real-world conservation.

Sustainable geopolymer catalysts for photo-Fenton treatment of industrial wastewater: The WASP project experience

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Keywords: geopolymer catalysts, photo-Fenton, wastewater recovery.

The development of innovative, highly efficient, and cost-effective approaches for the treatment and recovery of wastewater has become increasingly crucial in response to water scarcity driven by global climate change. The WASP project (Water As Sustainable Products - funded by Italian Ministry for Ecological Transition), addresses this challenge by developing sustainable solutions for the recovery of high-quality water from industrial wastewaters characterized by high Chemical Oxygen Demand (COD). Coordinated by the University of Bari Aldo Moro, the WASP project involved a multidisciplinary research team with expertise in chemistry, Earth sciences, veterinary medicine, pharmacy, and economics, along with three industrial partners. A central focus of the project was the application of Advanced Oxidation Processes (AOPs) for the reduction of pollutant loads in industrial wastewaters through the degradation of persistent organic contaminants. Whitin the search for catalysts capable of combining high efficiency with sustainability requirements, geopolymers emerged as particularly promising materials, demonstrating strong competitiveness compared to conventional systems in terms of efficiency, cost-effectiveness, formulation versatility, ease of shaping, resistance to repeated operational cycles, and overall superior sustainability. During the study porous and non-porous geopolymer-based catalysts were formulated using either pure metakaolin or metakaolin partially substituted with BFS (Blast Furnace Slag), as well as different alkaline activators, namely NaOH and sodium silicate, to optimize catalytic performance while minimizing costs and environmental impacts. Following iron impregnation, the obtained geopolymers were used as three-dimensional catalysts for heterogeneous photo-Fenton processes. Photo-oxidative treatment experiments were performed using both model pollutants and real industrial wastewaters, including scrubber water (SCRW) and the liquid fraction of digestate (LFD). Pure MK-based geopolymer catalysts achieved total organic carbon (TOC) abatements ranging from 40% to 90%, depending on the treated matrix. Similar or even better performances were obtained using BFS-based geopolymer catalysts, reaching TOC abatements of up to 97% and 78% for SCRW and LFD, respectively. The ESCAPE approach (Bontempi, 2017) was applied to estimate the embodied energy (EE) and carbon footprint (CF) associated with catalyst preparation. The results showed a reduction up to 93% in embodied energy for BFS-based geopolymers compared with pure MK-based material. Overall, the developed geopolymer catalysts demonstrated significantly enhanced degradation performances compared with conventional systems, while maintaining high stability, reusability and low environmental impact, thereby supporting the implementation of sustainable and circular approaches for industrial wastewater treatment and recovery.

Bontempi E. (2017) - A new approach for evaluating the sustainability of raw materials substitution based on embodied energy and the CO_2 footprint. J. Clean. Prod., 162, 162-169, https://doi.org/10.1016/j.jclepro.2017.06.028.

Effects of raw material changes on the composition and mechanical behaviour of porcelain stoneware tiles

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Keywords: Ukrainian clays, porcelain stoneware, Young's modulus.

The most important clays for the production of porcelain stoneware bodies have always been considered the Ukrainian clays coming from the Donbass region. The Russian - Ukrainian conflict has forced the ceramic industries to search for new clays coming from alternative regions around the world and to change the bodies formulations. Following these changes, several problems of breakages during the cutting of large slabs were encountered. This work aimed at the understanding of what has changed in porcelain stoneware formulations after the replacement of Ukrainian clays and how these changes affected the technological properties of the tiles. The idea was to combine different analytical techniques such as X-ray fluorescence (XRF) and X-ray Powder Diffraction (XRPD) to investigate the chemical and mineralogical composition of bodies batches and fired slabs produced before and after the replacement of Ukrainian clays. Furthermore, we used Impulse Excitation Technique (IET) to determine the Young's modulus and damping of the samples at room temperature and their dependence on temperature. Finally, we determined the porosity of the fired slabs and subsequently we investigated its relationship with the chemical and mineralogical composition and the Young's modulus.

A laboratory test by a Permeable Reactive Barrier to abate Sb from contaminated waters

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Keywords: antimony, permeable reactive barrier, mining areas.

Permeable Reactive Barriers (PRBs) are regarded as an efficient alternative to "pump&treat" technology to remediate contaminated waters by organic and inorganic compounds (e.g. heavy metals). Different processes can be applied to remove contaminants, e.g. adsorption, precipitation, denitrification and biodegradation. In this work, a laboratory PRB was built to verify whether the high concentrations of Sb (up to 20 mg/L) recorded in the Ca-SO_4 and Ca-(SO_4)HCO_3 contaminated waters from the former Sb-mining area of "*Le Cetine di Cotorniano*" (Siena) could quantitatively be abated. The mining history of *Le Cetine* is rather short since it lasted for about 70 years and shut down in 1948. The lab PRB consisted of 12 transparent lexan pools with PLA+ frames, lids, and connecting tubes, which are inert to chemical/biological processes and 3D printable. Each pool was filled with alternating layers of limestone, organic material, quartz sand and gravel. The main target was to block Sb, mostly occurring as Sb^{5+} (as computed by the geochemical code PHREEQC), within the organic layers, thus reducing the initial Sb concentration. Initially, all the 12 pools were leached with MilliQ water to assess the release of major and trace components by the filling material at a flow rate of 0.00167 L/sec. This operation was repeated three times to ensure that no heavy metal contamination (e.g. Sb), derived from the used materials, was occurring and to verify the presence of leakages in the lab PRB. Different aliquots were collected at different times and analyzed. Then, more than 60 L of Sb-contaminated water was collected at *Le Cetine* and transferred to the laboratory, ready to be injected into the PRB at the previously reported flow rate. Before the injection of the *Le Cetine* water, the PRB was filled with MilliQ water. At defined steps (ca. 30 minutes), the discharged water was sampled and analyzed for the pH, electrical conductivity, main components and Sb. The total sum of Sb collected at the end of the run was computed. The obtained results were positive since it was estimated that about 20% of the initial Sb was released, suggesting that the PRB was able to significantly retain most of the Sb. New tests will be performed at different flow rates and Sb concentrations to better evaluate the effectiveness of the lab PRB. Additionally, core drilling (about 1 cm in diameter) from each pool will be carried out to assess where Sb is mainly retained and, eventually, to either modify the organic/inorganic ratio of the alternating layers or use a more suitable material to increase the percentage of the Sb abatement. Even though these laboratory tests are in the early stages, the results appear to be encouraging. Eventually, different geometries and materials can be used when other dissolved inorganic contaminants are to be removed before installing in-situ PRBs.

From laboratory overburning tests to kiln operation: Mineralogical and thermodynamic controls on lime sticking tendency

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Keywords: lime, sticking tendency, thermodynamic modelling.

The sticking tendency (ST) of burnt lime at high temperature is a major cause of agglomeration, ring formation and blockages in industrial lime kilns. Although the Overburning Test (OBT) at 1300°C (Vola et al., 2021) provides a practical way to rank raw materials, the mineralogical and thermodynamic controls of lime sticking remain only partly constrained. This study investigates a selected set of calcitic and dolomitic carbonate rocks with different impurity contents and technological behaviour, combining OBT results with bulk chemistry, XRPD-Rietveld quantitative phase analysis and equilibrium melt modelling. The raw materials and their burnt products were characterized by WD-XRF and XRPD, with particular attention to minor phases and to the quantification of crystalline and amorphous components after high-temperature treatment. Thermodynamic calculations were used to estimate the amount and composition of liquid phase potentially generated at 1300°C. These data were compared with the experimentally measured ST, expressed as the normalized weight of lime/dololime blocks produced during the OBT. The results show that impurity content strongly influences melt generation, but does not directly control the degree of sticking. Samples with comparable calculated melt fractions may display markedly different ST values, whereas some high-ST materials show only limited predicted melt formation. This decoupling indicates that sticking is not governed by the mere amount of liquid phase, but by the nature, distribution and persistence of a binding phase capable of cementing lime grains during overburning. In calcitic materials, solid-state sintering and local melt-assisted bonding may coexist, whereas in dolomitic materials the behaviour is further controlled by the CaO-MgO system, periclase crystallite growth and the availability of Fe-, Al- and alkali-bearing phases. XRPD evidence of amorphous material in selected burnt products provides a more direct proxy for the effective binding phase than bulk impurity content or calculated melt fraction alone. A process-based framework is therefore proposed in which bulk composition defines the potential for melt formation, while crystallographic evolution and amorphous-phase development determine whether the system evolves toward weak aggregation or severe sticking. The integrated use of OBT, XRPD-QPA and thermodynamic modelling improves the interpretation of raw-material suitability for lime production and provides a more robust basis for preventing kiln blockages, particularly in plants operating under high-temperature regimes and/or with solid fuels.

Vola G. et al. (2021) - Investigation and prediction of sticking tendency, blocks formation and occasional melting of lime at HT (1300°C) by the overburning test method. Constr. Build. Mater., 294, 123577, https://doi.org/10.1016/j.conbuildmat.2021.123577.

S27.

Fluvial systems: From processes understanding to river management

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Reconstructing river planform evolutionary trajectories over the past 40 years using synthetic monthly Sentinel-2 MSI satellite data

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Keywords: rivers, remote sensing, deep learning.

Monitoring river planform dynamics through time is a crucial step to get insights into fluvial geomorphic processes and reconstruct the evolutionary trajectory of rivers. When using multi-spectral satellite methods, the portion of the river which experiences sediment transport - the active channel - can be defined as the water channel plus the unvegetated sediment bars. Although much research has been recently carried out on monitoring rivers through satellite images, most have been focused on using bands indices thresholding to only identify water. Thanks to the current rise of AI, deep learning models are now becoming available for fluvial applications. Carbonneau (Carbonneau, 2024) model has been globally trained to recognize river water, lake water, and sediment bars. The advantage of this workflow is threefold: using high temporal resolution data (monthly Sentinel-2 MSI medians), distinguishing between freshwater bodies, and classifying sediment bars. Nonetheless, a key limitation remains due to the short time window of Sentinel-2 data, covering less than a decade at the global scale (2017-2026).

In order to extend the time series applicability and keep the same global classification model, we developed and validated domain transfer algorithms to create synthetic Sentinel-2 images from Landsat 8 and 5 satellites, which will then become input for our existing Sentinel-2 classifier. This approach has the advantage of only requiring synchronous Landsat and Sentinel data for training and thus overcoming the need for labour intensive manual labels. By adopting this integrated pipeline, we are therefore able to monitor river water, lake water and sediment bars at 10 m resolution, monthly scale, over a 40-year period.

In order to test our methodology, we deployed the workflow on the entire Irrawaddy River, which is considered one of the largest remaining free-flowing rivers in the world. Monthly classifications were then aggregated in yearly frequency maps. Results show a progressive decreasing trend in area for the entire river from 1985 to 2025. Decrease was observed both in river water and sediment bars. Quantitative analysis revealed that the rate of change for sediment bars was double that of river water. Collectively the Irrawaddy River experienced a median loss of 11.5 km^2/yr in terms of active channel, yet our method revealed that just 30% of this loss would have been identifiable in researches focusing only on river water (3.6 km^2/yr). These findings highlight how detecting sediment bars in satellite analysis is crucial for gaining a comprehensive understanding of river planform evolution and its underlying geomorphic processes.

Carbonneau P.E. (2024) - Global Semantic Classification of Fluvial Landscapes with Attention-Based Deep Learning. Remote Sens., 16(24), 4747, https://doi.org/10.3390/rs16244747.

Reach-scale analysis of 150 years of channel changes in a poorly anthropized river of Southern Italy: the Calore River

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Keywords: channel adjustments, controlling factors, land use/land cover changes.

The Calore R. is one of the major rivers of Southern Italy, both in terms of channel length (~110 km) and flow discharge (~30 m^3/s). In this study, we present the results of a research aimed at reconstructing the channel changes experienced by the Calore R. between 1870 and 2023. To this aim, a GIS analysis of historical topographic maps, more recent topographic maps, orthophotos and Google Earth imagery was carried out and integrated with field-surveyed geomorphological data and literature data. Concurrently, a multitemporal analysis of the main possible controlling factors (i.e., land-use/land cover changes, variations in rainfall, floods and anthropogenic disturbances) has been performed. The results highlighted the occurrence of three distinct morphoevolutionary phases.

The first phase (Phase-1) occurred between the end of XIX century and 1930s. During this phase, river reaches experiencing widening, narrowing and stability coexisted, but the those experiencing widening (which accounted for ~30-50% of the river length) prevailed over those affected by narrowing (~25-30%). Single-thread channel patterns (i.e., sinuous, meandering, straight) decreased from ~70% of the river to ~40%, with an associated increase of transitional morphologies.

The second phase (Phase-2) started in 1930s and lasted until the end of XX century. During this phase, 90-100% of the channel experienced narrowing and more than 90% displayed a single-thread pattern. An average riverbed degradation of 2-3 metres is reported in literature.

Finally, the third phase (Phase-3) started at the end of XX century and is still occurring. It is characterized by widening pulsations, after which the river reprises to narrow. The channel has maintained a single-thread pattern for ~90% of its length.

As regards the controlling factors, the dominant widening and increase in multi-thread channel patterns detected during Phase-1 are coherent with literature data that report a humid climate and a diffuse deforestation, i.e. conditions which likely increased the sediment supply to the river. However, the same literature data demonstrated that not all the sub-basins were affected by deforestation. This could explain the occurrence of narrowing or stability in the reaches of the Calore R. fed by the less deforested sub-basins.

The severe narrowing and incision observed during Phase-2, as well as the drastic increase in single-thread channel patterns at the expense of multi-thread ones, are coherent with the increase in forested areas at the basin scale, which affected ~15 % of the basin area (Magliulo et al., 2022); with the sharp reduction in rainfall between 1980s and 1990s (Magliulo et al., 2021); and, finally, with the extraction of significant amounts of sediments from the riverbed, which occurred mainly between 1960s and 1990s in more than ten sites along the river.

Finally, the widening pulsations detected during Phase-3 are likely due to floods and probably interrupted a more general trend consisting of narrowing or stability. It is, however, worthy to note that the catastrophic flood of 14-15 November 2015 left evidence of channel widening in the ~25% of the river only. More in general, as for Phase-1, the coexistence, during Phase-3, of reaches with different behaviours (i.e., widening, narrowing, stability) suggests a significant control by local factors (e.g., type and intensity of human disturbances, differences in sediment supply from tributary sub-basins, and so on) compared to basin-scale ones.

Magliulo P. et al. (2021) - Channel adjustments over 140 years in response to extreme floods and land-use change, Tammaro River, Northern Italy. Geomorphology, 383, 18, https://doi.org/j.geomorph.2021.107715.

Magliulo P. et al. (2022) - Multidecadal land-use changes and implications on soil protection in the Calore River Basin landscape (Southern Italy). Geosci., 12, 156, https://doi.org/10.3390/geosciences12040156.

The Tiber and Aniene Integrated Informative System (SIITA): A tool for sustainable rivers management in the Metropolitan Area of Rome Capital

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Keywords: Aniene river contract, metropolitan area of Rome, Tiber river contract.

According to the Italian Environmental Code, the River Contract (RC) is a voluntary tool for strategic and negotiated planning, aimed at addressing water management and river basin issues. The RC involves public authorities, local stakeholders, and civil society in a shared process aimed at improving environmental quality, reducing hydrogeological risk, and promoting sustainable territorial development within a river catchment area. The public and private subscribers of the RC define a shared Action Plan (AP) and commit to its implementation. The RC contributes to the definition and updating of district planning tools at basin and sub-basin scale, specifically the Flood Risk Management Plan and the Water Management Plan.

In 2022, ten Wetland Contracts were signed in the Lazio Region, including those concerning the Tiber River basin (TRC, specifically concerning the lower Tiber stretch from the Castel Giubileo dam in Rome to its mouth) and the Aniene River basin (ARC, which covers the entire catchment area from its source in the Simbruini Mountains to its confluence with the Tiber River).

The Metropolitan City of Rome Capital (MCRC) has joined respectively the TRC in 2022 and then ARC in 2024, undertaking the role of coordinator of both contracts, assuring the administrative management of the whole process. A Technical-Scientific Secretariat (TSS) was established in 2025 to support MCRC in its management, planning, and monitoring activities, providing technical expertise and scientific coordination throughout the implementation process. In the dual role of subscriber and of entity in charge, MCRC is carrying on its own Action, with an across-the-board approach respect the two RC, aimed at the implementation of a common data platform: the Tiber and Aniene Integrated Informative System (SIITA).

The tool supports the development of both TRC and ARC, making data openly available through a Data Management System (DMS) platform, based on the open-source software CKAN. Datasets shared by the subscribers of the RC have been collected in the platform, covering a wide range of thematic areas, including land use, concessions in floodplain areas, chemical and ecological status of water bodies, hydrogeological risk zones, and more. The data catalogue is continuously evolving and provides all RC signatories with a unique opportunity to contribute to the construction of collective knowledge regarding the Tiber and Aniene river systems, as well as all related aspects. In addition to the development of the data catalogue, a WebGIS platform based on the open-source software TerriaJS has been implemented. This platform hosts an extensive repository of geospatial data easily accessible and viewable, including via mobile devices. The SIITA is intended to overcome the current fragmentation of data and to support evidence-based policy design and decision-making processes.

Emerging Challenges in Mediterranean Alluvial Plains: A Fragile Balance between Anthropogenic Impacts and Climate Change. Insights from the Arno Plain

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Keywords: sediment transport, fluvial risk, climate change impacts.

Alluvial plains are among the environments most vulnerable to climate change and anthropogenic pressures (Billi and Fazzini 2017). Increasing flood risk, coastal erosion, land subsidence, and groundwater salinization are only some of the challenges that are becoming increasingly widespread, with particularly evident impacts in Mediterranean coastal areas.

River deltas are of particular concern. After centuries characterized predominantly by progradation, many deltas have reversed their evolutionary trend over recent decades, showing a general tendency toward retreat at both national (Luppichini and Bini 2025) and Mediterranean scales (Besset et al. 2019). A key factor driving delta retreat is the progressive reduction of sediment supply from river catchments. However, sediment fluxes remain poorly constrained for most Italian rivers, creating a knowledge gap that limits not only our understanding of geomorphological processes but also the effective planning and management of these territories. Understanding these dynamics requires an integrated source-to-sink perspective, tracing sediment transfer from upland source areas to coastal depositional environments and highlighting the connections between fluvial processes and shoreline evolution.

Another major challenge affecting lowland areas is the frequency and magnitude of floods (Blöschl et al. 2019). Floodplains have been profoundly transformed compared with their natural conditions: rivers are frequently embanked, channelized, and straightened, and in some cases are perched above the surrounding floodplain, while adjacent lowlands are commonly managed through land-reclamation systems that may exacerbate subsidence processes.

In this context, understanding present dynamics and future scenarios requires a multidisciplinary approach that integrates historical, stratigraphic, geomorphological, climatic, and hydrological data into sufficiently long time series capable of revealing long-term trends and forcing mechanisms.

Applied to the Arno River basin, this approach has enabled the reconstruction of flood frequency over the last two millennia, highlighting its relationships with climate variability, atmospheric circulation indices, and sea-surface temperature fluctuations. The analysis has also provided insights into the effectiveness of mitigation measures implemented through time, identified the main evolutionary trajectories of the system, and clarified the role of human activities in the long-term evolution of floodplains.

When extended beyond the Arno basin, this research highlighted the role of small catchments and secondary watercourses in floodplain management. Likely because of limited adaptation and risk-mitigation measures, as well as their greater sensitivity to climatic variability, these systems have been responsible for the most severe impacts over the last three decades, including the highest loss of life.

Effective mitigation and adaptation strategies require a thorough understanding of floodplain evolution, continuous monitoring of key environmental variables, identification of ongoing trends, and assessment of plausible future scenarios.

Billi P. & Fazzini M. (2017) - Global change and river flow in Italy. Glob. Planet Change, 155, 234-246, https://doi.org/10.1016/j.gloplacha.2017.07.008.

Luppichini M. et al. (2022) - Deep learning models to predict flood events in fast-flowing watersheds. Sci. Total Environ., 813, 151885, https://doi.org/https://doi.org/10.1016/j.scitotenv.2021.151885.

Luppichini M. et al. (2024) - Climate change as main driver of centennial decline in river sediment transport across the Mediterranean region. J. Hydrol. (Amst), 636, 131266, https://doi.org/https://doi.org/10.1016/j.jhydrol.2024.131266.

Luppichini M. & Bini M. (2025) - 40-Year shoreline evolution in Italy: Critical challenges in river delta regions. Estuar. Coast Shelf Sci., 315, 109166, https://doi.org/https://doi.org/10.1016/j.ecss.2025.109166.

A national-scale satellite-based framework for continuous river hydromorphological monitoring

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Keywords: river hydromorphology, remote sensing, geomorphic monitoring.

The degradation of river ecosystems and the increasing impacts of flood hazards have highlighted the need for integrated river management approaches that simultaneously address hydromorphological conditions, ecological functionality, and river dynamics. Recent advances in satellite Earth Observation, machine learning, and cloud computing now enable continuous monitoring of river geomorphic processes at unprecedented spatial and temporal scales. However, despite this potential, operational satellite-based river monitoring at national scale remains limited due to data complexity, computational requirements, and the lack of harmonized infrastructures and funds aimed to integrate geomorphic information into management frameworks.

Within the Italian IRIDE program (https://www.esa.int/Applications/Observing_the_Earth/IRIDE), coordinated by a consortium of industries, universities, and public institutions, we implemented an operational framework for the systematic monitoring of river hydromorphology across Italy using Sentinel-2 monthly imagery (10 m resolution). The workflow combines deep-learning and machine-learning algorithms to delineate yearly active channels and monthly Macro-Geomorphic Units, including river water, exposed sediment bars, and in-channel vegetation. This geomorphic information is organized through a river-network segmentation framework based on 500 m Disaggregated Geographical Objects (https://github.com/EVS-GIS/fct-qgis), designed to analyse and aggregate geomorphic dynamics along streams according to the user needs.

The framework automatically updates active channel extent annually and generates derivative products describing channel width variations, geomorphic frequency maps, and indicators of river adjustments such as vegetation encroachment, channel widening, narrowing, and migration. Validation across Italian rivers with different geomorphic settings demonstrates high delineation performances for medium-large rivers.

This contribution presents the methodological workflow, validation strategy, and first national-scale applications of the IRIDE monitoring system, discussing its potential to support hydromorphological assessment frameworks, river restoration planning, habitat mapping, and flood-risk management through continuous geomorphic monitoring. More broadly, the framework provides a scalable infrastructure for integrating remote sensing products into process-based river management and for improving the identification of river trajectories and geomorphic sensitivity under changing environmental conditions.

Century-scale decline of suspended sediment flux in the Po River (Italy): Sediment management strategies and implications for long-term geomorphic evolution of the delta

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Keywords: river training works, wash-load, delta drowning.

This study investigates century-scale changes in suspended sediment flux in the Po River (Italy) and evaluates their geomorphic implications for the Po delta. Long-term records of suspended sediment transport collected at multiple monitoring stations are integrated with an analysis of anthropogenic drivers (i.e., land-use changes, in-channel mining, dam construction, and river training works) to reconstruct the spatiotemporal evolution of sediment dynamics across the basin.

Results reveal a marked and spatially asynchronous decline in suspended sediment flux. Reductions of approximately 48% first affected the middle course (1920s-1940s), mainly due to damming in the Alpine catchments, and later propagated to the lower course (1950s-1980s), driven by channelization, in-channel sediment storage, closure of the Isola Serafini dam (1964), and sediment trapping in Apennine tributaries due to the implementation of flood detention basin projects. Over the period 1924-2019, suspended sediment flux at the basin outlet decreased by more than 70%, declining from approximately 14 million tons per year in the 1920s-1940s to just over 4 million tons per year in the early decades of the 21st century (Brenna et al., 2026).

This reduction in fine sediment load has had critical consequences for delta dynamics. The phase of maximum decline in suspended load at the basin outlet coincides with the period of most rapid delta retreat (1950s-1970s; Cencini, 1998), when reduced sediment delivery, combined with extensive embankment construction, limited overbank deposition and hindered delta-plain aggradation. Under current conditions, the Po delta appears to be out of equilibrium considering the present sediment supply and lateral connectivity, and increasingly vulnerable to relative sea-level rise, raising the risk of drowning. The delta is therefore strongly dependent on continuous land-reclamation and maintenance works required to preserve subaerial areas.

A first-order assessment suggests that restoration of sediment fluxes, through the partial remobilization of tens of millions of cubic meters of sediment accumulated during the second half of the 20th century and currently stored within anthropogenic traps (e.g., deactivated secondary channels), together with the reconnection of channel-floodplain processes, could significantly enhance sediment delivery to the delta plain. Such interventions may help sustain vertical accretion rates (in the order of 2-3 mm/yr) comparable to projected sea-level rise over the 21st century, although their effectiveness will depend on improving lateral connectivity between distributary channels and delta plain within the deltaic system (Brunetta & Ciavola, 2024; Finotello et al., 2025). These findings highlight the need for integrated, basin-to-delta sediment and water management strategies to mitigate sediment deficits and support the long-term geomorphic evolution of this vulnerable environment.

Brenna A. et al. (2026) - The great decline of suspended sediment load in the Po River (Italy) over the last 100 years. Catena, 265, 109864, https://doi.org/10.1016/j.catena.2026.109864.

Brunetta R. & Ciavola P. (2024) - Evolution of wetlands in the northern part of the Po Delta: The experience of unmanaged realignments. Earth Surf. Process. Landf., 49(12), 4008-4031, https://doi.org/10.1002/esp.5936.

Cencini C. (1998) - Physical processes and human activities in the evolution of the Po delta, Italy. J. Coast. Res., 14(3), 775-793, https://www.jstor.org/stable/4298834.

Finotello A. et al. (2025) - Harnessing Natural Land-Building Processes in Human-Dominated River Deltas: Lessons from the Po River Delta (Italy). In: EGU General Assembly 2025, Copernicus Meetings, Abstract EGU25-13631.

The role of streams in defining landslide dams scenarios

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Keywords: multi-source hazard, landslide dams, risk management.

Interference between landslides and fluvial dynamics often leads to partial or total occlusion of riverbeds, a phenomenon known as "landslide dams". Although there are two actors involved in the occurrence of the phenomenon (landslide and stream), the main classifications of landslide dams known in the literature (e.g., Swanson et al., 1986; Costa & Schuster, 1987; Hermanns et al., 2006; 2010) do not consider the morphology of the streams affected by the dam, but focus primarily, if not exclusively, on the diversification of slope movements that cause partial or total occlusion of the riverbed and/or valley.

Based on these considerations, the note aims to: 1) highlight the role that the stream can play in the occurrence and, above all, in the evolution of the phenomenon; 2) characterize the phenomenon in order to highlight the variability of scenarios resulting from the interaction between "different landslides" and "different streams"; 3) propose the development of a new classification of landslide dams, which is inevitably more complex than previous ones - because it is more detailed - but more realistic with respect to the situations that can actually occur following the occurrence of the phenomenon.

The new classification essentially allows us to: 1) define in more detail the multiplicity of scenarios resulting from the combination of variables that come into play (belonging respectively to the river system and the landslide system) in producing the effects of riverbed damming; 2) define, for example: i) the speed of silting of the dam lake, which depends, for a given storage capacity, on the amount of solid transport of the affected stream; ii) the type and geometry of the dam, which depend on the geomorphological characteristics of the dammed valley, the geotechnical properties of the material of the landslide body, and the mechanism that produced it; iii) the potential evolution of the phenomenon itself, which varies significantly depending on the type of landslide dam that has occurred. Considering the evolutionary scenarios of the phenomenon, the new classification may be useful in identifying the most appropriate interventions to implement, both immediately, during emergency management, and in the medium and long term, for landscaping and risk mitigation.

Costa J.E. & Schuster R.L. (1987) - The formation and failure of natural dams. U.S. Geological Survey, Open-File Rep., 87-392, Vancouver (Washington), 39 pp.

Hermanns R.L. et al. (2006) - Landslide dams in the Central Andes of Argentina: Showing the need of revising the established landslide dams classification. Ital. J. Eng. Geol. Environ., Spec. Issue 1, 55-60, https://doi.org/10.4408/IJEGE.2006-01.S-06.

Hermanns R.L. et al. (2010) - The Classification of Rockslide Dams. In: Evans S.G., Hermanns R.L., Strom A. & Scarascia Mugnozza G. (Eds), Natural and Artificial Rockslide Dams, Lect. Notes Earth Sci., 133, Springer, Berlin, Heidelberg, 581-593, https://doi.org/10.1007/978-3-642-04764-0_24.

Swanson F.J. et al. (1986) - Landslide dams in Japan. In: Schuster R.L. (Ed.), Landslide Dams: Processes, Risk, and Mitigation. Proc. Session sponsored by the Geotech. Eng. Div. ASCE, Seattle, Washington, April 7, 1986, 131-145.

Will mountain rivers' morphology change in the next decades due to climate warming?

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Keywords: climate change, rivers, deglaciation.

Confined and partly-confined mountain rivers represent the largest share in terms of channel length globally, but their geomorphological dynamics has been much less investigated compared to the larger lowland rivers. Also, headwater channels have been rapidly increasing in length due to the ongoing deglaciation. Nonetheless, morphological patterns of mountain rivers and their temporal variations have been long known to be strongly influenced by amount and timing of sediment supply from their catchments, being these channels - markedly those steeper than 1-3% - most often naturally supply-limited, whereas transport-limited conditions tend to dominate in downstream channel segments. In addition, most anthropogenic pressures now widely present in mountain rivers (e.g., hydropower dams, flood mitigation/erosion-control works, and sediment removal) have further increased their degree of ordinary "sediment starvation" and extended it downstream, causing narrowing, bed incision and armouring. In other words, direct human-induced impacts in mountain rivers' morphology generally stemmed from an upstream sediment supply largely more reduced relative to bedload transport capacity.

Variations in the bedload supply/transport capacity ratio associated to the ongoing climate change appear instead to be more complex and spatially variable. In mountainous catchments, climate change has been determining important modifications on runoff and thus on bedload transport capacity (e.g., episodic through higher intensity and frequency of heavy rainstorms and prolonged by changing snow- and ice-melt contributions) as well as on sediment supply (e.g., more pronounced mass wasting due to heavy rainstorms and paraglacial adjustments; vast areas of newly exposed sediments left by deglaciation). However, the relative magnitude of variation between supply and transport capacity occurred in the past decades is largely unknown as quantitative data about bedload fluxes in mountain rivers are extremely scarce, and are even more so in the context of multi-annual to decadal monitoring activities addressing both runoff and sediment transport. Consequently, predictions on how rivers will change in the next decades in response to climate change are extremely uncertain, especially for our poor capacity to properly model sediment supply in complex watersheds (glacierised and non-glacierised alike).

The talk will present a state-of-the-art on the dynamics of bedload fluxes and their variations in headwater mountain rivers, as well as on the morphological changes observed in such environments. The most likely future changes in bedload supply/transport capacity ratio and the consequent morphological variations will be finally proposed for both glacierised and non-glacierised catchments, based on the current understanding of relative peak water vs peak sediment timing.

35 years of LULC changes in the alluvial plain and channel adjustments at the reach-scale of a dammed river: The case-study of the Tammaro R. (Southern Italy)

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Keywords: river morphological changes, controlling factors, dams.

The Tammaro R. (Southern Italy) is the main right tributary of the Calore River. Between the early 1980s and 1994, during a phase of severe channel narrowing started in the 1950s (Magliulo et al., 2021), the Campolattaro Dam (CD) was built for agricultural, drinking water, hydroelectric and flood attenuation purposes. Although the dam never operated at full capacity, a large reservoir formed (Campolattaro Reservoir), which was emptied in 2024. Concurrently with dam construction, the Tammaro alluvial plain underwent significant land cover-land use (LULC) changes.

In this paper, channel adjustments of the Tammaro R. during and after the construction of the CD were investigated over a 35-year period (1988-2023), together with LULC changes in the surrounding alluvial plain. Field-surveyed and literature data were analysed in a GIS environment and integrated with topographic maps, orthophotos and Google Earth imagery.

The results highlighted the extreme complexity and geomorphological dynamism of the Tammaro River. During dam construction (1981-1994), channel narrowing persisted only in the eight reaches immediately downstream from the dam (about 50% of the analysed river length), ranging from ∼13% to ∼53%. Such narrowing was probably related to sediment extraction from the riverbed for dam construction. Conversely, the remaining downstream reaches experienced stability or slight widening (∼5-15%).

In the following periods (1998-2004, 2005-2011 and 2012-2023), the river showed complex alternations of narrowing, widening and stability. Width changes ranged from −60% to +102%, suggesting a stronger control of local factors (e.g., riparian vegetation, confinement conditions and tributary sediment supply) than basin-scale drivers. In-channel human disturbances were negligible.

Unlike channel width, channel pattern remained substantially stable throughout the investigated period, with single-thread morphologies characterizing more than 85% of the river. Net incision decreased downstream from about 2.5 m to less than 1 m.

The morphological effects (Surian et al., 2016) of the extreme 2015 flood, the most severe since the 1920s, were probably reduced by flood attenuation by the CD. In 2023, only ∼40% of the river was wider than in 2011 and channel pattern did not change significantly.

These channel adjustments occurred within an alluvial plain affected by significant LULC changes. Forested areas increased from 18.9% to 30.7% of total land cover, while grasslands and pastures decreased from 12.5% to 6.4%. Agricultural land slightly decreased (47.9% to 46.0%), artificial surfaces increased (2.5% to 3.3%) and water bodies decreased (18.2% to 13.7%). Overall, these trends broadly mirrored those observed at the basin scale, with agricultural persistence and progressive forest expansion.

Magliulo P. et al. (2021) - Channel adjustments over 140 years in response to extreme floods and land-use change, Tammaro River, Nouthern Italy. Geomorphology, 383, 18, https://doi.org//j.geomorph.2021.107715.

Surian N. et al. (2016) - Channel response to extreme floods: Insights on controlling factors from six mountain rivers in northern Apennines Italy. Geomorphology, 272, 78-91, https://doi.org//j.geomorph.2016.02.002.

BankfullMapper: A tool for spatio-temporal monitoring of bankfull geometry from high-resolution digital topography

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Keywords: bankfull, fluvial geomorphology, high-resolution topography.

Understanding river channel bankfull geometry is essential for fluvial monitoring, hydraulic assessment, and flood-hazard analysis. The bankfull stage represents the point where water begins to spill onto the floodplain, typically recurring every 1-2 years. This stage and its corresponding discharge play a pivotal role in shaping channel morphology, making it critical for river management and hazard assessment.

In this study, we present and test BankfullMapper, a MATLAB-based semi-automated tool designed to detect bankfull elevation and estimate the associated discharge from high-resolution Digital Terrain Models (Delchiaro et al., 2025). The workflow divides the river corridor into evenly spaced cross-sections, computes a hydraulic depth function, and identifies morphological breakpoints using a peak-detection algorithm. Manning-based flow capacity estimation further enhances the tool's hydrological applicability.

The method is tested on multiple river systems in northern Italy, characterized by diverse morphologies and varying degrees of anthropogenic influence, allowing assessment of its robustness across different fluvial settings. Results show that BankfullMapper reliably captures spatio-temporal variations in channel geometry, achieving accuracy values >0.8 when compared with manually mapped active-channel boundaries. By focusing on morphological break identification, the tool provides a detailed and reproducible representation of bankfull geometry, offering a valuable resource for geomorphological analysis, river management, and flood-hazard assessment.

Delchiaro M. et al. (2025) - BankfullMapper: a semi-automated MATLAB tool on high-resolution digital terrain models for spatio-temporal monitoring of bankfull geometry and discharge. Comput. Geosci., 205, 106001, https://doi.org/10.1016/j.cageo.2025.106001.

Mid-term channel adjustments of the Sele River (Southern Italy)

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Keywords: river morphological changes, morphoevolutionary trajectorie.

The channel adjustments experienced by the rivers in Southern Italy have been investigated from the early 2010s only. At the state, some gaps still exist, as many rivers have not been adequately studied yet. This makes difficult reconstructing a common morphoevolutionary trend. This research provides a contribution in reducing this gap by investigating the channel adjustments experienced by the Sele River (Southern Italy) from the end of XIX century to 2020s and reconstructing its morphoevolutionary trajectory. Concurrently, a multitemporal analysis of the main controlling factors was also carried out. To this aim, historical and more recent topographic maps, orthophotos and Google Earth imagery were analysed in a GIS environment, together with land-use maps, and integrated with field-surveyed and literature data. The results showed the occurrence of two distinct morphoevolutionary phases. The first phase (Phase-1) started at the end of XIX century and lasted until early 2000s. It was characterized by a prolonged and intense narrowing, up to ~160 m. Within this phase, the reach-scale analysis showed the occurrence of two distinct sub-phases (1a and 1b). In sub-phase 1a (1870s-1950s), narrowing was dominant and affected increasing river lengths, but reaches characterized by widening or stability still accounted for ~25-45% of the channel.

The channel morphology was multi-thread in the ~50-60% of the river. In sub-phase 1b (1950s-early 2000s), widening totally ceased and narrowing affected ~88-96% of the Sele R., at rates of 1-2 meters per year. Single-thread channel patterns overwhelmed multi-thread ones. Incision was up to 5 meters.

During Phase-2, while in the first decade widening was strikingly dominant (affecting ~50-90% of the river), from 2010s onwards a dominant channel stability was detected (~40-55%), even if narrowing or widening still affected some reaches. Single-thread patterns still characterized up to 88% of the river length. As regards the controlling factors, few data are available for those of the sub-phase 1a, except for a documented decrease of the Sele R. flow discharge due to the springs capture. The coexistence, along the river, of reaches showing different behaviours suggested a dominant influence of local controlling factors. In particular, literature data report different rates of deforestation in the tributary sub-basins during this phase. The diffuse and intense narrowing and incision that characterized sub-phase 1b, as well as the disappearance of the multi-thread channel patterns in favour of single-thread ones, was probably due to a decrease in sediment supply induced by the increase, up to the 30%, of the forested areas at the basin scale (Magliulo et al., 2021) and by human disturbances (i.e., sediment extraction from the riverbed; hydromorphological effects of the Persano Dam). Such decrease was also favoured by the significant reduction in rainfall that occurred between early 1980s and late 1990s.

Finally, during Phase-2, extreme floods, such as that from 2010, controlled the main episodes of widening. Even if narrowing still affected some reaches, its sharp reduction compared to sub-phase 1b can be reasonably explained with the slowdown of the basin afforestation and the end of the sediment extraction from the riverbed since 1990s. However, even if the period observation is too short, the dominance of stable reaches suggest that Phase-2 could be of relative equilibrium.

Magliulo P. et al. (2021) - Land-use changes in the Sele River Basin Landscape (Southern Italy) between 1960 and 2012: Comparisons and implications for soil erosion assessment. Geographies, 1, 315-332, https://doi.org/10.3390/geographies1030017.

Seismic detection of bedload regime transitions in a proglacial stream: Rutor Glacier, 2025

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Keywords: bedload transport, seismic monitoring, proglacial stream.

Bedload transport in proglacial streams is a key driver of channel morphodynamics and downstream flood hazard in deglaciating catchments, yet continuous monitoring remains logistically challenging. Here we present results from a near-field seismic monitoring campaign at the proglacial stream of Rutor Glacier (Valle d'Aosta, NW Italy), conducted from 24 June to 16 September 2025. Three single-component vertical geophones (4.5 Hz, 200 Hz sampling rate) were deployed alongside a pressure transducer and direct Bünte trap sampling (29 samples). Power Spectral Density analysis using the Welch method identified two diagnostic frequency bands: 6-10 Hz as a hydraulic turbulence proxy (P_lf) and 40-50 Hz as a bedload-sensitive proxy (P_hf). Piecewise linear regression (Muggeo, 2008) applied to the P_hf-P_lf relationship identified two statistically robust breakpoints corresponding to water stages of ~20 cm and ~26 cm ($F(2vs1) = 1932$, $p \approx 0$), defining three distinct transport regimes validated by direct sampling: (1) stage 26 cm — widespread bedload with P_hf decoupling from P_lf. An anomalous event between 7 and 12 July 2025 revealed sustained elevated P_hf for six consecutive days despite falling stage, interpreted as a post-melt subglacial sediment flush following an intense late-June melting episodes. Intraday trajectory analysis in P_hf-P_lf phase space demonstrates a systematic hysteresis during this event, providing a seismically detectable signature of subglacial sediment reservoir inertia — a process completely invisible to stage-based monitoring. These results demonstrate that low-cost near-field seismic sensors can identify bedload initiation thresholds and detect subglacial sediment dynamics, with direct implications for early warning of sediment-related flood hazard in proglacial environments.

Muggeo V.M.R. (2008) - Segmented: an R package to fit regression models with broken-line relationships. R News, 8(1), 20-25.

Geomorphic adjustment of two highly confined streams to severe storms: Contrasting the Savio and Senio Rivers, Northern Apennines

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WITHDRAWN

The continental-scale Paraná-Paraguay-Uruguay drainage basin: A long-term lithospheric-control on fluvial system

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Keywords: Paraná-Uruguay drainage systems, basaltic magmatism, lithospheric control.

Continental-scale drainage systems typically develop over long geologic timescales within tectonically stable settings, where persistent long-wavelength/low amplitude topographic gradients favor drainage longevity. However, many cratons lack large river systems, suggesting that additional factors such as climate, magmatism, or dynamic topography can enhance or disrupt long-term drainage stability. The Paraná-Uruguay drainage basin provides an ideal setting to investigate this problem: it drains one of the largest intracratonic basins of South America, where Precambrian inheritance, Mesozoic magmatism, Cenozoic uplift, and deep-mantle dynamics have left a measurable imprint on landscape evolution. Although numerous studies have examined these controlling factors individually, their combined influence remains poorly constrained. We address this gap by integrating geological cross-sections, basalt thickness patterns, long-wavelength topographic filtering, flexural modelling, and morphometric analyses (slope, χ, ksn, divide stability), complemented by published residual and dynamic topography models. Our results show that the Paraná Basin behaves as a long-wavelength/low amplitude intracratonic depression shaped by the interplay between inherited basement structure, the Paraná-Etendeka volcanic load, and mantle-driven subsidence related to Nazca Plate subduction beneath South America. The Paraná-Uruguay basin interior is characterized by low channel steepness, subdued χ-gradients, and stable divides, whereas uplifted cratonic margins display steep escarpments and active divide retreat. This study provides a new integrative framework for understanding long-term landscape evolution in continental interiors and underscores the need to couple surface processes with deep-Earth dynamics.

Channel widening as a geomorphological response to the June 2024 Extreme Flood in Valnontey, NW Italian Alps

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Keywords: alpine catchments, channel widening, flood hazards.

High-magnitude floods (driven by extreme rainfall events) strongly affect Alpine catchments, where fluvial systems undergo geomorphological transformations. Channel widening in mountain basins is a dominant geomorphic response to extreme flood events, often associated with bank erosion (Ruiz-Villanueva et al., 2023). Therefore, effective flood risk evaluation and river management require: (i) identifying reaches prone to channel widening, and (ii) analysing the controlling factors governing the geomorphic effectiveness of high-magnitude floods in mountain catchments (Brenna et al., 2023), often neglected in conventional flood hazard assessment (Scorpio & Comiti, 2024).

On 29-30 June 2024, the Valnontey catchment in Cogne, Valle d'Aosta (NW Italian Alps), was impacted by an extreme rainfall-induced flood. The 24-hour rainfall reached ~120 mm, and the resulting torrential flow caused severe structural damage and socio-economic losses. The river network also underwent major geomorphological changes due to debris-flow and landslide activity. In August 2024, Intensive Post-Event Campaigns (IPECs) were carried out to estimate peak flood discharge and assess its geomorphological impacts. Peak discharge ranged between 200 and 250 $m^3 s^{-1}$ and was used to reconstruct the flood hydrograph through calibration of the KLEM (Kinematic Local Excess Model) rainfall-runoff model. Channel widening was quantified through manual GIS digitization of the active channel. The analysis followed the Italian IDRAIM hydromorphological framework (Rinaldi et al., 2015). Channel response was estimated by comparing the most recent pre-flood aerial imagery (2012) with post-event orthophotos from a LiDAR survey in August 2024. Width ratio (post-event width/pre-event width) and unit stream power (derived from peak flood discharge using KLEM) were calculated for six delineated reaches along the Valnontey River.

Mean width ratios in the analysed reaches ranged from 2 to 3 times the pre-event channel width. This response was primarily associated with erosion of floodplain islands within the active channel, coupled with enhanced sediment supply from proglacial deposits and downslope debris-flow activity to the river network. Width ratios were analysed in relation to channel bed slope, unit stream power, and confinement index. Variability in channel widening among reaches appears to be associated not only with these variables but also with the extent of managed river reaches. Hence, channel widening is not controlled solely by meteorological extremes (rainfall) and hydraulic forces (stream power), but morphological characteristics (i.e., lateral confinement, channel bed slope, sediment availability, transport mechanisms, and hillslope-channel coupling) are also decisive in controlling channel widening.

Brenna A. et al. (2023) - What drives major channel widening in mountain rivers during floods? The role of debris floods during a high-magnitude event. Geomorphology, 430, 108650, https://doi.org/10.1016/j.geomorph.2023.108650.

Rinaldi M. et al. (2015) - A methodological framework for hydromorphological assessment, analysis and monitoring (IDRAIM) aimed at promoting integrated river management. Geomorphology, 251, 122-136, https://doi.org/10.1016/j.geomorph.2015.05.010.

Ruiz-Villanueva V. et al. (2023) - River widening in mountain and foothill areas during floods: Insights from a meta-analysis of 51 European Rivers. Sci. Total Environ., 903, 166103, https://doi.org/10.1016/j.scitotenv.2023.166103.

Scorpio V. & Comiti F. (2024) - Channel changes during and after extreme floods in two catchments of the Northern Apennines (Italy). Geomorphology, 463, 109355, https://doi.org/10.1016/j.geomorph.2024.109355.

Deciphering the tectonic signature in arid landscapes: An insight into the central Al-Hajar Mountains (northern Sultanate of Oman)

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Keywords: landscape evolution, Oman, tectonic geomorphology.

The Al-Hajar Mountains (Mts) of the northern Sultanate of Oman represent a unique natural laboratory for investigating the geomorphic signature of tectonics in arid environments. Located along the northeastern margin of the Arabian Plate, this orogenic belt exhibits a multistage tectonic history accompanied by climatic variability. This study presents a multidisciplinary reconstruction of landscape evolution in the central Al-Hajar Mts, integrating: (1) geomorphological mapping derived from remote sensing and field surveys; (2) quantitative geomorphometry; and (3) Deep Learning algorithms.

The geomorphological mapping identifies key landforms shaped by the complex interplay between tectonics, surface processes, and climate. The region's landscape reflects a long evolutionary history beginning with Late Cretaceous obduction and subsequent uplift and doming, followed by Miocene-Quaternary erosion, karstification, and initiation of fluvial and slope processes. Tectonic activity has driven the development of structural features and monoclinal flanks, while karst processes have generated extensive underground networks and surface landforms. Fluvial and slope processes have produced incised valleys, alluvial fans, and pediments, with ongoing Quaternary tectonic activity influencing landscape dynamics.

Morphometric analysis reveals significant spatial variability among tectonic units, reflecting differential erosional patterns. Correlations between morphometric indices and fault density highlight spatial variations in the structural control over surface processes. The asymmetry in the spatial distribution of these indices reflects the long-term geomorphic imprint of doming, where regional uplift and local tectonic processes continue to govern topographic evolution and erosional patterns.

The developed Deep Learning algorithms were designed to automate the detection of fluvial features on multispectral SPOT 6 high-resolution satellite imagery, aiming to elucidate paleo-hydrological responses to tectonic shifts. This automated approach successfully mapped complex paleochannel systems on the Barzaman alluvial fan at the southern margin of the Al-Hajar Mts, differentiating between paleochannels and the underlying substrate. These results enhance the detection of past hydrological regimes, thereby deepening the understanding of Plio-Pleistocene evolution of fluvial systems.

By integrating geomorphological mapping, geomorphometry, and Deep Learning, this study offers a comprehensive synthesis of the complex interactions between tectonics, litho-structural setting, and climate. This multidisciplinary framework allows for the quantification of the roles played by both regional tectonic processes and local structural settings in shaping the landscapes of the Al-Hajar Mts. Ultimately, these findings contribute to broader insights into tectonic processes, landscape resilience, and future evolution in low-to-moderate tectonically active, arid environments.

What controls sediment transport in mountain catchments? Insights from indirect, long-term and continuous sediment transport measurements from the innovative monitoring stations of the Solda and Gadera rivers (South Tyrol)

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Keywords: sediment transport, moutain rivers, seismic monitoring.

Suspended sediment and bedload transport play a key role in regulating erosion and aggradation processes of mountain rivers. Although it is crucial to estimate sediment transport rates to study river morphodynamics and manage flood risk, direct measurements often lack temporal resolution and predictions are challenging because of a complex interplay between sediment supply and hydrological forcing. In this context, indirect methods such as the use of turbidimeters and passive seismic sensors (e.g. geophone plates) have been shown to provide long-term and continuous measurements of suspended sediment and bedload transport.

Here, we present the results obtained with the innovative monitoring stations of Ponte Stelvio (Solda river) and Mantana (Gadera river) designed to monitor both water and sediment fluxes as a part of the operational gauging network of the Civil Protection Agency of Bolzano (South Tyrol, Italy). The two catchments are characterized by a different extension (130 km^2 vs 383 km^2) and hydrological regime (nivo-glacial vs nivo-pluvial), respectively. Suspended sediment transport is indirectly measured by turbidimeters, while bedload transport is estimated by geophone plates installed on the riverbed, which record the seismic signal generated by particle impacts. In order to calibrate the instruments, we used direct measurements conducted between 2023 and 2025 with automatic pumping samplers, bedload slot samplers and electronically controlled mobile bedload traps. The comparison between sediment transport and water discharge measurements shows that, although rainfall-induced floods generated significant sediment transport peaks in both rivers, more frequent (but lower) water flow conditions related to snow and glacier-melt transported a large share of the annual sediment yield in the long term. Another similarity between the Solda and Gadera rivers involves the sediment yield trend throughout the monitored period (i.e. 2014-2025 for the Solda river, and 2021-2025 for the Gadera river), where the 2023 was marked by a threefold increase in both suspended sediment and bedload transport for both rivers compared to the previous years. Since the strongest sediment mobilization was observed in July and August, we advance this is due to the combined effect of intense snow and glacier-melt associated with high air temperature and rainfall events that impacted both mountain catchments. Despite these analogies, additional analyses on bedload concentrations are needed to investigate the impact of factors other than runoff (e.g sediment supply) on the two catchments. These findings underline the usefulness of such monitoring strategies to provide long-term and continuous sediment transport estimations, and to investigate the controlling factors on sediment transport dynamics in different mountain catchments.

Tracking coarse bedload transport with active RFID tracers in a glacier-fed Alpine catchment

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Keywords: bedload transport, RFID pebble tracking, Alpine rivers.

Bedload transport in Alpine rivers is highly episodic and spatially heterogeneous, making direct observations of coarse sediment movement difficult. Tracer-based pebble tracking provides an opportunity to investigate particle-scale transport dynamics, including travel distances and virtual velocities. We present results from an active RFID pebble-tracking experiment conducted in the glacier-fed Sulden/Solda catchment (Eastern Italian Alps), a highly dynamic Alpine basin characterized by strong seasonal meltwater forcing and abundant sediment supply from proglacial areas.

A total of 110 natural pebbles with intermediate axis lengths greater than 50 mm were equipped with active ultra-high-frequency RFID transmitters and released in August 2025 within the Sulden River. Two stationary RFID antenna systems installed along the river monitored downstream particle passage over an 11.2 km stretch of the river system. In addition, three-dimensional particle models were reconstructed using structure-from-motion photogrammetry to quantify particle size and shape characteristics, including key shape and roughness metrics.

Of the 110 released tracers, 98 pebbles (89%) were detected at the upstream antenna, and 44 pebbles (40%) were subsequently detected at the downstream station. Travel times between antennas ranged from 1.7 to 37.6 days, with an average travel time of 12.8 days. This indicates that most particles required approximately one to two weeks to traverse the monitored river section. The movement of the tagged pebbles occurred in several distinct transport pulses, reflecting the episodic nature of coarse sediment transport in Alpine rivers.

Preliminary statistical analyses suggest that transport dynamics were more strongly influenced by stochastic entrainment and local hydraulic conditions than by intrinsic clast properties. The experiment provides new insights into coarse sediment mobility in glacier-fed Alpine rivers and highlights the potential of active RFID systems for improving understanding of sediment connectivity and transport regimes in rapidly changing glacier-fed catchments.

From catchment to channel: How altered sediment connectivity and in-channel human impacts shaped the evolution of two Apennine rivers

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Keywords: channel changes, (dis)connectivity, human impacts.

Over the last centuries, geomorphological evolution of river systems has been controlled by interacting natural and anthropogenic drivers operating across different spatial and temporal scales. They include direct in-channel interventions and indirect catchment-scale land use changes that have altered the natural conveyance of sediment supply. Understanding past evolutionary trajectories and the role of controlling factors is essential to interpret present river conditions and support sustainable management of fluvial systems.

This study analyses the multi-temporal evolution of the Taro River and its main tributary, the Ceno River (Northern Apennines, Italy), over the past 70 years with the aim of comparing the evolutionary trajectories of the two rivers. Main issues of this study include the investigation of: (i) the links between channel adjustments and sediment dynamics along the hillslopes; (ii) the effect of land use changes on sediment (dis)connection to the channel network; and (iii) the role played by in-channel human disturbances, including gravel mining and channel works, on the channel adjustments.

Channel width variations were quantified using multi-temporal orthophotos (1954-2020), while bed-level changes were derived from topographic cross-sections. At the basin scale, land use changes and sediment connectivity were analysed using multi-temporal land cover maps and the Index of Connectivity, while variations in sediment supply were estimated from multi-temporal changes in landslide-prone areas and their connectivity. At the reach scale, the impact of human activities was assessed by mapping gravel extraction sites and in-channel constructions.

Results reveal a progressive afforestation, starting after the 1950s in the Ceno and after the 1970s in the Taro catchment, accompanied by a widespread reduction in landslide susceptibility. These trends led to a reduction in sediment supply and connectivity to the channel network. Both rivers underwent marked channel narrowing, with width reductions up to 50% in the Taro and up to 38% in the Ceno. Analysed rivers also experienced significant bed incision, with median values of -3.3 m in the Taro and -2.5 m in the Ceno. However, the Taro River showed a distinctly amplified and more rapid response, with the most intense adjustments occurring between 1954 and 1976, clearly linked to extensive gravel mining and the construction of in-channel works, which were entirely absent in the Ceno River.

These results demonstrate that similar catchment-scale trends can produce markedly different channel responses when compounded by local human disturbances, highlighting the need to account for both large and local-scale drivers when designing effective management strategies.

Recent evolution of the Serio River (Italy): Linking lateral migration, channel recovery, and long-term trajectories

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Keywords: lateral migration, channel recovery, bed level changes.

River evolution is driven by continuous morphological adjustments, strongly influenced by both natural processes and human pressures. To properly understand current channel behaviour, it is essential to investigate past evolutionary trajectories, which provide the context for recent changes and ongoing changes.

This study focuses on a segment about 21 km long of the Serio River (Northern Italy), a gravel-bed river with a wandering-braided planform morphology. The aim of this work is to investigate lateral migration processes and to assess their role in recent channel evolution (last ~20 years), also in comparison with long-term trajectories. Channel evolution over short- (2002-2024) and long-term (1889-2024) periods was reconstructed through multi-temporal mapping of the active channel, based on one historical map (1889), 14 sets of orthophotos (1954-2023) and three satellite image sets (2019, 2020, 2024). Short-term lateral migration was quantified in terms of bank erosion and floodplain formation rates. To investigate the relationship between lateral and vertical adjustments, channel bed elevation changes were analysed over the short and long periods, through cross-sections, field surveys and DoD analyses.

Recent river dynamic was very intense, resulting in widespread bank erosion that on average affected more than 30% of the total banks, but locally was up to 70%. Bank erosion rates, calculated over the last ~20 years, ranged from 0.6 to 1.5 m/yr. However, lateral erosion was partly compensated by floodplain formation processes, with accretion rates ranging between 1.0 and 2.2 m/yr. As a result, channel adjustments alternated between widening and narrowing across successive intervals, while the overall short-term period was characterised by a substantial dynamic equilibrium in most reaches. In contrast, long-term analysis reveals a pronounced bed-level lowering in recent decades, with most incision (up to 7 m) occurring before the early 2000s, and a general trend of historical channel narrowing (up to ~70% of the initial width in 1954). These results suggest an ongoing phase of partial morphological recovery following the historical narrowing/incision phase. Finally, to identify areas prone to future channel dynamics and assess morphological recovery potential, the erodible corridor was delineated by combining historical channel shifting (from multi-temporal mapping) with potential future erosion areas (from bank erosion rates).

SAFEQUALITY project: Integrating geomorphology and hydraulics to assess past, present and future river dynamics for flood risk mitigation and morphological quality improvement in the Panaro River (Italy)

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Keywords: Panaro River morphodynamic, flood risk, multidisciplinary approach.

Apennine rivers provide essential ecosystem services and water resources, but also pose increasing risks to people and infrastructure due to flood hazards, which are expected to intensify under climate change. Addressing these challenges requires interdisciplinary approaches that integrate geomorphology, hydraulics, engineering, and environmental management. In this context, the SAFEQUALITY project aims to investigate the past evolution, present condition, and future trajectories of the Panaro River (Northern Italy), with the dual objective of improving flood safety and enhancing river morphological quality.

The project focuses on a 50 km long segment of the Panaro River and is structured around three main objectives: (i) reconstructing river morphological changes over the last century to quantify channel narrowing, bed elevation changes, planform adjustments, and vegetation dynamics; (ii) assessing the current geomorphological and hydraulic conditions to identify river segments most prone to flooding, bank erosion, and climate-driven instability; and (iii) predicting future channel evolution and evaluating the potential effectiveness of river restoration measures.

To achieve these goals, SAFEQUALITY adopts an integrated multi-method approach combining historical analysis, field surveys, remote sensing, geomorphological and geomorphometric analyses, sediment connectivity assessment, and hydraulic modelling. Historical channel adjustments are reconstructed using multi-temporal orthophotos, historical maps, and topographic cross-sections, while current river conditions are evaluated using grain-size surveys, morphological quality indices, and automated extraction of morphological features from high-resolution DTMs through the LANDMARK analysis tool. Hydraulic simulations based on HEC-RAS, supported by field measurements and remote sensing validation, are used to estimate spatial patterns of flow dynamics, sediment transport, and potential future erosion/deposition trends.

By integrating geomorphological and hydraulic perspectives, SAFEQUALITY provides a comprehensive understanding of river sensitivity and adjustment trajectories, supporting more sustainable river management and restoration strategies. The project is expected to contribute to European priorities on climate adaptation and water resilience, offering transferable methodologies for assessing flood risk and morphological recovery potential in river systems.

Multi-stage landscape evolution as result of regional uplift, local drainage integration, and karst groundwater flow in the Aterno and Tirino basins (central Apennines)

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Keywords: drainage integration, carbonate landscape, Quaternary.

This study reconstructs the long-term geomorphic evolution of the Aterno and Tirino basins in the central Apennines, aiming to identify the main controls on drainage integration, fluvial incision, and paleolandscape development from the Late Miocene to the present. We integrated geomorphological mapping of paleosurfaces with digital terrain model analysis using the Surface Classification Method. River long profiles, χ-plots, normalized steepness indices (k_{sn}), and knickpoint distributions were extracted with LSDTopoTools. Paleosurface ages were constrained through correlation with dated continental deposits. Incision rates were estimated from age-elevation relationships for each basin sector. Hydrogeological data from regional aquifers were analyzed to compare cumulative discharge trends with channel morphology. Four paleolandscape levels, dated from the late Messinian to the Middle Pleistocene, record successive phases of landscape evolution linked to thrust-top sedimentation, lacustrine environments, and extensional tectonics. Incision histories show a long-term decrease in incision until ~1.5 Ma, followed by spatially variable acceleration associated with regional and local tectonics, and basin integration. River-profile metrics reveal knickpoints aligned with paleosurface remnants and previous drainage configurations, marking discrete incision waves and tributary captures. Hydrogeological observations indicate that high groundwater discharge from the Gran Sasso and Sirente aquifers strongly conditioned incision patterns: the Tirino Basin underwent early integration with the Sulmona base level, whereas the Aterno Basin records later groundwater capture and localized incision in the San Venanzio Gorge. Groundwater-driven discharge emerges as a key control on incision efficiency and drainage integration in carbonate mountain landscapes, complementing tectonic and climatic forcing.

Downstream variation of bed material in the Piave River, Eastern Alps, Italy

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Keywords: downstream grain size variation, Piave river, Pebble count technique.

Bed material calibre is a key driver of river morphodynamics, as it controls sediment transport regimes, influences channel morphology, and affects overall river stability (Church, 2006). Its rate of spatial change also has significant implications for downstream variations in flow resistance and sediment transport. Therefore, bed material characterization is crucial for understanding river sediment dynamics and, more broadly, its morphodynamics.

This study provides a detailed characterization of the bed material of the Piave River, a large gravel-bed river in the eastern Italian Alps. Specifically, we investigated longitudinal variations in sediment calibre, seeking to relate this trend to natural and anthropogenic controlling factors. The analysis focuses on a 180 km stretch of the Piave River from Sappada to Ponte di Piave.

Following the IDRAIM framework (Rinaldi et al., 2016), the main stem of the Piave River was segmented into 54 geomorphologically homogeneous reaches. Sediment sampling was conducted on the surface material using the Pebble Count technique (Wolman, 1954), with measurements taken at one representative spot per reach, at major tributary confluences defining reach boundaries, and both upstream and downstream of major anthropogenic structures, resulting in a total of 70 sampling sites. To complement the grain size analysis, qualitative observations such as the bed state (e.g. underloose or overloose state), were collected for each reach, providing preliminary insights into present vertical trend of the channel bed.

The results provide a comprehensive characterization of the Piave River's bed material, highlighting longitudinal variations in D50 (i.e., the median grain-size) and D84. Discontinuities in D50 and D84 trend were identified and attributed to both natural factors (e.g., lateral sediment inputs from tributaries) and anthropogenic influences (e.g., in-channel filtering structures and mining). These findings are consistent with and expand upon the complex downstream sediment size pattern previously documented by Surian (2002) and allow advancing the understanding of sediment dynamics in the Piave river also from a temporal-evolution perspective.

Church M. (2006) - Bed Material Transport and the Morphology of Alluvial River Channels. Annu. Rev. Earth Planet. Sci., 34(1), 325-354, https://doi.org/10.1146/annurev.earth.33.092203.122721.

Rinaldi M. et al. (2016) - IDRAIM - Sistema di valutazione idromorfologica, analisi e monitoraggio dei corsi d'acqua - Versione aggiornata 2016. ISPRA, Manuali e Linee Guida, 131/2016, Roma, https://www.isprambiente.gov.it/it/pubblicazioni/manuali-e-linee-guida/idraim-sistema-di-valutazione-idromorfologica-analisi-e-monitoraggio-dei-corsi-d2019acqua-versione-aggiornata-2016.

Surian N. (2002) - Downstream Variation in Grain Size along an Alpine River: Analysis of Controls and Processes. Geomorphology, 43(1-2), 137-149, https://doi.org/10.1016/S0169-555X(01)00127-1.

Wolman M. (1954) - A Method of Sampling Coarse River-bed Material. Eos Trans. Am. Geophys. Union, 35(6), 951-956, https://doi.org/10.1029/TR035i006p00951.

Early morphodynamic recovery in a restored Alpine river: The Mareta River case study

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Keywords: river restoration, geomorphic unit survey, dem of difference.

The implementation of the Water Framework Directive has driven the assessment of European rivers toward process-based evaluation of hydromorphological conditions. However, detecting short-term channel adjustments in restored systems remains a key challenge. This study investigates the post-restoration channel trajectory of the Mareta River (NE Italian Alps), historically channelised and incised due to intensive gravel mining and check-dams construction (Scorpio et al., 2020). Building upon previous datasets over more than a decade, new high-resolution UAV-derived DEMs and orthophotos significantly increase the temporal resolution of available topographic data, shifting from sparse observations (2012-2016-2018) to a higher-frequency monitoring framework (2024-2025-2026). This improvement enables the detection of short-term channel adjustments at the reach scale that are typically overlooked in restored Alpine rivers. DEMs of Difference (DoD) are used to quantify spatial patterns and volumes of erosion and deposition (Williams et al., 2020), while Geomorphic Unit Survey (GUS) mapping and related indices (GUSI-R and GUSI-D) are analysed to track temporal changes in geomorphic unit richness and density (Belletti et al., 2017). This study explicitly tests the hypothesis that early-stage recovery is expressed by (I) increasing geomorphic unit diversity, (II) a shift in the erosion/deposition balance, and (III) spatial correspondence between depositional areas and the expansion of active geomorphic units. Results indicate a progressive transition from incision-dominated conditions toward enhanced lateral activity and sediment storage. Increases in GUS indices are observed in reaches where DoD analyses highlight net deposition and bar development, suggesting that sediment accumulation is directly linked to the reactivation of channel processes at the reach level. The higher temporal resolution of UAV surveys proves critical in capturing these localised and transient dynamics. The integration of volumetric (DoD) and process-based (GUS) metrics, combined with increased survey frequency, provides a robust framework for detecting subtle geomorphic changes over short timescales. This approach supports a more process-oriented evaluation of restoration trajectories and offers practical implications for adaptive river management in Alpine environments.

Belletti B. et al. (2017) - Characterising physical habitats and fluvial hydromorphology: A new system for the survey and classification of river geomorphic units. Geomorphology, 283, 143-157, https://doi.org/10.1016/j.geomorph.2017.01.032.

Scorpio V. et al. (2020) - Restoring a glacier-fed river: Past and present morphodynamics of a degraded channel in the Italian Alps. Earth Surf. Process. Landf., 45, 2804-2823, https://doi.org/10.1002/esp.4931.

Williams R. D. et al. (2020) - Let the river erode! Enabling lateral migration increases geomorphic unit diversity. Sci. Total Environ., 715, 136817, https://doi.org/10.1016/j.scitotenv.2020.136817.

Computer vision-based optical flow system for real-time river surface velocity monitoring

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Keywords: river monitoring, optical flow, computer vision.

Recent advancements in computer vision are reshaping environmental monitoring, offering novel opportunities for automated analysis in geomorphology. This work presents the development and application of a cost-effective optical flow system designed to estimate river surface velocity fields from fixed video monitoring stations, providing a scalable solution for hydrological analysis and flood-risk management (Eltner et al., 2020; La Salandra et al., 2022).

The proposed methodology relies on a versatile computer vision-based framework capable of tracking the displacement of water surface patterns (Sabato et al., 2025) — such as ripples, foam, and floating debris — within standard RGB video sequences. By integrating both dense (Farnebäck, DeepFlow) and sparse (Lucas-Kanade) optical flow algorithms, combined with geometric perspective transformation and advanced statistical aggregation (e.g., 80th percentile and median filtering), the tool generates stable, high-resolution velocity time-series. Furthermore, a custom multithreaded architecture ensures robust, near real-time processing directly from IP camera RTSP streams. Experimental validation across diverse Italian riverine environments demonstrates the system's robustness under varying lighting conditions and flow regimes, successfully capturing both steady and transient hydrodynamics (Muste et al., 2008).

A primary strength of this approach is its operational flexibility and low barrier to entry. Implementing conventional cameras and open-source software eliminates the reliance on expensive proprietary instrumentation, making the system particularly suitable for establishing permanent observation networks in data-scarce or flood-prone regions. Continuous surface velocity monitoring provides essential data for calibrating hydrodynamic models, identifying morphological changes, and supporting decision-making processes.

Beyond technical implementation, this research emphasizes the critical integration of computer vision tools into broader territorial management frameworks. Strengthening collaborations with stakeholders, including Basin Authorities and civil protection agencies, through shared data analytics significantly enhances the efficacy of early-warning systems. Ultimately, this study highlights how intelligent, low-cost monitoring solutions can drive more proactive responses to extreme events, fostering greater resilience in vulnerable communities.

Eltner A. et al. (2020) - Technical Note: Flow velocity and discharge measurement in rivers using terrestrial and unmanned-aerial-vehicle imagery. Hydrol. Earth Syst. Sc., 24, 1429-1445, https://doi.org/10.5194/hess-24-1429-2020.

La Salandra M. et al. (2022) - Probabilistic hydro-geomorphological hazard assessment based on UAV-derived high-resolution topographic data: The case of Basento river (Southern Italy). Sci. Total Environ., 842, 156736, https://doi.org/10.1016/j.scitotenv.2022.156736.

Muste M. et al. (2008) - Large-scale particle image velocimetry for measurements in riverine environments. Water Resour. Res., 44, https://doi.org/10.1029/2008WR006950.

Sabato G. et al. (2025) - Optical Flow for Wave Characterization in a 2D Water Flume Using Video Analysis: A Cutting-Edge Tool for Coastal Monitoring. In: EGU General Assembly Conference Abstracts, EGU25-424, https://doi.org/10.5194/egusphere-egu25-424.

Morphological effects induced by an extreme flood in the Misa River (Central Italy)

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Keywords: channel widening, riverbank erosion, over bank deposits.

This study investigates the morphological responses of the Misa River (Eastern Apennines, Italy) to a high magnitude flood that occurred on 15th September 2022. Research was based on field surveys and geomorphological analysis of multi-temporal orthophotos acquired before (April 2022) and immediately after the flood (September 2022). The most relevant geomorphic processes caused by the flood were the active channel widening, the sedimentation of overbank deposits on the terraces and the transport of significant amounts of large wood. Notably was the fact that during the peak of the flood the channel width increased to values up to 9 times (median width ratio during the flood (Wr_{flood}) = 3) the channel before the flood, but immediately after, it narrowed to 7 times the channel before (median width ratio after the flood Wr_{after}; median =2).

Overbank coarse deposits were locally found on terraces, at median elevation of 3.5 m with respect to the talweg, but in many cases also exceeding 6 m. Median Wr_{flood} was 4.2 in the reaches characterized by the sedimentation of overbank deposits and 1.6 in the reaches with a prevalence of lateral bank erosion. A link between the active channel pattern and the widening was detected, as in the sinuous reaches, it was less intense (Wr_{flood} = 1.6) then in the reaches with transitional pattern (Wr_{flood} = 3.5).

Main geomorphic effects assessed in the Misa River where blamed to boundary conditions, in particular to the bank's material - dominantly composed of cohesive deposits- and morphology, mainly near-vertical, and to the presence of riparian vegetation that contributed to stabilize the banks.

S28.

Multi-scale and multi-source approaches to the assessment and mitigation of ground instabilities

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From static to dynamic landslide susceptibility: A spatiotemporal GAM approach in the Belluno Alps (NE Italy)

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Keywords: landslide susceptibility, generalized additive models, Alps.

Landslides are dynamic geomorphic processes controlled by both static terrain conditions and temporally varying triggering factors, particularly rainfall. Nevertheless, most landslide susceptibility models adopt a static perspective, limiting their ability to represent evolving slope instability. This study presents a dynamic landslide susceptibility framework based on multi-temporal inventories and a spatiotemporal modeling approach. The analysis focuses on the Cordevole Basin in the Belluno Alps (northeastern Italy), where five landslide inventories (pre-2006 to 2021) were compiled from historical records and high-resolution orthophotos. Landslide occurrence was modeled at the slope-unit scale using a hierarchy of models, including logistic regression and generalized additive models (GAMs), progressively incorporating non-linear effects, temporal dependence, and spatial structure. Predictor variables included DEM-derived topographic factors and cumulative rainfall over multiple antecedent periods. Results indicate that slope gradient and short- to mid-term rainfall are the primary controls on landslide occurrence. The spatiotemporal GAM outperforms conventional models, achieving higher predictive accuracy (AUC up to ~0.85) and effectively capturing non-linear and time-dependent relationships. Among rainfall metrics, the 14-day accumulation provides the most reliable proxy for triggering conditions. These findings highlight the importance of integrating temporal dynamics into susceptibility modeling and demonstrate the potential of spatiotemporal approaches for improving hazard assessment, early warning systems, and land-use planning in mountainous regions.

Investigation and modelling of hydrological preparatory factors controlling the mobility of rainfall-driven slow-moving landslides: Insights from multi-temporal monitoring data in the Liguria Region (NW Italy)

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Keywords: ground instabilities, slow-moving landslide, hydro-geotechnical monitoring data.

Slow-moving landslides frequently affect urbanized slopes and can involve a wide variety of soil and rock materials. Their evolution is often governed by long-term geomorphological and hydrogeological processes, and movement generally occurs along one or several pre-existing failure surfaces where the shear strength has reached residual conditions. Typically, these landslides can remain active for decades or even centuries, displaying movement rates that range from very slow to extremely slow. Nevertheless, they may experience sudden accelerations that can cause significant damage and casualties; therefore, understanding and forecasting the conditions that induce movement acceleration is a crucial issue for effective landslide hazard assessment and the design of early warning systems. These changes are strongly influenced by hydrological and hydrogeological processes, particularly pore-water pressure variations induced by rainfall and snowmelt. However, the relationship between hydrological forcing and landslide displacement is complex, as it depends on both external environmental conditions and internal slope characteristics. Therefore, long-term hydro-geotechnical monitoring is essential for understanding and predicting landslide behaviour.

In this contribution, we present results from research activities carried out within the framework of the RETURN project (multi-Risk sciEnce for resilienT commUnities undeR a changiNg climate), funded by the Italian Ministry of University and Research (MUR) and the European Union's NextGenerationEU programme. The study focuses on a reactivated slow-moving landslide located in the Liguria Region (NW Italy): the Fontane di San Bernardo landslide in the Northern Apennines (eastern Liguria, Genoa Province).

Long-term hydro-geotechnical and meteorological datasets (2015-2024), including groundwater levels, pore-pressure data, rainfall, and temperature records, were analyzed to investigate the temporal relationships between hydrological variables and slope movements. A simple, physically based groundwater model was implemented and calibrated using these datasets to quantify the response of the groundwater table to discrete rainfall events.

Preliminary results highlight that both the hydrological and kinematic responses of the landslide vary depending on the characteristics of precipitation events—particularly their intensity and duration. Moreover, the pore-pressure signal appears to capture and interpret major displacement episodes more effectively than fluctuations in the groundwater table alone. The outcomes of this study provide a valuable basis for developing quantitative models capable of simulating and predicting the hydrological preparatory processes influencing the kinematic behaviour of slow-moving landslides, thereby contributing to improved risk mitigation and early warning strategies in complex geomorphological contexts.

From multitemporal landslide data to critical rainfall thresholds and associated return periods: A data-driven framework for rainfall-induced shallow landslide hazard assessment

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Keywords: multitemporal landslide inventory, daily rainfall threshold, hazard mapping.

Rainfall-induced shallow landslides are widespread in northern Tuscany, where intense rainfall events interact with steep topography and heterogeneous geological settings. Within the activities carried out for the CARG Sheet 249 "Massa-Carrara" (Disperati et al., 2025), we develop a data-driven framework to estimate spatially distributed critical daily rainfall thresholds (PGC) and the associated return periods (Tr_{PGC}). Although landslide catalogues providing triggering dates are available (e.g. Brunetti et al., 2025), they generally represent a subset of the landslides that actually occurred. We show that multitemporal inventories constraining landslide occurrence dates within temporal windows may be used to support regional-scale hazard assessment. To this aim, we compile a multitemporal landslide inventory from aerial images acquired between 1954 and 2021. For each landslide, an occurrence time window (FTO) is defined by the dates of the most recent image where the landslide is absent and the oldest image where it is observed; the preceding interval is defined as non-occurrence time window (FTN). The basic assumption is that intense daily rainfall events recorded during the FTN did not exceed the local critical condition, whereas at least one rainfall event within the FTO must have been compatible with landslide triggering. Daily rainfall models for 1954-2021 are interpolated by Universal Kriging using elevation as an auxiliary variable (Nigro et al., 2024). The study area is partitioned into multiple sets of unique condition units (UCU), combining geology, morphometry, geomorphology, land use and mean annual rainfall. As the interactions among predisposing factors are not "a priori" known, alternative UCU configurations are tested to account for different terrain controls on the spatial variability of PGC. For each UCU with landslides, intense daily rainfall events occurring within FTN and FTO are compared using a confusion-matrix approach, and the PGC is estimated by maximizing a skill score. For UCU without observed landslides, the 99th percentile of intense daily rainfalls is assumed to represent a lower limit of the PGC. Repeating the procedure across the ensemble of UCU configurations allows us to obtain multiple spatial models of PGC which are combined to extract a robust central PGC value and associated dispersion index. Tr_{PGC} is then estimated by applying the GEV analysis to annual maxima of daily rainfall (Coles et al., 2001). The resulting models show that Tr_{PGC} varies at hillslope scale. A preliminary independent validation of PGC is finally performed using an intense rainfall event that occurred in April 2025 and triggered dozens of shallow landslides.

Brunetti M.T. et al. (2025) - An enhanced rainfall-induced landslide catalogue in Italy. Sci. Data, 12, 216, https://doi.org/10.1038/s41597-025-04551-6.

Coles S et al. (2001) - An introduction to statistical modeling of extreme values. Springer, 209 pp, https://doi.org/10.1007/978-1-4471-3675-0.

Disperati L. et al. (2025) - Note Illustrative della Carta della Pericolosità Geologica d'Italia alla scala 1:50.000, F. 249 Massa-Carrara, ISPRA - Serv. Geol. d'It., Roma, https://doi.org/10.15161/oar.it/p8vrh-2s575.

Nigro M. et al. (2024) - Investigating a Century of Rainfall: The Impact of Elevation on Precipitation Changes (Northern Tuscany, Italy). Water, 16, 19, https://doi.org/10.3390/w16192866.

Geodetic-topographic monitoring of the landslide in the urban center of Motta Sant'Anastasia (Sicily, Italy)

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Keywords: monitoring, GNSS, landslide.

Geotetic and topographic monitoring for defining the kinematics and dynamics of geological processes, such as ground deformation, is a fundamental practice to study these types of phenomena. The monitoring must be calibrated by the analysis of spatio-temporal factors, these characterise the deformation rate and must be supported by preliminary stratigraphich and geological surveys, and by geomorphological, hydrological and geotechnical studies. In this work, the research team of the Geodynamic & Geomatic laboratory (University of Catania) in agreement with the municipally of Motta Sant'Anastasia (CT), designed and installed a GNSS network to monitor and define the kinematics of a landslide affected in the north-eastern area of the urban center. The landslide movement is eastward oriented and is made up by chaotic clayey-sandy materials (Servizio Geologico d'Italia, 2010). The area affected by the gravitational process is evidenced by fractures in the sidewalk, asphalt, buildings, and walls. The landslide develops in a complex geological-stratigraphic context, characterized by superficial alluvial deposits gradually transitioning to the bottom with gravelly sands, sands, sandy clays, and grey-blue Plio-Pleistocene clays interbedded with sandy lenses of probable volcanic origin. The layer of sand lenses may represent a preferential pathway for water infiltration and storage. It is also identified as the slip surface of the landslide. In 1984, a retaining wall and sub-drainage wells were constructed to stabilize the landslide movements. Since 2023, we established and monumented three permanent GNSS stations and twelve GNSS discontinuous points. One permanent station is located in the stable area, outside the landslide, while the other two are located astride the crown zone. The discontinuous points are orthogonally arranged with respect to the landslide movement and above the retaining wall. After three years of measurements, the permanent stations outside the crown area show no significant movements, whereas the permanent station inside the crown and the central discontinuous measurement points allowed us to define a rate of motion of 9 and 12 mm/month, respectively. These movements are likely related to the progressive failure of the retaining wall due to the progressive motion of the landslide over time.

Servizio Geologico d'Italia (2010) - Carta Geologica d'Italia alla scala 1:50.0000, F. 633 Paternò. ISPRA, Roma.

Characterizing a sinkhole prone area: New data from the San Martino River valley (Metropolitan Area of Rome Capital)

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Keywords: Lago Puzzo, sinkhole prone areas, geological and geophysical investigations.

In the lower Tiber River valley, Pleistocene N-S trending shear zones, controlling the formation of subsiding basins, have been identified (Bortolani & Carugno, 1979; Faccenna & Funiciello, 1993). In particular, the San Martino Valley, a right tributary of Tiber developed in correspondence of a significant morpho-tectonic element, shows the typical predisposing factors of a sinkhole prone area (local seismicity, endogenous gases emissions, hydrothermal circulation, recent tectonics, presence of a karstified calcareous bedrock under a thick sedimentary cover). Historical sources document in fact the occurrence along the valley, since half 19th century, of subsidence and of surface collapses, hosting ephemeral lakes (Console & Nisio, 2020). In October 2020, a low-magnitude earthquake occurred near the town of Capena, characterized by a very shallow hypocenter and unusual absence of aftershocks. The event, accompanied by underground rumbling noises, perceived also in the following days, reinforced attention on the issue; local administrations and scientific institutions consequently promoted new investigations, aimed at land monitoring and safety of population and infrastructures (De Ritis et al., 2025).

This study focuses on the "Lago Puzzo" sinkhole, one of the most representative and still actively evolving multiphase collapse structures within the San Martino Valley. An integrated geophysical and remote sensing approach was applied to investigate the current evolutionary stage of the sinkhole system and to assess potential instability processes affecting the area. The investigation combined magnetic and gravimetric surveys, Electrical Resistivity Tomography (ERT), ambient seismic noise measurements, and satellite-based InSAR analyses, in order to detect possible ground deformation patterns, characterize shallow subsurface structures, and identify zones potentially affected by instability. In addition, a spectral analysis of seismic data was carried out on the 2020 earthquake, with the aim of evaluating whether the event could be related to ongoing evolution within the underlying karstic bedrock and to possible geological or geomorphological surface effects. Although no direct causal relationship was identified between the earthquake and the evolution of the Lago Puzzo sinkhole, the integrated geophysical and remote sensing dataset provided valuable insights into the present deformation state and structural setting of the area. Moreover, in April 2026 the Geological Department of the Metropolitan City of Rome performed a 120 m deep drilling, beside the provincial road running along the valley, and very close to the Lago Puzzo. New stratigraphic data analysis and hydrogeological measurements are in progress, in cooperation with INGV and Roma TRE University. The preliminary results contribute to improving hazard assessment and monitoring strategies in this sensitive sector of the metropolitan area of Rome.

Bortolani L. & Carugno P. (1979) - Lineamenti geologico-strutturali dell'area a sud del Monte Soratte (Lazio centro-settentrionale). Boll. Soc. Geol. Ital., 98(3), 353-373.

Console F. & Nisio S. (2020) - Il Lago di Leprignano o Lago Nuovo (Capena, Roma). In: Pantaloni M., Console F., Argentieri A., Mantero D. (Eds), I siti della memoria geologica del Lazio, Memorie Descrittive della Carta geologica d'Italia, 61-68.

De Ritis R. et al. (2025) - Assessing the Impact of the October 2020 Capena Earthquake on the Lago Puzzo Sinkhole (San Martino Valley, Rome, Italy): Seismological, InSAR, and Geophysical Evidence of Possible Causal Relationships. Pure Appl. Geophys., 182, 3919-3937, https://doi.org/10.1007/s00024-025-03810-2.

Faccenna C. & Funiciello R. (1993) - Tettonica pleistocenica tra il Monte Soratte e i Monti Cornicolani (Lazio). Il Quaternario, 6(1), 103-118.

National-wide automated classification of ground instabilities processes based on multi-modal deep learning

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Keywords: multi-modal, deep learning, ground instabilities.

Ground instabilities are among the most catastrophic geohazards in Italy. Ground instabilities processes can occur in vertical or downslope directions, including subsidence, landslides, Deep-Seated Gravitational Slope Deformations (DSGSDs), and deformation related to open-pit mining activities. The identification and classification of these processes are essential for sustainable land-use planning and targeted hazard mitigation, as they can severely threaten infrastructures and human lives. Earth observation (EO) provides large amounts of heterogeneous monitoring data over large areas, such as interferometric synthetic aperture radar (InSAR) displacement time series, multispectral satellite imagery, and terrain related products. However, the effective integration of multimodal data for improved classification of ground instabilities processes remains a major challenge.

In this study, we propose an automated framework for the identification and classification of ground instabilities processes through the integration of multimodal Earth observation datasets. Active Deformation Areas (ADAs) were first generated at the national scale using European Ground Motion Service (EGMS) products and ADA tools (Navarro et al., 2020). For each ADA, temporal and spatial data was extracted from multiple data sources. The proposed deep learning framework consists of two branches. The first branch analyses InSAR displacement time series to characterize temporal deformation patterns. The second branch extracts spatial and morphological information from geospatial imagery and terrain related products. The extracted features from the two branches are subsequently integrated through a Long Short-Term Memory (LSTM) based fusion strategy to perform the final classification.

To evaluate the proposed approach, a ground deformation dataset containing more than 26,000 active deformation areas was constructed. The dataset includes four deformation classes: landslide, subsidence, DSGSD, and mining induced deformation. The proposed model achieved an overall classification accuracy higher than 90% on both ascending and descending datasets. The results demonstrate the potential of multimodal deep learning methods for the automated classification of large-scale ground instabilities processes.

Navarro J.A. et al. (2020) - ADAtools: Automatic Detection and Classification of Active Deformation Areas from PSI Displacement Maps. ISPRS Int. J. Geo-Inf., 9(10), 584, https://doi.org/10.3390/ijgi9100584.

An integrated regional-scale framework for landslide susceptibility assessment to support land-use planning

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Keywords: landslide susceptibility, multi-source spatial data integration.

Regional-scale landslide susceptibility analysis requires consistent and operational approaches capable of integrating heterogeneous spatial information from multiple sources. However, landslide and environmental datasets are often heterogeneous, fragmented, and difficult to integrate consistently due to differences in classification schemes and spatial resolution. This study develops an integrated regional-scale framework for landslide susceptibility assessment based on the harmonization of multi-source spatial data. The workflow includes the standardization of heterogeneous landslide inventories, the alignment of environmental datasets in terms of spatial resolution and extent, and the generation of additional thematic layers derived from existing data. The approach combines landslide inventories and remote sensing-derived information to improve the characterization of second-generation landslides. Potential first-generation landslides are instead identified through pixel-based logistic regression modelling validated through spatial K-fold cross-validation. A geomorphological-hydrological approach is also applied to assess the runout of debris-flow landslides, enabling the identification of potential propagation areas. Since different landslide processes are governed by different controlling factors, dedicated susceptibility analyses are required. Continuous susceptibility outputs derived for the different landslide processes are reclassified into classes and integrated through a rule-based data-fusion procedure. The final product consists of a binary layer derived from the synthesis of individual landslide susceptibility maps, defining the presence or absence of instability. Despite its synthetic structure, the final map preserves information on the underlying instability processes affecting each area, providing a comprehensive and effective overview of regional-scale instability criticalities. The Lazio Region (Central Italy) was selected as a test case for the application of the proposed framework. From a methodological perspective, the proposed workflow represents a transferable framework for the identification and comprehensive evaluation of ground instabilities at large scale through the harmonization and fusion of heterogeneous spatial information. From an applicative perspective, the resulting outputs provide an overview of territorial criticalities, supporting stakeholders involved in territorial management and land-use planning activities.

Underground cavities and seismic hazard: The critical case of Castelnuovo (L'Aquila)

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Keywords: underground cavities, seismic hazard, L'Aquila earthquake.

The relationship between local seismic response and subsurface characteristics represents a key issue in seismic hazard studies, particularly in areas characterized by complex geological conditions and a widespread presence of anthropogenic underground cavities (Borghini et al., 2011; Sica et al., 2014; Evangelista et al., 2016). Abruzzo provides an emblematic example of this complexity, with numerous historic settlements built on heterogeneous geological substratum and affected by natural and man-made underground cavities developed over centuries. In this context, the village of Castelnuovo, nearby L'Aquila, represents a particularly significant case study for the anomalous concentration of seismic damage recorded after April 6, 2009 Mw 6.3 L'Aquila earthquake (2009AQEQ) due also to the widespread presence of underground cavities beneath its historic center located on a notable hill (Durante et al., 2018). Following the 2009AQEQ, cases of widespread collapses of vaults or walls of the underground cavities were not uncommon. In some instances, these contributed to the failure or settlements of the buildings above. Furthermore, historical seismicity data show that Castelnuovo exhibits anomalous, outlier behavior regarding the distribution of seismic damage. In fact, for any historical or recent earthquake—even those at great epicentral distances—a very high level of seismic damage has been recorded for Castelnuovo. This could be likely induced by the site's specific geological, lithotechnical, and geomorphological context. Based on the above, we present the preliminary results obtained for the Castelnuovo case study, conducted under an agreement with the Special Office for Reconstruction - USRC (https://www.usrc.it/) aimed at implementing the research project titled "Earthquakes and sinkholes in Abruzzo: L'Aquila and the surrounding villages". This project is being conducted as part of the 2nd-level inter-university master's degree program titled "Sinkholes and underground cavities: characterization, modeling, and risk mitigation", within the framework of the GeoSciences-IR project coordinated by ISPRA. This research project aims to investigate the role of underground cavities in the seismic hazard assessment of Castelnuovo through a detailed, data-driven geostatistical analysis of local geological, lithotechnical, and spatial data, as well as the updated distribution and characteristics (vault depth, volume, etc.) of the underground cavities. Furthermore, we compare these data, via a back-analysis approach, with the damage and vulnerability maps produced after the 2009AQEQ. The research, still in its preliminary stages, highlights how the most severe damage levels induced by the 2009AQEQ were recorded in areas with a higher density of underground cavities and at the highest elevations of the hill where the Castelnuovo historic center is located.

Borghini A. et al. (2011) - Studio degli effetti del sisma del 06/04/2009 sulla Frazione di Castelnuovo, Comune di San Pio delle Camere (AQ). In: Atti del XIV Convegno Nazionale ANIDIS "L'ingegneria sismica in Italia", Bari, 231-242.

Durante F. et al. (2018) - Censimento e mappatura della rete di cavità che sottende il paese di Castelnuovo, San Pio delle Camere (AQ). Geol. Ambient., 3, https://www.earth-prints.org/server/api/core/bitstreams/0d5d2a1d-f761-47cc-b84b-66241bcaecc9/content.

Evangelista L. et al. (2016) - The influence of the 3D morphology and cavity network on the seismic response of Castelnuovo hill to the 2009 Abruzzo earthquake. Bull. Earthq. Eng., 14, 3363-3387, https://doi.org/10.1007/s10518-016-0011-8.

Sica S. et al. (2014) - Ground motion amplification due to shallow cavities in nonlinear soils. Nat. Hazards, 71, 1913-1935, https://doi.org/10.1007/s11069-013-0989-z.

Developing a European land subsidence database through systematic review evidence and EGMS ground motion products

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Keywords: land subsidence, EGMS, Europe.

Land subsidence is a widespread geohazard affecting infrastructure, groundwater resources, coastal lowlands, and urban sustainability worldwide. In Europe, where many densely populated coastal and low-lying regions host major industrial, agricultural, and cultural assets, understanding subsidence processes is essential for long-term socio-economic resilience and spatial planning. To address this need, this study presents a European Subsidence Database developed from a systematic literature review covering 1981-2025, with integration of EGMS Level-3 ground motion data from 2019-2023.

A total of 533 Scopus-indexed documents were screened in Rayyan AI (a platform designed to support systematic review workflows) and refined in accordance with PRISMA guidelines to ensure a transparent article selection process. Bibliometric analyses using VOSviewer and Bibliometrix were conducted to summarize publication patterns and thematic trends. Following data extraction and synthesis, the 12 European countries were classified by publication frequency: Italy, Spain, Netherlands, and Greece as High; Poland, Germany, France, and England as Moderate; and Czech Republic, Sweden, Hungary, and Belgium as Low. The synthesis of the reviewed studies reveals that dominant subsidence mechanisms differ across Europe, reflecting regional contrasts in sedimentary settings, hydrogeological conditions, and anthropogenic controls.

In Italy, subsidence is associated with a range of natural and anthropogenic drivers, including groundwater withdrawal, compaction of compressible Holocene alluvial, deltaic, and coastal deposits, tectonic and volcanic processes, peat oxidation, and hydrocarbon extraction. Spain and Greece are characterized by subsidence mainly related to excessive groundwater withdrawal, alongside natural consolidation and tectonic and mining-induced processes. In Netherlands, the main driving factors include peat oxidation, drainage-induced consolidation, and hydrocarbon extraction. Poland and Czech Republic are mainly associated with mining-related subsidence from active underground mining and post-mining processes. Across Germany, France, England, Belgium, Sweden, and Hungary, subsidence is generally localized and linked to combined anthropogenic and geological factors, including infrastructure loading, tunneling/mining, groundwater overexploitation, compressible sediments, and local geological conditions. Together, these findings provide a brief synthesis of the dominant causes and reported deformation trends of land subsidence across Europe. In parallel, the planned cross-comparison with EGMS ground motion products will provide a consistent recent reference layer for comparison with these outcomes and to identify active areas that may require further attention.

High-frequency near-real time UAV-LiDAR monitoring during the 2025 Boccassuolo earthslide-earthflow emergency (Northern Apennines, Italy)

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Keywords: earthflow, multi-temporal UAV-LiDAR monitoring, offset tracking.

The Boccassuolo earthslide-earthflow reactivation in spring 2025 (Modena Province, Northern Apennines, Italy), rapidly became one of the most relevant recent landslide emergencies in the Italian Apennines because of its dimensions, rapid evolution and impact on local communities. During April 2025, the landslide progressively evolved from the source area to the toe zone, mobilizing more than 5×10^6 m^3 of material over a length of approximately 3 km and an area of about 60 hectares. By the end of April, the phenomenon partially blocked the Dragone Torrent, causing the formation of a temporary landslide-dam lake extending over more than 6000 m^2 and impounding approximately 20,000 m^3 of water. The event caused road interruptions, isolation of rural settlements and damage to buildings, leading first to the declaration of a regional state of emergency and subsequently to a national state of emergency.

Because of the rapid evolution of the phenomenon, a UAV-LiDAR monitoring campaign was activated from early April 2025 with the collaboration between the University of Modena and Reggio Emilia, the Regional Agency for Territorial Security and Civil Protection and the National Fire Brigades. High-frequency UAV surveys were carried out every 3-4 days, providing high-resolution DEMs (0.25 m) and orthophotos (0.10 m) suitable for rapid multi-temporal analyses. The near-sensing UAV-based approach was selected for the inadequate resolution, cloud coverage and timing of availability of satellite imagery, in an emergency framework which requires daily situation assessments, and for the impossibility of implementing a ground-based monitoring network, due to the large velocity and almost liquid-state reached by the moving mass and for the absence of a panoramic observation point.

The monitoring workflow was specifically conceived to provide rapid and spatially distributed information on landslide evolution under emergency conditions by exploiting multi-temporal datasets. Planimetric displacements were assessed by Offset Tracking with Optical Flow algorithms, validated by Homologous Point Tracking (HPT). At the same time, elevation changes due to the evolution of depletion and accumulation dynamics were assessed by DEMs of Difference (DoD). During the paroxysmal phases of activity, results evidenced displacement rates in the order of several metres per day, and allowed to assess and forecast the most active sectors of the landslide, thus supporting emergency management and operational decision-making. The results highlight how UAV-LiDAR surveys can represent an effective and rapidly deployable monitoring aid during landslides emergencies and provide practical insights into the advantages and limitations of offset tracking approaches based on multi-temporal UAV datasets for the near-real-time assessment of rapidly evolving slope instabilities.

Application of high-frequency geotechnical monitoring to identify kinematic landslide precursors and manage geo-hydrological risk in urban environments

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Keywords: urban landslide risk, kinematic precursors, automated geotechnical monitoring.

Geotechnical monitoring is a fundamental aspect of engineering design and geohydrological risk management. Given the increasing frequency of extreme weather events, systematic monitoring facilitates the robust design validation and the implementation of reliable early warning systems (Sciarra et al., 2022; Mangifesta et al., 2024). Digitalization and IoT have radically transformed geotechnical monitoring, evolving it from an occasional check process to near real-time data acquisition. The integration of wireless systems and cloud analysis platforms powered by machine learning algorithms enables a more precise understanding of soil kinematic response. This contribution examines the effectiveness of automated monitoring networks in providing dynamic knowledge frameworks for land management. In this context, identifying kinematic and/or hydraulic precursors that exhibit anomalous variations before an instability phenomenon becomes paroxysmal plays a central role. The monitoring activity currently in progress in the Santa Maria district of the Municipality of Chieti is precisely based on the research and analysis of these critical kinematic indicators. Historically, the investigated area is defined by complex evolutionary dynamics and instability impacting the urban environment. The lithostratigraphic sequence consists of a lower, clayey-sandy, low-permeability interval and an upper, arenaceous-sandy interval. The latter is often reworked by previous slope movements and features a wide transition zone with sandy and clayey lenses that are closely intermingled. This configuration represents a structural weakness that makes the area susceptible to the development of preferential slip surfaces. The installation of an integrated network of tiltmeters, crack gauges, piezometers and automated inclinometer system (Allasia et al., 2021), all of which are remotely controlled and capable of continuous reading, has made it possible to monitor the evolution of specific criticalities in real time. Evidence of instability, ranging from significant structural damage to buildings losing their verticality and rotating, is strongly validated by instrumental data from ongoing geognostic investigations. Investigations and measurements have confirmed the existence of active slip surfaces located at significant depths (averaging between 20 and 40 meters below ground level). This study evaluates the effectiveness of integrating high-resolution biaxial tiltmeters, which are used to monitor the rotational trends of vulnerable buildings, with AIS (Automatic Inclinometer Systems). These automated systems operate continuously within boreholes and overcome the limitations of manual readings by capturing every slight acceleration of the deep slip plane with millimetric precision (Allasia et al., 2020). This methodology establishes a technical framework required for designing specific stabilization measures and developing a civil protection protocol centered on objective, real-time early warning thresholds.

Allasia P. et al. (2020) - Advances on Measuring Deep-Seated Ground Deformations Using Robotized Inclinometer System. Sensors, 20(13), 3769, https://doi.org/10.3390/s20133769.

Allasia P. et al. (2021) - The Role of Measure of Deep-Seated Displacements in the Monitoring Networks on Large-Scale Landslide. In: Casagli N., Tofani V., Sassa K., Bobrowsky P.T., Takara K. (Eds), Understanding and Reducing Landslide Disaster Risk. WLF 2020. ICL Contribution to Landslide Disaster Risk Reduction, Springer, Cham, https://doi.org/10.1007/978-3-030-60311-3_4.

Mangifesta M. et al. (2024) - A Methodologic Approach to Study Large and Complex Landslides: An Application in Central Apennines. Geosciences, 14, 272, https://doi.org/10.3390/geosciences14100272.

Sciarra N. et al. (2022) - Methodological Approach for the Study of Historical Centres of High Architectural Value Affected by Geo-Hydrological Hazards: The Case of Lanciano (Abruzzo Region—Central Italy). Geosciences, 12, 193, https://doi.org/10.3390/geosciences12050193.

Integrated geomorphological, remote sensing and meteoclimatic analysis of the Roncovetro Landslide (Northern Apennines, Italy)

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Keywords: complex landslide, meteoclimatic analysis.

The Roncovetro landslide (Canossa, Reggio Emilia) is one of the largest and most complex long-lasting earthflows of the Northern Apennines, affecting marly-clayey formations of the Ligurian and Subligurian Units. Its evolution, documented since the early 20th century, is characterized by recurrent reactivations driven by the combined influence of geological predisposition, prolonged rainfall and, potentially, seismic perturbations. This study, in collaboration between INGV (National Institute of Geophysics and Volcanology) and University of Chieti-Pescara, aims to provide an integrated characterization of the geomorphological features of the landslide and to investigate the mechanisms controlling its recent evolution and presents a multidisciplinary approach integrating geomorphological and multi-sensor analysis aimed at quantifying the landslide's recent activity, internal structure and trigger-response dynamics.

A multidisciplinaryThe approach and multi-source dataset was developed combining:

(i) Photointerpretation of historical and recent orthophotos;
(ii) LiDAR-derived DTMs and multi-temporal change-detection analyses (2014, 2023-2024);
(iii) Detailed geomorphological field mapping at 1:5000 scale using ISPRA criteria;
(iv) Ground-based monitoring through GNSS time series (2021-2026);
(v) Meteoclimatic analysis from ARPAE datasets to assess rainfall patterns and cumulative thresholds.

Geomorphological mapping allowed the identification of two main source areas (Monte Staffola and Roncovetro), characterized by roto-translational movements evolving downslope into earth-flow mechanisms within the transit and accumulation zones. Multi-temporal LiDAR differencing revealed elevation changes exceeding 30 m between 2014 and 2024 and a mobilized volume of ~500.000 m^3, largely redistributed within the landslide body. Historical records and GNSS data in the source area at Monte Staffola, documented seasonal to annual displacement cycles, with velocities ranging from

This integrated approach provides new insights into the internal architecture, kinematics and multi-hazard sensitivity of the Roncovetro landslide, offering a basis for future monitoring strategies and for improving the understanding of complex earthflow dynamics in the Northern Apennines.

NATURA: AI-Driven geospatial data integration and hydrometeorological modelling for advanced landslide hazard assessment

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Keywords: artificial intelligence, Earth observation, hazard assessment.

Landslides are among the most destructive natural hazards worldwide, producing severe human, environmental, and economic impacts under increasing climate and anthropogenic pressures. NATURA is a five-year research project funded by the Italian Ministry of University and Research (MUR) under the Fondo Italiano per la Scienza (FIS) programme, focused on developing advanced artificial intelligence (AI) frameworks for geospatial data integration and hydrometeorological modelling to improve landslide hazard assessment and environmental risk management.

The project integrates very high-resolution remote sensing imagery, satellite Earth Observation data, UAV-based surveys, meteorological datasets, terrain analysis, and geospatial AI techniques within a unified modelling framework. Advanced deep learning architectures, including transformer-based semantic segmentation models and foundation-model approaches, are employed to automatically detect, map, and monitor landslides across heterogeneous environmental conditions. Temporal hydrometeorological variables and terrain deformation indicators are additionally incorporated to enhance predictive capabilities and improve the spatio-temporal understanding of slope instability processes.

A major objective of NATURA is the development of scalable and transferable AI methodologies capable of supporting near real-time hazard assessment and operational decision-making for civil protection agencies, environmental authorities, and regional planners. The project also investigates explainable AI strategies to improve model interpretability, robustness, and operational applicability within geoscientific workflows.

The proposed framework contributes to the advancement of digital geosciences by bridging Earth Observation, machine learning, geomorphology, and environmental modelling. Preliminary results highlight the strong potential of integrated AI-driven geospatial systems for improving landslide inventory generation, hazard characterization, and climate-sensitive risk assessment across multiple spatial scales.

Natural field laboratories for AI-based hybrid forecasting of rock slope failures through multi-scale monitoring and numerical modelling

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Keywords: artificial neural networks, rock slope failures, hybrid forecasting.

Time to failure for rock slopes represents one of the most challenging issues in natural hazard assessment, due to the elusive nature of precursory signals and the complex interplay of preparatory, predisposing and triggering factors. Recent developments in Artificial Intelligence (AI) combined with high-resolution monitoring and Earth Observation (EO) offer new opportunities to set up forecasting strategies and to improve temporal prediction of rock slope failures and support early warning systems and risk mitigation.

The ongoing research is carried out in the natural field laboratories of the TestingLAND Rome Technopole infrastructure in Acuto (FR), Poggio Baldi (FC) and Ventotene island (LT), providing multi-scale and multi-source datasets integrating geotechnical monitoring, photogrammetry, meteoclimatic observations and numerical modelling. The proposed research investigates the role of environmental forcing in the progressive preparation of rock slope failures through AI-based approaches trained on both monitored and forecasted environmental data.

At the Acuto Field Laboratory (Fiorucci et al., 2020), ten-year-long multi-parametric monitoring data trained Artificial Neural Networks to distinguish thermoelastic and potentially plastic deformation phases preceding limit equilibrium after a subcritical state. Thermal excursions, rainfall probability and cumulative meteo-climatic gradients emerged as key preparatory factors (Marmoni et al., 2020), with models showing promising transferability to external validation sites affected by rockfall.

The research further explores hybrid strategies integrating data-driven methods and physically based numerical modelling (von Rueden et al., 2020) through digital twin concepts to provide forward scenarios of rock mass failures under changing climatic conditions. Stress-strain numerical modelling results, EO-derived environmental variables and field monitoring data will be blended into hybrid datasets to train physically informed AI models able to recognise the progressive transition from preparatory to triggering conditions across spatial and temporal scales. The research activities also include the installation of new low-impact IoT environmental sensors at field laboratories and external validation sites to enable spatial upscaling of monitoring networks, near-real-time environmental data acquisition and transferability over different lithological and meteo-climatic conditions.

Fiorucci M. et al. (2020) - Comparison of approaches for data analysis of multi-parametric monitoring systems: insights from the Acuto test-site (Central Italy). Appl. Sci., 10(21), 7658.

Marmoni G.M. et al. (2020) - Modelling of thermo-mechanical effects in a rock quarry wall induced by near-surface temperature fluctuations. Int. J. Rock Mech., 134, 104440.

Von Rueden L. et al. (2020) - Combining machine learning and simulation to a hybrid modelling approach: Current and future directions. In: Berthold M., Feelders A., Krempl G. (Eds), Advances in Intelligent Data Analysis XVIII. IDA 2020. Lecture Notes in Computer Science, 12080, Springer, Cham, https://doi.org/10.1007/978-3-030-44584-3_43.

When radar protects people and history: Safety of workers and the Abbey of Sant'Eutizio

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Keywords: Umbria, hazard, radar.

The Abbey of Sant'Eutizio is a special place for Christianity as it is the birthplace of Western monasticism. The earthquakes of 1979, 1997, and 2016 struck the Abbey, and the following describes the technical measures undertaken by the Regional Geological Section staff during and after the 2016 earthquakes (Motti et al., 2020). The Abbey of Sant'Eutizio is one of the oldest monastic complexes in Italy and was built where Western monasticism was born in the 4th century AD.

The 2016 earthquake caused several collapses, both of the religious buildings and of the travertine slab on which they stood (Motti et al., 2022). In particular, a 30-meter-high, 470-cubic-meter travertine pinnacle was about to collapse, destroying what remained of the Abbey of Sant'Eutizio and the monastic complex. It was decided to intervene immediately, demolishing the unstable travertine pinnacle. To ensure the safety of construction workers during the demolition of the travertine pinnacle, a monitoring system was installed. The monitoring system was based on a ground-based interferometric radar capable of providing measurements with millimetric accuracy and an alert system designed to generate alarms that would signal the possible occurrence of a deformation event potentially affecting the demolition area. The activation of the alarms would have indicated the need for workers present in the area to evacuate the construction site. A technical group was formed to support the assessment of slope stability conditions in the construction area. It consisted of representatives from the various entities involved in the cliff safety project, along with company representatives and workers, following operational tests and specific calibrations. The pinnacle removal work was completed on schedule and with maximum safety monitoring. During the monitoring activities, it was discovered that the same monitoring could also be used to monitor the effect of the steel beams of the external wall facing of the large seminary building. This information was immediately put to use by providing it to the designers, who had never imagined real-time monitoring of the masonry structures available while they were carrying out the consolidation work. In addition to real-time monitoring for worker safety, unforeseen benefits were achieved regarding safety, prevention, conservation, and the prevention of structural deformation of the buildings.

Motti A. et al. (2020) - Saint'Eutizio of Preci: technical and geological history of the place where western monasticism was born - Sant'Eutizio di Preci: vicissitudini tecniche e geologiche del posto dove è nato il monachesimo occidentale. Regione Umbria, 237 pp., https://doi.org/10.13140/RG.2.2.28755.53281.

Motti A. et al. (2022) - Assessing active and capable faulting as best practice for post-earthquake reconstruction activities: the Sant'Eutizio Abbey case study, in the epicentral area of the 2016 central Italy seismic sequence. Ann. Geophys.,65(1), SE105, https://doi.org/10.4401/ag-8793.

IRIDE / EGMS satellite data for ground deformation monitoring: Case studies and potential uses

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Keywords: hazard, landslide, ground motion.

An experiment was conducted with the following objectives: assessment of continuous ground motion from satellite data (IRIDE Grid Ground Motion with the European Ground Motion Service 2019-2023); subsequent analyses with different types of landslides (active landslides, dormant landslides, landslide-prone areas, subsidence); assessment for interference with the elements of the Emergency Limit Condition (ELC) and assessment of possible interference with buildings in the municipality of Perugia.

The experiment used a wide range of data: satellite data from the European Ground Motion Monitoring Service (Motti, 2025); IRIDE satellite data with cross-monitoring of ground motions and identification of "hotspots" of vegetation cover changes; geomorphological maps of landslide risk (PAI); local seismic risk map of the Umbria Region; maps of the Umbria Region derived from the analysis of the Emergency Limit Conditions (ELC) (Motti et al., 2024); geological map of the Umbria Region and database of the Ecographic Cadastral System of the Umbria Region for the Municipality of Perugia.

The data were processed consecutively: the databases were used in QGIS by importing the previously downloaded DBs in shp format and the WMS/WFS services; reprojections were performed to homogenize the different DBs; color palettes were defined to simplify visualization; continuous movement intervals greater than 5 mm per year were chosen to match EGMS and IRIDE; case study 1 was developed by performing intersections between the continuous movements and the affected CLE elements; case study 2 was developed by performing intersections between the continuous movements and the affected buildings in the municipality of Perugia; spatial analyses were performed on the collected data to homogenize and select specific information useful for subsequent processing.

The results obtained from the intersections between the different layers allowed for different visualizations and the identification of ground motion from satellite data for the 6-year period (2019-2024). These included areas defined as being in a state of degradation, both in continuous motion and not in continuous motion, and areas not defined as being in a state of degradation, both in continuous motion and not in continuous motion. Finally, elements of the CLE, excluding connecting infrastructure, located within the areas of continuous motion, were identified, as well as the buildings of the Municipality of Perugia located within the areas of continuous motion.

The experiment achieved all objectives: assessment of continuous ground motion from satellite data (GGM with EGMS 2019-2023); subsequent analysis with the different types of landslides (active landslides, dormant landslides, areas at risk of landslides, subsidence); subsequent assessment with buildings; subsequent assessment with the elements of the CLE (Emergency Limit Condition).

Motti A. (2025) - Report on the analysis of satellite data for Umbria for the years 2019-2024. Regione Umbria, 20 pp., https://doi.org/10.13140/RG.2.2.22317.19687.

Motti A. et al. (2024) - Strumenti per la prevenzione del rischio sismico nella Regione Umbria: tra SUM e CLE. In: Benigni M.S., Fontana C., Giuffrè M., Tomassoni V. (Eds), A dieci anni dall'istituzione dell'analisi della Condizione Limite per l'Emergenza: strategie, ricadute e futuri possibili, Edizioni Consiglio Nazionale delle Ricerche, 62-65, https://doi.org/10.32053/A_DIECI_ANNI_DA_ISTITUZIONE_ANALISI_CONDIZIONE_LIMITE_PER_EMERGENZA_.

From UAV acquisition to risk assessment: An integrated approach for improved geotechnical modeling of rock slopes

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Keywords: UAV-based photogrammetry, geomechanical surveys, rockfall hazard.

The use of Unmanned Aerial Vehicles (UAVs) for geological surveys has become a widespread and transformative technique in modern engineering geology (Wstoby et al., 2012). The availability of high-quality UAV-mounted digital cameras, combined with advanced photogrammetry software, has significantly enhanced the accuracy and resolution of engineering and structural geological data collection. By generating photogrammetric 3D models, it is now possible to perform virtual geomechanical surveys and acquire detailed structural data from areas that are otherwise inaccessible using traditional field methods. Rock slope stability is governed by the orientation, persistence, and spacing of joint sets, which can substantially decrease the overall strength of the rock mass. Understanding these structural patterns is therefore a crucial aspect of engineering geological investigations. The present study introduces an integrated methodology that combines UAV-based photogrammetry with advanced analytical techniques to perform comprehensive 3D geotechnical modelling. The proposed workflow comprises several key steps: UAV data acquisition, 3D model generation, virtual geomechanical survey, cluster analysis, extraction of principal joint sets, 2D spatial analysis, and final 3D geotechnical modelling. To test the proposed methodology, the Monte Conero (Italy) case study was selected, focusing on the Piangrande area. This site consists of a highly fractured rocky slope developed within the Scaglia Rossa Formation, which represents part of an eroded, tectonically deformed anticline (Gigli & Casagli, 2011). The slope analyses have been undertaken using UAV based LiDAR and photogrammetric models and DEM (Itasca Consulting Group, Inc. 2023. 3DEC—Three-Dimensional Distinct Element Code (Version 9.6), Itasca Consulting Group, Inc., Minneapolis, MN, USA), and FEM-DEM (Geomechanica Inc. Irazu: 2D/3D Finite-Discrete Element Software for Geomechanical Analysis, Geomechanica Inc, Toronto, ON, Canada) numerical codes, so to verify the advantages and limitations of the different methodologies. A preliminary runout analysis is then computed to evaluate the risk for the buildings located in proximity of the slope.

Gigli G. & Casagli N. (2011) - Semi-automatic extraction of rock mass structural data from high resolution LiDAR point clouds. Int. J. Rock Mech., 48, 187-198.

Westoby M.J. et al. (2012) - Structure-from-motion photogrammetry: a low-cost, effective tool for geoscience applications. Geomorphology, 179, 300-314.

Integrating multi-sensor monitoring and numerical modelling to investigate the evolution of very slow-moving landslide on the eastern slope of Mt. Amiata, Italy

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Keywords: slow-moving landslide, integrated monitoring, numerical modelling.

Very slow-moving landslides pose a persistent threat to infrastructure, as they accumulate deformation over long periods and may evolve toward catastrophic failures with potential risks to human life. This study presents a complex roto-translational landslide system located on the eastern slope of Mt. Amiata, near the town of Abbadia San Salvatore, Italy. The landslide has been active for more than three decades, affecting infrastructures and posing risk to habitants. We investigate the landslide through an integrated multi-sensor approach combining satellite InSAR, GNSS, robotic total station measurements, levelling surveys, and geotechnical instruments, including inclinometers, Time Domain Reflectometer (TDR) and piezometers. Observations allow to support engineering-geological modelling and finite element method (FEM) numerical analyses. The results show that both the complex terrain morphology and displacement pattern make it difficult to rely on a single monitoring technique. Instead, the integration of different monitoring systems provides significant advantages, as missing or uncertain information from one method can be compensated by others. Moreover, direct cross-validation among measurements also allows the uncertainty and precision of each technique to be assessed. The integrated monitoring network allowed the slope to be monitored from 2019 to 2026 with mm-scale precision. We also integrated nearly 30 years of satellite InSAR data from ERS, Envisat, and Sentinel-1 missions to infer the long-term displacement history of the slope. The results indicate an average displacement rate of approximately 5 cm/year, consistent with the local morphology and geomorphological evidence. A preliminary comparison between displacement time series and precipitation records indicates that rainfall may contribute to some acceleration phases, with an apparent time lag in the slope response. The FEM analyses provide insights into the geometry and behaviour of the shear surface, particularly where subsurface measurements are limited. Time-dependent numerical analyses also provide relevant hints by highlight the creeping behaviour of the slope, with episodes of seasonal acceleration. The observed mechanism suggests both retrogressive and progressive processes, likely controlled by weak clay-rich horizons commonly associated with the Ligurian units. Moreover, also the uncomfortable contact between the Cretaceous Ligurian units and the overlying Quaternary volcanic flows represent a well-developed weakness zone. This study demonstrates the need for long-term landslide monitoring based on integrated approaches, combining multi-sensor observations with advanced numerical analyses to improve the interpretation of landslide kinematics, deformation mechanisms, and future evolution.

Quantitative analysis of landslide triggers, activity and evolution through integrated remote sensing and ground observations

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Keywords: quantitative landscape analysis, multi-sensor landslide monitoring.

Landslides represent widespread natural hazards frequently associated with intense rainfall and seismic shaking, especially in geodynamically active regions such as the Apennines (Italy). Understanding the quantitative relationships between triggering factors, slope response and long-term geomorphic evolution is essential for improving hazard assessment. Global evidence indicates that the interaction between meteorological and tectonic forcing may enhance slope instability, with rainfall-modified mechanical conditions influencing coseismic susceptibility and, conversely, seismic perturbations preconditioning slopes to subsequent rainfall-induced failures.

This contribution presents the conceptual framework and first developments of a research project aimed at quantifying the interactions among seismicity, rainfall and geomorphic processes through an integrated quantitative geomorphology and multi-sensor monitoring approach.

The study focuses on the Roncovetro landslide (Reggio Emilia), a complex earthflow, historically affected by both significant earthquakes (e.g., 1996 Mw 5.4) and intense rainfall events. It offers an opportunity to investigate how antecedent hydrological conditions and seismic history jointly influence slope stability. The site constitutes an ideal natural laboratory for analysing landslide (i.e., complex earth flows) dynamics in a multi-temporal and multi-hazard perspective combining:

- remote sensing analyses, including repetitive UAS surveys;
- quantitativecomparison and change detection between historical and recent topographic datasets (LiDAR-DTMs) for the assessment of volumetric changes and long-term morphological evolution;
- field-based geomorphological mapping, to validate remote sensing outputs and refine the internal structures of the landslide body;
- ground-based monitoring (GNSS stations, UWB sensors) providing high-frequency displacement time series;
- geostatistical analysis of meteorological data, acquired from a regional weather station to derive rainfall thresholds and antecedent moisture conditions.

A key component of the project is the quantitative assessment of trigger-response relationships. Statistical tools, including correlation functions, cross-correlation analyses and lag-based metrics, are being applied to multi-temporal datasets (rainfall, displacement time series, seismic signals) to quantify the degree of coupling between external forcing and slope movements.

The integration of quantitative analysis and field investigations of the landslide makes it possible to outline: i) mechanism (from rotational in the detachment areas, to earth flow in the transit-accumulation area); ii) volume changes (~500.000 m^3 almost entirely internal to the landslide; the total soil loss is neglectable); iii) speed variability (from

GIS-based rock-fall susceptibility assessment along the north-west coast of Malta

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Keywords: coastal geomorphology, GIS, rock fall.

Widespread instability processes along Mediterranean coastal cliffs significantly increase geological hazards and associated risks. Such phenomenon are becoming more common with increasing climate extremes and anthropogenic pressure. Coastal instability in the form of rock fall is widespread along the northern coasts of the Island of Malta (central Mediterranean Sea) and is strictly connected to the local lithological characteristics and structural setting. The interaction between coastal morphology and structurally controlled rock masses, combined with heavy rainfall and intense storm events, leads to frequent rockfall events that threaten Maltese beaches, tourism, and infrastructure. Nevertheless, extreme weather events, whose spatial and temporal impact is influenced by the ongoing climate and land use changes, are expected to increase rock-fall hazard along the Maltese coasts (Sarkar et al., 2026). In this context, this study reflects a multi-scale and multi-source approach for rockfall susceptibility assessment combining geomorphological investigations, remote sensing, and GIS-based analyses. The area of investigation stretches from the coastal sectors of Paradise Bay to Gnejna Bay which includes six hotspot embayments of the north-west coast of Malta. The methodological approach of this study has taken into consideration high-resolution LiDAR-derived Digital Terrain Models (1 m resolution), orthophotos, satellite imagery, and detailed field-based geomorphological surveys. Potential detachment zones were identified using slope-threshold analysis (>45°) and validated through field observations of persistent joints, and lateral-spreading fractures along the edges of the cliffs. The QPROTO tool in QGIS environment was used for rockfall propagation analysis and detection of runout zones. The tool integrates specific parameters including block volume, block mass, source elevation, detachment index, energy-line angle, and lateral spreading angle to simulate runout trajectories and estimate kinetic-energy distribution of the rock blocks (Castelli et al., 2021; Sarkar et al., 2024). Susceptibility maps were classified into five classes ranging from very low (Class S1) to very high (Class S5) based on kinetic-energy thresholds. Model outputs were validated and compared with observed boulder accumulations and rockfall inventory of the affected coastal cliffs. The results indicate a significant spatial variation in rock fall susceptibility. Gnejna Bay shows the maximum percentage area under high runout probability level (29.3%). This signifies high kinetic energy within this zone, followed by Anchor Bay (27.9%) and Golden Bay (27.5%). However, Il-Qarraba promontory, Paradise Bay and Ghajn Tuffieha Bay have 25.9%, 25.5% and 25.1% area under high runout probability level respectively. In these sites, remarkable rock-fall runout probability levels are primarily due to the presence of steep limestone cliffs and numerous persistent discontinuities along the cliff edges (Devoto et al., 2020). The outputs of the research and the replicability of the method provide a valuable tool for authorities managing similar coastal environments worldwide, aiding the definition of sustainable mitigation measures.

Castelli M. et al. (2021) - Preliminary modeling of rockfall runout: definition of the input parameters for the QGIS plugin QPROTO. Geosciences, 11(2), 88, https://doi.org/10.3390/geosciences11020088.

Devoto S. et al. (2020) - Advantages of using UAV digital photogrammetry in the study of slow-moving coastal landslides. Remote Sens., 12(21), 3566, https://doi.org/10.3390/rs12213566.

Sarkar N. et al. (2024) - Rock-fall runout simulation using a QGIS plugin along north-west coast of Malta (Mediterranean Sea). Nat. Hazards, 120,14553-14570, https://doi.org/10.1007/s11069-024-06821-9.

Sarkar N. et al. (2026) - Multi-risk assessment in the NW coast of the Island of Malta (central Mediterranean Sea). Nat. Hazards, 122(6), 255, https://doi.org/10.1007/s11069-025-07767-2.

Spatial and temporal variation of rainfalls in the dolomitic debris-flow site of Acquabona (BL), Northeastern Italy

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Keywords: heavy rainfalls, debris flows, Acquabona (NE Italy).

Debris flow events represent a major risk for inhabitants and infrastructures of mountainous areas. A fundamental tool for understanding their behaviour is represented by monitoring stations (Berti et al, 1999; Scotton et al, 2011), through which it is possible to analyse the initiation processes of the phenomenon, the behaviour in the flow zone and determine the accumulation processes and the stopping distance. The determination of the triggering conditions is based, in the presence of suitable hydrogeological conditions, on the measurement of the triggering rainfall events and, consequently, of the precipitation thresholds for their occurrence (Caine, 1980). This work focuses on the analysis of rainfall data collected over the last ten years, from 2015 to 2025, using three rain gauges installed along the Acquabona river (Dolomites, Eastern Italian Alps, Boite torrent catchment), within a site characterized by almost annual debris flows formation. The three rain gauges were installed at planimetric and altimetric distances of the order of a few hundred meters, close to the debris-flow stopping zone, in the flow zone and in the formation zone. Particular attention was paid to the calibration and maintenance of the used tilting rain gauges, installed in spring and removed in autumn.

The recorded precipitation data show considerable variability if the peak intensity is evaluated for time intervals shorter than an hour, which generally characterise the triggering of dolomitic debris flows, even if within the same small hydrographic basin (of the order of 0.5 km^2) and at short distance from each other. The precipitation data recorded within the Acquabona river basin were correlated with the precipitation recorded at the neighbouring meteorological stations managed by ARPAV (Regional Agency for Environmental Prevention and Protection of Veneto, Italy), all located within the Boite torrent catchment, at a planimetric distance between 2,000m and 10,000m and an altimetric distance between 25 m and 1,300 m. A greater correlation between precipitation intensity at short time periods was observed with the Faloria and Cortina stations, the planimetrically closest stations, with values of the determination coefficient of the linear regression model, however, always lower than 0.5. The precipitation data analysed and the debris-flow events that have been detected over the years (Iverson, 2000) describe a phenomenon whose prediction depends heavily on the possibility of obtaining rainfall data inside the debris-flow triggering area.

This result seems to justify the difficulty encountered when trying to base the occurrence forecast on precipitation data detected even at a short distance from the triggering area. The observations reported here suggest that, where possible, it is essential to collect rainfall data inside the area believed to be the triggering area, to directly observe the flow phenomena, and to adopt mitigation measures compatible with these conditions.

Berti M. et al. (1999) - Field observations of a debris flow event in the Dolomites. Geomorphology, 29, 265-274.

Caine N. (1980) - The rainfall intensity-duration control of shallow landslides and debris flows. Geogr. Ann. A, 62, 23-27, https://doi.org/10.2307/520449.

Iverson R.M. (2000) - Landslide triggering by rain infiltration. Water Resour. Res., 36(5), 1897-1910, https://doi.org/10.1029/2000WR900090.

Scotton P. et al. (2011) - The debris flow monitoring system of Acquabona Torrent (Cortina d'Ampezzo, Belluno, Italy). In: Genevois R., Hamilton D.L., Prestininzi A. (Eds), Proceedings of the 5th Int. Conf. on Debris Flow Hazards Mitigation, Padova, Italy, June 7-11, 2011, pp. 595-603, https://doi.org/10.4408/IJEGE.2011-03.B-083.

Integrated monitoring of the Corvara Earthslide-Earthflow (Eastern Alps) from 2022 to 2025: Insights from remote sensing, RTS data and meteo-climatic forcing

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Keywords: high-frequency monitoring, optical flow analysis, meteo-climatic forcing.

The Corvara landslide is a large scale earthslide-earthflow affecting the Dolomitic area of South Tyrol (Italy). The phenomenon extends over ~3.4 km, involves an area of about 2.2 km^2 and a volume of roughly 30 Mm^3, and is articulated into multiple source areas, a track zone, and a low-activity accumulation sector. The landslide shows strong spatial and temporal heterogeneity of displacement rates, ranging from centimetres per year in the accumulation area to several metres per year in the most active sectors.

This contribution summarizes recent results obtained between 2022 and 2025 through the integration of remote sensing surveys and in situ monitoring in the framework of SoLoMon and SoLoMon 2 projects, financed by the Autonomous Province of Bolzano (PAB). Continuous monitoring has been carried out since late 2022 using a Robotic Total Station (RTS), providing high-frequency displacement time series for the main kinematic domains. RTS data highlight differential displacement patterns and episodic acceleration phases, with cumulative displacements reaching several metres in the transition zone over three years.

Remote sensing analyses are based on the comparison between a helicopter-borne LiDAR survey acquired in August 2022 and a UAV-based LiDAR survey performed in June 2025. Multi-temporal DEMs were analysed through DEM of Difference (DoD) and optical flow techniques applied to hillshade products, allowing the identification of erosion and accumulation patterns as well as planimetric displacement. Optical flow results are consistent with RTS measurements, confirming the spatial distribution of the most active sectors and their main kinematics.

Finally, a preliminary assessment of meteo-climatic forcing suggests a clear influence of rainfall and snow accumulation/melt on displacement rates. In particular, acceleration phases observed by RTS often coincide with periods of intense precipitation and late-season snowmelt, underlining the combined role of rainfall infiltration and seasonal snow dynamics in controlling landslide activity.

Towards integrated surface and subsurface monitoring of landslides: GNSS and inclinometric observations from the Cazzaso landslide (NE Italy)

Zuliani D.*[1], Fabris P.[1], Franceschini R.[1], Tunini L.[1], Curone D.[2], Chersich M.[2], Peressi G.[3], Bertoni M.[1], Compagno A.[1], Galvi S.[1], Del Negro E.[1], Magrin E.[1], Magrin A.[1], Ponton C.[1], Bottaro G.[1], Peronio M.[1], Comelli P. & Picozzi M.[1]

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Keywords: landslide monitoring, GNSS, inclinometers.

Landslide monitoring increasingly requires the integration of complementary observations capable of supporting the interpretation and reliability assessment of slope deformation measurements. In this context, combining continuous GNSS observations with inclinometric measurements can improve the operational management of monitoring systems installed in unstable environments.

This work presents recent developments of the monitoring system (Tunini et al., 2024) installed at the Cazzaso landslide (Carnic Alps, Northeastern Italy), an active slow-moving landslide affecting a populated alpine area characterized by complex geological and hydrogeological conditions. Since 2016, the site has been monitored through a continuous GNSS network composed of low-cost single-frequency receivers (Zuliani et al., 2022a; 2022b), progressively integrated with rainfall measurements (Franceschini et al., 2026) and additional geophysical instrumentation. In 2025, the monitoring framework was further enhanced through the integration of inclinometric sensors installed on selected GNSS antenna poles. The inclinometers were introduced to monitor pole inclination and support the quality assessment and interpretation of GNSS displacement measurements, helping identify conditions requiring maintenance actions such as pole realignment or relocation.

The integrated approach allows continuous verification of the stability of GNSS installations operating in a highly dynamic landslide environment, improving the robustness and reliability of long-term displacement observations. Preliminary results highlight the usefulness of combining GNSS and inclinometric measurements to support operational landslide monitoring activities and improve data quality control under unstable slope conditions.

The Cazzaso case study represents an example of a multi-source monitoring strategy for ground instability assessment in alpine environments, demonstrating how the progressive integration of complementary sensors can strengthen operational landslide monitoring frameworks and support future risk mitigation applications.

Franceschini R. et al. (2026) - Deriving rainfall thresholds with XAI and GNSS measurements for a large landslide. Landslides, 23(3), 741-754.

Tunini L. et al. (2024) - Monitoring and modelling moraine landslides: an example from Cazzaso village (Carnic Alps, Italy). Bull. Geophys. Oceanogr., 65(3), 327-346, https://doi.org/10.4430/bgo00459.

Zuliani D. et al. (2022a) - Cost-effective, single-frequency GPS network as a tool for landslide monitoring. Sensors, 22(9), 3526, https://doi.org/10.3390/s22093526.

Zuliani D. et al. (2022b) - LZER0: A Cost-Effective Multi-Purpose GNSS Platform. Sensors, 22(21), 8314, https://doi.org/10.3390/s22218314.

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Geoscience, Risk and Sustainable Development: Integrated Approaches for Environments and Society

CONVENERS & CHAIRPERSONS:

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Defining background values in soils of abandoned mining areas: Methodological framework and case studies from Sardinia (Italy)

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Keywords: background values, mine areas.

Sardinia hosts one of the most extensive mining legacies in Europe, with major metallogenic districts characterized by naturally elevated metal concentrations. The long history of mining has generated widespread abandoned mining areas (AMD), where anthropogenic contamination overlaps with geogenic anomalies. A total of 151 AMDs have been identified in Sardinia, predominantly concentrated in the Sulcis-Iglesiente-Guspinese district (Sardinia SW; 103 sites), and secondarily in the Sarrabus-Gerrei district (Sardinia SE; 30 sites), while the remaining sites are scattered across the island. In such contexts, defining reliable background values (BV) is critical but inherently complex.

The determination of BVs represents a key component of the Regional Remediation Plan (PRB) for these sites (RAS, 2018; RAS, 2019). The methodological approach adopted in this study is based on the Italian National System for Environmental Protection (SNPA) guidelines for the determination of BVs, which provide a structured framework for data acquisition, conceptual modelling, and statistical analysis, and has been specifically tailored to account for the peculiar geo-mineralogical characteristics of Sardinia (SNPA, 2018). First, given the high number of AMDs, typically small in extent and densely clustered, spatially contiguous sites with similar mining history and geo-mineralogical characteristics were grouped into 54 homogeneous mining zones at regional scale. Second, lithological domains were defined at regional scale across the entire island, representing geological units characterized by homogeneous lithological and ore-deposit features controlling geochemical variability. As a result, for each mining zone, the lithological domains with mining relevance were identified, and at least 30 soil samples were collected for each domain. Overall, BV determination in Sardinian AMDs relies on a large integrated dataset (2199 soil samples plus 1259 legacy analyses). For each lithological domain within each mining zone, non-parametric statistical approaches are applied to derive descriptive parameters, maximum values, and 95th percentile Upper Prediction Limits (UPL) for the main contaminants defined by Italian environmental legislation (Italian Republic, 2006), providing a quantitative basis for environmental assessment and land-use decision-making. Preliminary results from two pilot areas, Arenas-Tiny and Rosas, within the Sulcis-Iglesiente-Fluminese district, show that widespread mineralized bodies can generate extremely high concentrations of contaminants such as Pb, As and Zn in soils, reaching levels up to one to two orders of magnitude above the contamination threshold values set by Italian legislation (Italian Republic, 2006). This creates a highly complex environmental setting, requiring a rigorous and site-specific approach to assess environmental and human health risks and to support sustainable land management strategies. With this work, we aim to provide authorities and local communities with a robust tool to support land-use planning and informed decision-making within these mining zones, allowing the discrimination between areas impacted by legacy mining activities and those reflecting naturally elevated metal concentrations, as required by national legislation, for future civil and industrial purposes.

Italian Republic (2006) - Legislative Decree No. 152 of 3 April 2006. Environmental Code (Testo Unico Ambientale). Official Gazette of the Italian Republic.

RAS (2018) - Deliberazione della Giunta Regionale n. 61/40 - Determination of Background Values (VDF) project. Bollettino Ufficiale della Regione Autonoma della Sardegna (BURAS).

RAS (2019) - Deliberazione della Giunta Regionale n. 8/74 - Regional Remediation Plan (PRB). Bollettino Ufficiale della Regione Autonoma della Sardegna (BURAS).

SNPA (2018) - Linee guida per la determinazione dei valori di fondo per i suoli e le acque sotterranee. Sistema Nazionale per la Protezione dell'Ambiente, ISBN:978-88-448-0880-8.

Natural enrichment of potentially toxic elements in the Ferrara coastal area: Influence of sediment provenance and coastal dynamics

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Keywords: sediment geochemistry, potentially toxic elements, Adriatic Sea.

This study provides an integrated seasonal and cross-shore characterization of sediments along the Ferrara coastal sector (NW Adriatic Sea, Italy), with the aim of evaluating the relationships between sediment dynamics, provenance, and potentially toxic element (PTE) distribution. Four coastal sites (Goro, Volano, Estensi, and Spina) were investigated through seasonal sampling campaigns conducted between summer 2023 and summer 2024 across different geomorphological zones, including swash zone, lower and upper backshore, dune foot, and dune crest. An integrated methodological approach combining grain-size analyses, carbonate determination, WD-XRF, ICP-MS, and environmental quality indices (Igeo, CF, and PLI) was applied.

The sediments are predominantly composed of medium to fine sands and generally exhibit well to very well sorted textures, indicating low- to moderate-energy depositional environments controlled by wave action, aeolian processes, and riverine sediment supply. Geochemical results reveal significant spatial and seasonal variability associated with hydrodynamic conditions and sediment provenance. Goro and Volano display marked enrichments in Fe_2O_3, TiO_2, Cr, Ce, La, V, Y, and Zr, particularly during autumn, winter, and spring, linked to the accumulation of PTE-bearing heavy minerals transported mainly from the Po River basin. At Volano, the occurrence of placer-like enrichment bands in the upper backshore and dune foot indicates strong hydrodynamic sorting and storm-related concentration processes. Conversely, Estensi sediments exhibit a more homogeneous geochemical signature consistent with Apennine-derived inputs from the Reno River basin, with limited evidence of anomalous enrichments. Spina shows intermediate characteristics, where coastal reworking processes partially obscure the geochemical fingerprint of the Reno-derived sediments.

Environmental quality indices indicate generally low contamination conditions, although localized enrichments and exceedances of Italian regulatory thresholds for Cr, V, Co, and Ni were detected at Goro and especially at Volano. These anomalies are interpreted as predominantly geogenic rather than anthropogenic, reflecting the natural occurrence and hydrodynamic concentration of heavy minerals derived from ultramafic and metamorphic lithologies within the Po catchment. The results highlight the strong interaction between sediment transport dynamics, provenance, and natural geochemical background in controlling PTE distribution along the Ferrara coast. This integrated approach provides updated baseline data for future coastal monitoring, environmental assessment, and management strategies in highly dynamic coastal systems.

Natural geochemical variability and diffuse trace metal enrichment in lagoon sediments: The case of the Goro Lagoon (Northern Adriatic Sea)

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Keywords: lagoon systems, trace elements, sediments.

Lagoon sediments represent highly dynamic depositional systems in which sedimentological, mineralogical and anthropogenic processes interact to control trace element distribution. In this study, major oxides and trace elements (Co, Cr, Ni, Pb, V, Zn and Cu) were investigated in surface sediments from the Goro Lagoon (Northern Adriatic Sea) by integrating newly acquired 2023 geochemical data with previously published datasets collected between 2003 (Provincia di Ferrara, 2007) and 2015 (Natali & Bianchini, 2018).

To reduce the influence of grain-size variability, the most suitable conservative element for normalization was preliminarily evaluated through regression analysis and multivariate statistical approaches. Based on these assessments, Al_2O_3 was selected as the most appropriate normalizer.

Enrichment Factors (EFs) were calculated adopting background values reported by Migani et al. (2015). EFs revealed generally low to moderate enrichments throughout the lagoon system, with Pb, Zn and Cu showing the highest relative enrichment patterns, whereas Cr and Ni appeared to be mainly controlled by lithogenic and mineralogical variability. Threshold values calculated using median and interquartile range (IQR) statistics highlighted only a limited number of anomalous samples, suggesting the absence of severe or widespread contamination.

Principal Component Analysis (PCA) performed on standardized and Al_2O_3-normalized datasets explained 67.28% of total variance within the first two principal components and identified distinct sedimentary-geochemical domains. In particular, siliciclastic/carbonatic components (SiO_2, CaO, Cr and Ni) were clearly separated from fine-grained sediment phases enriched in Fe_2O_3, TiO_2, MnO, LOI and Pb-Zn-Cu. The multivariate results indicate that Cr-Ni variability is predominantly linked to mineralogical controls, whereas Pb, Zn and Cu display preferential association with Fe-Mn oxides and organic-rich fractions.

The comparison among sampling campaigns also highlighted partial temporal differentiation within the lagoon system. Samples collected between 2003 and 2005 showed higher compositional dispersion and greater geochemical heterogeneity, whereas 2015 and especially 2023 datasets formed more coherent compositional clusters. In particular, 2015 sediments were preferentially associated with siliciclastic and detrital signatures dominated by Cr and Ni, while 2023 samples showed stronger association with reactive fine-grained phases and Pb-Zn-Cu enrichment patterns. However, these differences likely reflect the combined influence of sedimentological variability, provenance changes and sampling distribution rather than unequivocal progressive contamination trends.

Migani F. et al. (2015) - Geochemical characterization of surface sediments from the northern Adriatic wetlands around the Po river delta. Part I: Bulk composition and relation to local background. J. Geochem. Explor., 156, 72-88.

Natali C. & Bianchini G. (2018) - Natural vs anthropogenic components in sediments from the Po River delta coastal lagoons (NE Italy). Environ. Sci. Pollut. Res. Int., 25, 2981-2991.

Provincia di Ferrara - Servizio Risorse Idriche e Tutela Ambientale (2007) - Caratterizzazione granulometrica, geochimica e microbiologica dei sedimenti della Sacca di Goro. Rapporto tecnico, Provincia di Ferrara, 185 pp.

Evidence of repeated hydrothermal explosions in a Pleistocene spring-related carbonate system (southern Tuscany, Italy): Implications for hazard assessment

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Keywords: hydrothermal explosions, spring-related carbonate system, hazard assessment.

Hydrothermal explosions are among the most spectacular and violent phenomena in hydrothermal and geothermal areas, typically developing with few or no premonitory signals. They occur when pressurised hot water stored in shallow rocks suddenly flashes to steam, violently disrupting the overlying confining units. After the initial blast, the site may either become rapidly quiescent or evolve into a centre of sustained or episodic hydrothermal activity. Although often underappreciated, they pose significant natural hazards because they can eject non-juvenile material as ballistic debris entrained in gas, steam, mud, or boiling water, and may also generate density currents, including base surges and cold pyroclastic density currents.

Despite their hazard potential, the geological record of hydrothermal explosions remains poorly constrained because their deposits are commonly unrecognised, misattributed, or obscured within the stratigraphic record. This limits reconstruction of their recurrence, dynamics, and impacts over geological and historical timescales. This gap is particularly significant in carbonate hot-spring systems, where travertine deposits are generally interpreted as archives of relatively steady fluid discharge. To date, hydrothermal explosion features have been mainly documented in silica-depositing geyser basins and acid-sulphate thermal areas, whereas carbonate hot-spring systems lack clear evidence of comparable explosive activity.

Here we first identify features consistent with hydrothermal explosions in a Pleistocene travertine geobody in southern Tuscany, Italy. Evidence includes crater-like depressions, subvertical pipe-like conduits, hydrothermal cement-filled fractures, lithoclastic breccias, and fluid-escape structures. The succession includes interbedded volcaniclastic deposits altered locally to clay-rich horizons. Integrated stratigraphic, sedimentological, petrographic, mineralogical, geochemical, petrophysical, and geochronological data indicate recurrent shallow mechanical failure, focused fluid upflow, and brecciation in a compartmentalised hydrothermal system. Results indicate transient overpressure in a shallow, composite, seal-bounded reservoir, promoted by permeability contrasts between travertine, volcaniclastic layers, and secondary hydrothermal calcite sealing fractures and pores. Sudden decompression, plausibly linked to seismic rupture in a regional tectono-magmatic setting, may have triggered explosive venting.

The studied succession preserves a previously unrecognised record of hydrothermal explosions in travertine system. This study provides a geological framework for identifying past shallow hydrothermal instabilities and assessing their recurrence potential. These results contribute to improving the recognition of hazardous hydrothermal processes in active and dormant geothermal areas, supporting more robust hazard assessment and risk mitigation strategies in environmentally sensitive geothermal landscapes.

Water quality and environmental sustainability in mediterranean fluvial systems: The case of Alcantara and Simeto rivers

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Keywords: environmental sustainability, Alcantara and Simeto river, anthropogenic impact.

In a Mediterranean context made fragile by climate change, sustainable water resource management requires robust interpretive models capable of distinguishing between natural processes and the impact of human activities. This paper presents the preliminary results of a PhD project aimed at the geochemical and environmental characterization of the two main rivers of eastern Sicily: the Alcantara and the Simeto.

The Alcantara stands out in Sicily's hydrographic landscape for the regularity of its flow and its extraordinary geological history. Its course, which winds for 48 km from the Nebrodi Mountains to the Ionian Sea, is deeply shaped by its interaction with the Etna volcanic system. The iconic Alcantara Gorges, formed about 10,000 years ago, feature spectacular basalt columns created by the rapid cooling of lava flows, which were subsequently shaped by river erosion. This geological complexity, situated at the confluence of metamorphic, sedimentary, and volcanic units, results in a differentiated hydrological response and an inherent environmental fragility.

Water samples were collected along the longitudinal profile of the Alcantara River, from its main springs to its mouth, have made it possible to outline a preliminary picture of the distribution of nutrients, contaminants emerging, trace elements, major elements, and physicochemical parameters (T, O_2, Eh, pH, EC) during seasonal peaks. The data reveal a close correlation between the basin's lithology and water chemistry, highlighting the geogenic contribution resulting from silicate weathering. However, localized anomalies emerge at specific anthropogenic input points, linked to urban areas and agricultural activities.

To integrate the data into a broader interpretive context, the project plans to extend the investigations to the Simeto River, which has a large watershed and more intensive land use. Comparing the two river systems will enable to distinguish the influence of natural weathering processes from the contributions related to industrial and agricultural activities, contributing to the definition of local geochemical backgrounds.

This integrated approach, which combines the study of nutrients and heavy metals, aims to provide an interpretive model that supports sustainable water resource management and the mitigation of human impacts on fragile Mediterranean river ecosystems, stressed by climate change.

Sustainable management of floods; the case study of IBRI 14 Dam, Oman

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Keywords: rockfill recharge dam, semi-arid climate, dam project.

The increase in world water consumption and the lack of balance between supply and demand may lead to critical situations in several countries all over the world. Since the availability of surface water is very limited in various regions, groundwater is often the only reliable source of fresh water. This problem especially affects arid and semi-arid countries such as Oman. The Sultanate, located in the southeastern corner of the Arabian Peninsula, experiences precipitation generally lower than 250 mm per year (Al-AJMI, 2018) with some years characterized by the complete absence of rainfall. Moreover, the study area is often affected by exceptional floods that caused extensive damage to local infrastructure and engineering works. In recent years, the Government of the Sultanate of Oman has planned the construction of recharge dams to support and better manage a traditional irrigation system called Aflaj (Al-Mamary, 2021). These dams temporarily collect floodwaters and release them slowly downstream, increasing the water flow into the above-mentioned local distribution system. The IBRI 14 Dam is the largest one among those projected. In this work, the geological and geotechnical criteria adopted for the design and construction of this rockfill recharge dam are outlined, specifically describing the main features of the hydraulic structure. The project and construction of the Dam were subdivided into many phases: Feasibility study, Detailed design, and Supervision phase. In the first phase several aspects had been considered such as local water request, geomorphology, the availability of alluvial deposits and other points from a technical and economic point of view. These were essential for determining the appropriate location and size of the dam. In this way, on site surveys and laboratory tests have been realized to determine the geotechnical and hydraulic characteristics of the foundation soils. Based on the tests results, the second phase regarding the detailed design has been developed. During this phase the geotechnical design of the Dam embankment has been defined, focusing on the typical problems associated with rockfill recharge dams, such as Internal Erosion and Dam Slope Protection, Seepage and Filtration as well as Slope Stability. Finally, during the construction, particular attention was paid to materials controls. Several checks were carried out on reinforced concrete structures and on the embankment materials, such as layer thickness, degree of compaction, and permeability coefficient. The final configuration of the IBRI 14 Dam, completed in 2020, consists of an 8 m high rockfill embankment made of granular fill, with an impervious plastic concrete core, an ungated gabion spillway, and two bottom outlets. This work represents a useful case study on the complete cycle of realization of a dam, also considering that it had been affected by huge flooding during construction, suffering no significant damage (Canzoneri et al., 2025).

Al-Ajmi D.N. (2018) - Climate Aridity: The Sultanate of Oman as a Case Study. Int. J. Earth Sci. Geol., 1, 1-3, ISSN:2642-1569.

Al-Mamary S.A. (2021) - Effect of climate change on Aflaj in the Sultanate of Oman. ICE Publishing, https://doi.org/10.1680/oicwe.65253.131.

Canzoneri V. et al. (2025) - Geological and Geotechnical Studies Aimed at the Project and Construction of Rockfill Recharge Dams: The Case Study of the Wadi Sulayf Dam, Wilayat Ibri Region, Oman. Geotechnics, 5(4), 74, https://doi.org/10.3390/geotechnics5040074.

Integrating geodiversity into Planetary Health and Planetary Boundaries: The case of Italy

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Keywords: geodiversity, planetary health, planetary boundary.

Geodiversity, defined as the natural range of geological, geomorphological, soil, and hydrological features and processes, represents the physical and process-based foundation of ecosystems and a key component of territorial resilience (Toivanen et al., 2026). However, its role remains insufficiently integrated into sustainability, risk reduction, and health-oriented planning frameworks. This contribution proposes a conceptual framework for incorporating geodiversity into the perspectives of Planetary Health and Planetary Boundaries, using Italy as an emblematic case study.

Italy is characterized by exceptional geodiversity (Casaburi et al., 2024), resulting from its complex tectonic setting, active volcanism, strong relief gradients, extensive coastlines, karst systems and long-lasting human-environment interactions. These features support essential ecosystem services, including freshwater regulation, soil fertility, biodiversity patterns, cultural landscapes and tourism (Alahuhta et al., 2018). At the same time, they are associated with high exposure to geohazards, such as earthquakes, volcanic eruptions, landslides, floods, and coastal erosion, whose impacts are increasingly amplified by climate change, land-use pressures and urban expansion.

From a Planetary Boundaries perspective, several critical boundaries relevant to the Italian territory, including land-system change, freshwater alteration, climate regulation, and biosphere integrity, are closely linked with geodiversity. Soil degradation, river regulation, sediment starvation along coasts, and the loss of geomorphological connectivity can reduce the buffering capacity of landscapes and increase the vulnerability of socio-ecological systems.

The proposed framework links geodiversity, ecosystem services, geohazards and anthropogenic pressures within a common interpretative scheme, highlighting how the physical and abiotic framework of the territory influences both environmental functioning and human well-being within a Planetary Health perspective. It may also support the development of geodiversity indicators suitable for comparing territorial fragility, ecosystem-service provision, and exposure to natural hazards. Geodiversity should therefore be considered not only as an object of geoconservation, but as an operational component of environmental governance. Its integration into spatial planning, ecosystem-service assessment, risk management, and climate-adaptation strategies can strengthen early warning, disaster risk reduction and landscape resilience. Italy thus represents a strategic laboratory for translating geoscientific knowledge into more sustainable and health-oriented territorial policies.

Our approach recognizes geodiversity as an integrative paradigm strengthening the operational link between Planetary Health and Planetary Boundaries by explicitly incorporating the abiotic foundation of ecosystems into health, environmental, and spatial planning policies. In Italy, such an approach can support more resilient development pathways, enhance disaster risk reduction, protect cultural landscapes, and promote intergenerational and territorial justice. Safeguarding geodiversity is thus not only a matter of geoconservation, but a prerequisite for maintaining human well-being within the safe operating space of the Earth system in the Anthropocene.

Alahuhta J. et al. (2018) - The role of geodiversity in providing ecosystem services at broad scales. Ecol. Ind., 91, 47-56.
Casaburi A. et al. (2024) - Geodiversity of Italy. J. Maps, 20(1), 2340988.
Toivanen M. et al. (2026) - Geodiversity and resilience: A scoping review. Ambio, 1-21.

A multi-parameter index to support monitoring of torrent control structures

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Keywords: torrent control structures, watershed management, index.

Transversal torrent control structures (TTCSs) are fundamental components for managing mountain watersheds and mitigating geo-hydrological risks. With the growing frequency and intensity of extreme events driven by ongoing climate change, the status assessment of the structural condition of these structures has become an increasing challenge for watershed management strategies. To address this need, this study presents a Potential Fragility Index (PFI), a regional-scale screening tool specifically designed to identify structures potentially prone to damage. The PFI aims to classify TTCSs based on their potential fragility, identify potential hotspots, and support monitoring activities.

The PFI methodology integrates intrinsic structural characteristics, such as construction material, height, and age, with extrinsic environmental factors, including substrate lithology and geomorphometric susceptibility to debris flows. Weights used to evaluate evaluating the relative importance of each factor in determining the potential fragility of the structures were assigned based on the evaluation of the answers to a structured questionnaire addressed to both professional practitioners and academic specialists.

The index was implemented across the Fella, But, and Degano basins in the Friuli-Venezia Giulia region of northeastern Italy, covering an inventory of 3,594 structures. The conceptual coherence of the index was assessed through field observations of 282 structures across seven sub-catchments. The results demonstrate that structures located in headwater zones and along debris-flow propagation reach consistently exhibit higher PFI values, in agreement with deterioration patterns documented through field observations. In contrast, TTCSs located on alluvial fans and in low-slope channel reaches tend to exhibit lower fragility classes, reflecting the prevalence of depositional processes and reduced hydraulic stress. Notably, TTCSs sharing similar intrinsic and extrinsic characteristics may display contrasting current conditions depending on the dominant geomorphological processes within their respective sub-catchments, underscoring the role of local processes in controlling structural deterioration.

The PFI proves to be both broadly applicable and transferable across a range of geomorphological contexts, as it is based exclusively on readily available regional datasets. It therefore represents a practical and scalable decision-support tool for guiding the prioritisation of maintenance actions and enhancing resource allocation in regional watershed management.

Impact of the 2011 Puhyeue-Cordón Caulle Plinian Eruption on sedimentary systems Over 13 Years - a multisciplinary approach

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Keywords: volcanism, environmental response, remote sensing.

Plinian eruptions exert a strong control on surface processes, triggering rapid and long-lasting perturbations in sedimentary systems and landscape. This study investigates the post-eruptive evolution of fluvio-lacustrine systems following the 2011 eruption of the Puyehue-Cordón Caulle volcanic complex (VEI 5). The aim of quantifying sediment dynamics and assessing its spatial and climatic controls at the basin scale over a 13-year period (2011-2023). A quantitative multi-temporal analysis of satellite imagery using Google Earth Engine and SNAP was performed to characterize geomorphic surface changes at selected time steps. Transitions among active channels, bare volcaniclastic deposits, stabilized or vegetated surfaces, and inundated areas were systematically mapped to evaluate channel reworking and floodplain dynamics. In parallel, sediment availability was assessed using an erosion modelling framework based on the Erosion Potential Method (EPM), allowing estimation of basin-scale sediment production (W) and identification of areas more susceptible to sediment generation and remobilization. Results highlight a pronounced geomorphic reorganization following the 2011 eruption. The Golgol River underwent partial transformation into a braided system due to intense tephra input during the first ~7 years, affecting approximately 1.0 km^2 of the fluvial valley. Concurrently, lakes, particularly in sectors located downwind of the eruptive column, experienced sustained increases in suspended sediment load, resulting in elevated turbidity and enhanced sediment delivery to deltaic systems. Both southwestern and southeastern deltas show significant progradation, with a marked acceleration after 2015. The integration of remote sensing observations with EPM-derived sediment production patterns reveals a strong spatial correspondence between areas of high sediment yield and zones of active geomorphic change. These findings provide new quantitative constraints on the spatio-temporal evolution of post-eruptive landscapes at mid-latitude environments. The proposed integrated workflow demonstrates the value of combining satellite time-series analysis with erosion modelling to link sediment availability, climatic forcing, and geomorphic response. This approach contributes to improving our understanding of how large explosive eruptions impact sediment routing systems over decadal timescales.

Propagation of deformation in a deep-seated landslide evidenced by integrated geomorphological and monitoring data: A case study in the Northern Apennines (Italy)

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Keywords: landslide kinematics, deformation propagation, integrated monitoring.

Understanding the spatial organization of movement in deep-seated landslides is fundamental for improving their characterization and the assessment of geological risk. This study focuses on the Casale-Colla landslide (Northern Apennines, Italy), integrating high-frequency GNSS monitoring and high-resolution topographic data through integrated approaches to investigate the relationship between surface morphology and landslide kinematics. The landslide is characterized by a complex internal structure involving multiple kinematic sub-units and a large spatial extent, reaching depths of 40 m. Continuous GNSS measurements provide cumulative planimetric displacement time series, which were analysed in relation to rainfall data to investigate its influence on landslide kinematics. From these data, velocity fields were derived along the landslide profile. In order to allow comparison of relative kinematic variations, velocities were normalized with respect to the maximum value observed along the profile. This approach highlights spatial differences in landslide activity independently from absolute displacement rates. The normalized velocity distribution is interpreted in relation to the geomorphological setting of the landslide, reconstructed through high-resolution UAV-based LiDAR-derived topography. This allows the integration of geomorphological and monitoring data, permitting the identification of slope segmentation, morphological discontinuities, and variations in landslide extent and internal organization. The integrated analysis provides insight into the spatial organization and propagation of deformation within the slope, highlighting how morphological variability may influence the distribution and transfer of movement along the landslide body. This study demonstrates that the combined use of environmental monitoring and high-resolution topographic analysis represents an effective approach for investigating landslide dynamics in complex and high-vulnerability contexts, contributing to improved hazard assessment and supporting sustainable territory management.

Building a sustainable transportation path for crude oil to minimize emergency scenarios

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Keywords: crude oil migration, numerical simulations, variably saturated zones.

In this presentation, we analyze, through numerical simulations, an emergency scenario in which an onshore pipeline transporting crude oil at high pressure breaks, and the contaminant migrates through the variably saturated zone.

CactusHydro accurately resolves the sharp discontinuities and temporal dynamics of three-phase immiscible fluid flow, thereby accurately tracking contaminant migration over time through a variably saturated zone with different water-saturation and porosity values. We analyze various scenarios encompassing different climatic conditions, including rainfall-induced water saturation, and different porosity values in the variable-saturation porous medium zone, resulting in 17 transient numerical simulations.

Our results suggest that, for crude oil, the distribution of leaked oil may not extend deeper than 2 meters within 10 days, and therefore can be helpful in constructing pipeline paths that avoid or reduce pollution.

GeoSciences IR: An integrated and interoperable geological infrastructure for environmental hazard monitoring and sustainable territorial management

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Keywords: geosciences, research infrastructure, FAIR.

Environmental geology increasingly requires integrated and interoperable infrastructures capable of supporting hazard assessment, territorial monitoring, and evidence-based decision making under rapidly changing environmental conditions. Within this framework, GeoSciences IR represents a national effort to strengthen coordination among regional geological surveys and research institutions through the development of an open, FAIR-compliant, and interoperable geoscientific infrastructure. The project, funded through the Italian National Recovery and Resilience Plan (PNRR), addresses the growing need for harmonized geological data, advanced monitoring services, and operational tools supporting environmental risk mitigation and sustainable territorial management.

GeoSciencesIR integrates multi-source and multi-temporal datasets, including satellite earth observation products, geological mapping, georesource information, landslide inventories, marine geology data, and 3D subsurface models.

The infrastructure has been developed through a user-centred approach involving regional geological surveys and institutional stakeholders from the earliest design phases. Continuous interaction with end users enabled the definition of interoperable services, open APIs, customized visualization tools, and training modules aligned with operational needs and policy requirements. Particular emphasis has been placed on interoperability with consolidated paneuropean data infrastructures in the geological domain, including EPOS and EGDI, fostering cross-border data sharing and standardized geoscientific services.

The GeoSciencesIR experience demonstrates how integrated digital infrastructures, satellite monitoring technologies, and collaborative governance frameworks can enhance environmental hazard assessment, improve territorial resilience, and bridge the gap between scientific observation and decision-making processes.

Quantifying the Impact of climate variations on crop production and agricultural market dynamics

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Keywords: climate variations, sustainability, crop price forecasting.

The susceptibility of crop production systems to both short-term and long-term climate variations significantly influences the availability and pricing of food resources, raising critical concerns regarding the sustainability and security of global food markets (Di Tommaso et al. 2023, 2026; Pacelli et al., 2025). Against this backdrop, integrating agricultural response models with market price fluctuations provides a powerful framework for advancing sustainable agriculture and market efficiency. While crop yield forecasting allows for the anticipation of unexpected production scenarios, accurate multi-month price forecasting is crucial for mitigating the informational impact of exogenous shocks and reducing transitory price volatility. Reliable forecasting systems enable market participants to promptly update expectations, thereby stabilizing dynamics in contexts exposed to unpredictable climatic variables.

This ongoing research investigates the relationship between crop yields and climatic variability, with a primary focus on wheat cultivation in Italy. The study centers on developing advanced statistical methodologies for short-term crop yield forecasting based on the monitoring of key climatic indices. The methodology involves integrated least squares and resampling methods designed to analyze time-varying regression models (Guerriero et al., 2026). The primary aim is to assess the vulnerability of crop yields to climatic fluctuations, determine if this sensitivity exhibits changes over time, and provide data-driven approaches with physical interpretability for capturing intricate climate-yield relationships. For modeling agricultural commodity price variations, the research utilizes Seasonal AutoRegressive Integrated Moving Average models (SARIMA and SARIMAX). While SARIMA models effectively capture recurring periodic patterns typical of agricultural markets, they are limited by a univariate structure. To overcome this, the SARIMAX model incorporates exogenous regressors, such as precipitation, temperature, inflation, and fertilizer prices, into the forecasting process. Empirical evidence confirms that including these variables significantly improves forecasting accuracy and enhances the model's capacity to anticipate sudden shifts in agricultural market prices. The proposed tools can enable data-driven planning and quantitative economic risk analysis. These methods are intended to support stakeholders across the food supply chain, regulatory bodies (e.g., FAO, EU Commission), and investors in stabilizing markets and ensuring food security.

Di Tommaso C. et al. (2023) - The impact and the contagion effect of natural disasters on sovereign credit risk. An empirical investigation. Int. Rev. Financ. Anal., 87, 102578. https://doi.org/10.1016/j.irfa.2023.102578.

Di Tommaso C. et al. (2026) - The contagion effect of natural disasters in the Sovereign CDS market: Which causes? Int. Rev. Financ. Anal., 111, 105102. https://doi.org/10.1016/j.irfa.2026.105102.

Guerriero V. et al. (2026) - Forecasting by means of a novel regression approach involving time-varying parameters: wheat yield projection based on climatic data. Environ. Res. Commun., 8, 035027, https://doi.org/10.1088/2515-7620/ae4b91.

Pacelli V. et al. (2025) - The link between climate and systemic risk: A bibliometric and systematic literature review. Res. Int. Bus. Financ., 79, 103072, https://doi.org/10.1016/j.ribaf.2025.103072.

Integrated seabed mapping for assessing coastal defence interactions with Posidonia oceanica habitats in Southern Italy

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Keywords: coastal geology, Posidonia oceanica, seabed mapping.

Coastal defence works are increasingly implemented along Mediterranean shorelines affected by erosion and sediment-budget alteration. However, their planning requires detailed knowledge of seabed conditions, especially in areas characterized by the occurrence of protected benthic habitats. In this context, *Posidonia oceanica* meadows represent a priority habitat of high ecological and geomorphological value, as they contribute to sediment stabilization, coastal protection and the maintenance of marine biodiversity.

This study presents an integrated approach for mapping and zoning *P. oceanica* meadows along the coastal sector of Calopezzati, on the Ionian coast of Calabria, southern Italy. The area falls within the Special Area of Conservation IT9310048 “Fondali Crosia-Pietrapaola-Cariati”. The methodological workflow combines pre-existing bathymetric data, Side Scan Sonar surveys, georeferenced underwater video observations, Sentinel-2 multispectral imagery and supervised classification within a GIS environment.

Acoustic backscatter analysis allowed the identification of seabed facies compatible with sandy substrates, mixed or hard bottoms, and sectors characterized by continuous or discontinuous vegetation cover. Video frames were used to validate the acoustic interpretation and to support the classification of multispectral imagery. The integration of the different datasets allowed the definition of a three-class zonation, including areas where *P. oceanic*a occurrence is excluded or unlikely, areas with confirmed meadow presence, and areas characterized by discontinuous cover or suitable substrate, interpreted as mosaic and intramatte sectors.

The overlay between the habitat zonation and the planned coastal defence works highlights potential interactions mainly with areas characterized by discontinuous cover or suitable substrate. These sectors represent sensitive zones, where uncertainty regarding habitat continuity should be explicitly considered during planning and impact assessment.

This study demonstrates how the integration of acoustic data, satellite imagery and direct observations can provide an operational decision-support tool in coastal environmental geology, contributing to the sustainable management of coastal defence works and to the protection of sensitive marine habitats.

Simulating the wind-driven release of naturally occurring fibrous minerals

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Keywords: computational fluid dynamics, asbestiform minerals.

Naturally occurring asbestiform minerals like erionite and asbestos group minerals, are identified as group 1 carcinogens by IAPC. In Türkiye, the Cappadocian region shows high mesothelioma rates linked to weathering of erionite bearing ignimbrites and the usage of erionite bearing ignimbrite stones in older buildings (Carbone et al., 2011), while other regions like Mihalıççık pose ongoing exposure risks from altered ultramafic sequences hosting tremolite and chrysotile minerals (Metintaş et al., 2017). Yet despite our ability to identify where these minerals occur geologically and measure the number of fibers in soil and dust media, transportation of the fibers and the amount of human exposure. The missing piece is understanding how fibers actually escape from rock and become airborne—the physical mechanics of fiber release and dispersal that connect geology to atmospheric transport. Existing macroscopic trajectory models frequently rely on assumed emission rates, failing to capture the interaction between localized rock weathering and boundary layer fluid dynamics.

This study proposes a multi scale computational framework to experimentally determine mineral specific aerodynamic emission fluxes and integrate them into deterministic Computational Fluid Dynamics (CFD) transport simulations. Because this work is in early stages, we focus here on describing the methodology that connects atmospheric dynamics with engineering geology principles.

Our methodology comprises four integrated phases. Initially, fieldwork and laboratory characterization to assess the geomechanical properties of host rock matrices and establish baseline mineralogical compositions alongside fiber morphological distributions. Then environmental conditions will be simulated in laboratory to quantify temporal degradation pathways and mechanical properties of asbestiform mineral bearing rocks. Additionally, wind tunnel investigations will be conducted to determine threshold friction velocities and establish mineral-specific aerodynamic emission fluxes under aeolian conditions. Finally, these empirically derived parameters are incorporated into a computational framework utilizing modified drag equations that account for non-spherical fiber geometry, enabling numerical simulation of aerodynamic fiber detachment and atmospheric transport processes.

Model validation will be performed through comparison with directionally resolved field passive sampling data. By integrating host-rock degradation mechanics with microscale computational transport modeling, this investigation advances beyond conventional geological hazard characterization toward a mechanistically grounded, predictive exposure assessment framework.

Carbone M. et al. (2011) - A mesothelioma epidemic in Cappadocia: scientific developments and unexpected social outcomes. Nat. Rev. Cancer, 11(2), 147-154, https://doi.org/10.1038/nrc2994.

Metintaş S. et al. (2017) - Environmental asbestos exposure-induced mesothelioma risk mapping of Turkey. Carcinogenesis, 38(11), 1098-1105, https://doi.org/10.1093/carcin/bgx083.

Geostructural and geotechnical analyses of the Castrocucco Rockfall (Maratea, Southern Italy)

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Keywords: rockfalls, landslide hazard, fracture network.

On 30 November 2022, a major rockfall event occurred at the Castrocucco cliff (Maratea, Southern Italy), affecting a sector of the SS18 national road (Santo & Massaro, 2025). Following the event, emergency stabilisation measures and monitoring activities were implemented to allow the safe reopening of this strategic coastal infrastructure while awaiting the construction of a bypass tunnel.

This work presents an integrated and multidisciplinary methodological approach for characterising rockfall, assessing susceptibility, and managing monitoring systems that affect high-traffic transportation networks. The study combines detailed geological and geostructural surveys with high-resolution remote sensing techniques based on UAV photogrammetry and digital outcrop analysis. High-detail point clouds, orthophotos, and frontal reconstructions of the cliff were used to identify discontinuity systems, define homogeneous sectors of the slope, and support the spatial distribution of monitoring sensors.

In particular, stability analyses and rockfall reconstructions were carried out through the comparison between pre-event and post-event DEMs, allowing the definition of a geological-geotechnical model of the event. Additionally, the role played by the water circulation, the permeability of the rock mass, and the influence of the cataclasite along the sliding plane were investigated.

The proposed workflow highlights the importance of integrating geostructural and geotechnical analyses within a comprehensive susceptibility framework. The methodological approach developed for the Castrocucco cliff may represent a useful reference for the management of critical infrastructures exposed to rockfall hazard in similar geological and geomorphological settings.

Santo A. & Massaro L. (2025) - Landslide monitoring and maintenance plan along infrastructure: the example of the Maratea major rockfall (Southern Italy). Landslides, 22, 975-987, https://doi.org/10.1007/s10346-024-02409-3.

Multidisciplinary analysis of a volcanic coastal cliff threatening archaeological heritage: The case of Baia Castle cliff (Phlegrean Fields, Naples)

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Keywords: rockfall hazard, cultural heritage risk, earthquake-induced landslides.

The Baia Castle cliff, composed of volcanic deposits, including trachytic tuff and pyroclastic layers, lies in the western sector of the Gulf of Naples within the Phlegrean Fields caldera. This steep cliff is affected by ongoing geomorphological changes that threaten both archaeological heritage and coastal infrastructure. In this seismically active volcanic setting, cliff instability is driven by the combined action of pervasive fracturing, marine erosion, and bradyseismic activity, which frequently triggers rockfalls (e.g., Rosser et al., 2013). This study presents an integrated assessment of rockfall hazard based on high-resolution UAV photogrammetry, semi-automatic point cloud analysis, field structural surveys, and laboratory geomechanical testing, with the aim of reconstructing the structural setting of the tuffaceous cliff and identifying the main failure mechanisms. Additionally, the earthquake-induced rockfall occurred in March 2025 was analysed in detail.

Analysis of 495 discontinuities, combining field and digital data, revealed five main sets, dominated by steeply dipping fractures oriented NW-SE and NE-SW, consistent with the regional tectonic framework (i.e., Apenninic and anti-Apenninic orientations). Kinematic analyses showed that wedge sliding is the most critical failure mechanism on all the main slope faces, while direct toppling represents a secondary but relevant instability mode. Field observations confirmed the widespread presence of discontinuity-bounded blocks prone to detachment, with potential source volumes ranging from a few cubic metres up to about 100 m^3.

Comparison of pre- and post-event vertical digital elevation models shows that the March 2025 rockfall produced a maximum local cliff retreat of 5.6 m and a total mobilized volume of approximately 280 m^3. Seismic site response analysis suggests that the collapse cannot be linked to a single triggering earthquake, but rather to a progressive weakening of the rock mass caused by repeated low-magnitude shallow seismic events, superimposed on persistent wave erosion and weathering processes affecting the tuff. In a broader historical perspective, the retreat of the cliff since Roman times is estimated to be at least 10 m, corresponding to an average erosion rate of about 5 mm/yr.

The results highlight the central role of cumulative seismic damage in controlling instability at the Baia Castle cliff and demonstrate the effectiveness of an integrated workflow for assessing rockfall hazard in coastal volcanic and heritage sites.

Rosser N.J. et al. (2013) - Coastline retreat via progressive failure of rocky coastal cliffs. Geology, 41, 939-942, https://doi.org/10.1130/G34371.1.

Retrospective analysis of an app developed for emergency and geological response activities

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Keywords: Umbria, landslide, emergency.

The Geological Section of the Umbria Region is an integral part of the regional Civil Protection system and is responsible for responding to all emergency situations identified in the Regional Multi-Risk Plan. To this end, since 2022, the Umbria Region's Geological Office has been implementing an application that allows real-time reporting of emergency assessments, including locations, photos, and feedback. The activation and use of the app, in addition to responding to the changing landscape of emergencies caused by climate change, has allowed for the consolidation and improvement of the quality and efficiency of on-site inspections during emergencies, including through the use of trained, experienced, and team-oriented personnel and annual field exercises. The app was developed following the steps outlined in the Technology Readiness Level (TRL) scale. Climate change is causing a shift in the number of emergencies that have occurred in Umbria over the past five years. Specifically, emergencies are linked to increasingly intense phenomena, urban areas are increasingly affected by connection infrastructure, and the frequency of mudslides/debris flows, bank erosion, and even landslides has increased, with the Apennine and hilly areas being the most affected. Emergency geological response times have been shortened by at least one day, and the number of daily field checks possible has increased. Following the use of the app, 400 landslides in 35 different emergency situations, from regional to local, were mapped, georeferenced, photographed, and described. Civil protection officials were able to immediately see the various situations, as if they were on the ground, and decide on the appropriate actions to take for public and private safety. During three regional emergencies, the app enabled a geological assessment to be completed every 20 minutes for each two-person team of geoscientists; all data and photos were immediately georeferenced, displayed, and managed as an online database in open GIS format. The data was made immediately available to decision makers and operational emergency response teams, also helping to reduce the approval times for specific emergency regulations.

Provincial Road No. 70 (Is Cattas): Research on best solutions for hydrogeological risk mitigation, cost-benefit assessment of interventions and administrative provisions in the Province of Sulcis Iglesiente

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Keywords: risk mitigation, monitoring.

The new Province of Sulcis Iglesiente took over territorial jurisdiction from the former Province of Southern Sardinia, covering the areas of Sulcis and Iglesiente, effective on June 1, 2025. With the administrative management of the inherited projects, particular attention was paid to those relating to the protection of people and the preservation of the territory exposed to adverse weather events related to ongoing climate change. This includes the decision to intervene on provincial road no. 70, at km 12+160, near a hydraulic crossing (a finsider type manhole) located in the hamlet of Is Cattas in the municipality of Santadi.

It should be noted that, again this year, during the emergency situations that occurred on January 19, 20, and 21, 2026 (Cyclone Harry), the road section suffered from extraordinary water flows that, within 24 hours, caused the manhole crossing Provincial Road No. 70 to overflow.

Precisely because of the recurrence of these events, the current early stages of designing the digital terrain model and hydraulic study have highlighted the near impossibility of reaching a solution capable of completely addressing the hydrogeological risk parameters, without the potential use of resources far greater than those currently available.

Given the above, with a view to optimal cost/benefit analysis, a risk mitigation intervention will be designed with civil protection measures, postponing any definitive resolution (verification of the 200-year flood flow) of all critical issues in the area to subsequent structural interventions. In this regard, in order to improve the flow capacity of the existing “finsider” pipeline, the existing structure will be strengthened by expanding the flow section and installing monitoring stations to interface with warning devices aimed at protecting the population by automating the closure of the section and consequently reducing the exposure of road users. The expansion works will be designed in accordance with the model currently in force in the Hydrogeological Planning Plan of the Sardinia Region and in accordance with the Technical Construction Standards pursuant to Ministerial Decree of 17.01.2018 and the related Explanatory Circular No. 7 of 07.01.2019 (Par. C5.1.2.3), with particular regard to planning for the adaptation of existing building.

Extreme rainfall events, road surface failure, and frontal instability. The effects of climate change and hydrogeological risk on emergency management in the new Province of Sulcis Iglesiente: Events of January 19-21, 2026

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Keywords: rainfall, risk management.

During the first months of "administrative running-in", the newly formed Province of Sulcis Iglesiente (operational since 01.06.2025) gradually proceeded to normalize the ordinary and extraordinary administrative management of its assets, with the human and instrumental resources made available by the administrative division of the defunct Province of South Sardinia, in favor of the new public bodies that took over.

In this unique and sensitive context of "administrative structuring," between January 2026 (peak phase) and the subsequent months of February and March, the province had to redouble its efforts with additional emergency management measures, implemented in response to the challenges induced by Cyclone Harry, which severely impacted much of the province's jurisdiction.er Province of the South Sardinia to benefit the new incumbents.

This state of emergency, as administratively resolved by the Council of Ministers on January 26, 2026, and subsequently established by the management act pursuant to O.C.D.P.C. No. 1180 of January 30, 2026, severely affected most of the Sulcis area and part of the Iglesiente area, requiring intensive management of the dangers and risks that manifested themselves especially between January 19 and 21, with a prolonged deployment of forces in the field also in the following weeks, to manage the residual risk.

Many roads were flooded due to water pouring from areas adjacent to the roadway, with significant and continuous runoff and spills damaging several kilometers of extensive roadways. This resulted in damage to the hillsides of the roads, with both localized and widespread gravitational effects, as well as extensive damage to the road surfaces and asphalt pavement. In many cases, there was a sudden worsening of the previous cracking patterns typical of normal fatigue deterioration. Greater critical issues arose in cases of worsening operational conditions, with the formation of extensive ruts, gaping cracks, subsidence, and deep potholes, requiring increased efforts by the Authority's Road Services personnel.

Particular problems were encountered on provincial roads 1, 2, 70, 71, 73, 75, 76, 78, 78bis, 82, 83, 109, and 110, requiring emergency, high-urgency, and day-and-night response. This required the mobilization of vehicles and personnel, both from the in-house company and external contractors, to restore the site to its original condition, install warning signs, and secure unstable roadsides. In some cases, it was necessary to temporarily close several kilometers of roads to protect public safety. In the following weeks, the damage and the requirements for complete restoration and elimination of residual risk were assessed, with an estimated resource requirement of over five million euros, for which funding requests were submitted.

Landslide 3D geological modelling using Gempy and InSAR displacement time series

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Keywords: landslides, InSAR, 3D modeling.

Geological 3D modeling is a fundamental aspect in landslide analysis. Although geologic maps can be often retrieved, their interpretation and/or the extraction of 3D model may be challenging. This work introduces an innovative, integrated QGIS-based framework that simplifies 3D geological model creation through two novel components: the 3D GemPy Model Builder, a user-friendly interface to the GemPy Python library (Wu & Sun, 2021), and the InSAR Tools toolbox, which uniquely derives sliding surfaces directly from InSAR Line of Sight displacement time series. Although the study of landslides using SAR data is widely recognized (Raucoules et al., 2013; Delbridge et al., 2016), our approach innovatively combines remote sensing data (InSAR-derived PS measurements from EGMS), LiDAR-refined boundary detection, and geological mapping into a unified workflow within QGIS. The methodology systematically progresses from landslide perimeter delineation, through cross-sectional sliding surface depth estimation, to automated 3D geological surface generation. This innovative integration significantly reduces technical barriers, enabling non-specialist professionals to produce 3D geological models compatible with advanced numerical solvers, a capability previously limited to highly specialized teams. The case studies are presented to show the capabilities of the tools and highlight their advantages and limitations, as we will show this approach works only for a limited number of landslide movement types (Cruden & Varnes, 1996), despite this the framework represents a paradigm shift in making sophisticated landslide modelling accessible to a broader community of geological and geotechnical professionals.

Cruden D.M. & Varnes D.J. (1996) - Landslide Types and Processes. Transp. Res. Board Spec. Rep., 247, 36-75.

Delbridge B.G. et al. (2016) - Three-Dimensional Surface Deformation Derived from Airborne Interferometric UAVSAR: Application to the Slumgullion Landslide. J. Geophys. Res. Solid Earth, 121, 3951-3977.

Raucoules D. et al. (2013) - Time-Variable 3D Ground Displacements from High-Resolution Synthetic Aperture Radar (SAR): Application to La Valette Landslide (South French Alps). Remote Sens. Environ., 139, 198-204.

Wu J. & Sun B. (2021) - Discontinuous Mechanical Analysis of Manifold Element Strain of Rock Slope Based on Open Source GemPy. In: E3S Web of Conferences, EDP Sciences, 248, 03084.

Integrating multi-temporal datasets from the Little Ice Age to present: A comprehensive approach to geohazard assessment in the Belvedere Glacier basin (MOHYCAM project)

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Keywords: paraglacial processes, Belvedere glacier, geohazard assessment.

In a context marked by accelerating climate change and intensifying environmental pressures, the western Italian Alps exemplify territories where geological and geomorphological settings strongly influence vulnerability to natural hazards. During the Holocene, glacier extents have steadily contracted, with the most marked retreat occurring after the Little Ice Age (LIA, ca. 1830 CE). This rapid deglaciation has unleashed a suite of geohazards in the newly exposed proglacial zones: collapsing steep rock walls, debris-prone drift-covered slopes, and sediments quickly swept downstream during high rainfall events and subsequent floods. These processes condition the landscape in a paraglacial regime, requiring an integrated, system-based approach to support sustainable risk mitigation strategies.

The MOHYCAM project (Modified HYdrogeological hazards under complex ClimAte and environmental conditions: Monitoring activities and mitigation strategies) addresses these challenges through multi-temporal and multi-source datasets. By combining satellite and aerial imagery, orthophotos, UAV photogrammetry, historical cartographic maps with field surveys, we reconstruct the Late Holocene evolution of the Belvedere glacial basin and map glacial retreat, alongside destabilisation of rock walls and glacial deposits and landforms. This integrated methodology enables assessment of erosion patterns that have produced frequent mass-flow events in recent decades.

Mapping past slope instabilities and flood-related phenomena, as well as current risk zones, demonstrates how interdisciplinary approaches can bridge the gap between observation and decision-making. The resulting knowledge supports development of diverse monitoring strategies and organisation of training workshops aimed at strengthening community resilience, thereby improving local population's capacity to respond to extreme events. This contribution highlights how systematic geohazard assessments can inform sustainable territorial planning under changing environmental conditions.

Microclimatic monitoring networks in show caves, a tools for the conservation of underground geodiversity

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WITHDRAWN

Radon in Sardinian caves (Italy): Geological setting or ventilation control?

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WITHDRAWN

Temporal changes in soil elastic parameters ($\Delta V/V$, Δf_0) and their Interdependence

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Keywords: time series analysis, seismic noise, site effects.

Single-station ambient-noise monitoring is increasingly recognized as a valuable tool for investigating temporal variations in subsurface mechanical properties and their possible implications for geological hazard assessment and environmental monitoring. Geodetic techniques such as GPS and InSAR have revealed vertical ground motions on daily and seasonal timescales, while seismic observations provide complementary information on the evolution of subsurface elastic properties through passive and continuous measurements. In this framework, the resonance frequency (f_0) and the H/V spectral ratio derived from ambient seismic noise could indicate temporal changes in near-surface conditions. Recent studies documented seasonal variations in both resonance frequency (Lattanzi et al., 2023) and H/V spectral ratios (Vassallo et al., 2022) as well as temporal changes in seismic-wave velocity ($\Delta V/V$) derived from ambient-noise cross-correlation (Mao et al., 2022). Since seismic velocity is directly related to elastic moduli and stiffness, understanding the relationship between $\Delta V/V$ and resonance-frequency variability is essential for interpreting the physical processes controlling subsurface dynamics.

This study investigates the relationship between temporal variations in $\Delta V/V$ and f_0, assessing whether seismic-velocity changes alone can explain the observed resonance-frequency variability. We analyzed long-term recordings from broadband stations in the Los Angeles Basin together with a Swiss station located in a well-constrained 2D Alpine basin, allowing the comparison of different geological and geomorphological settings. For selected stations, both H/V peak variability and frequency shifts of individual spectral features were investigated. Results confirm the presence of both seasonal and diurnal variations in resonance frequencies and H/V peaks. However, the temporal behaviors strongly depend on the geological setting and wavefield characteristics. In the Los Angeles Basin, H/V peaks mainly reflect Rayleigh-wave behavior typical of 1D conditions, whereas in the Alpine basin they are associated with body-wave resonance effects linked to 2D basin geometry. No common seasonal trend emerged between the investigated areas, suggesting that local geological conditions, hydrological processes, and wave-propagation effects interact in controlling subsurface seismic response. The observed resonance-frequency variations are significantly larger than those expected from $\Delta V/V$ changes alone, indicating that seismic-velocity variations or simple hydrological effects cannot fully explain the temporal evolution of site response. These findings highlight the importance of integrated and long-term passive seismic monitoring for improving the understanding of subsurface processes and their possible implications for environmental monitoring and seismic hazard characterization.

Lattanzi G. et al. (2023) - On the time-stability of resonance frequencies in deep basins. Geophys. J. Int., 234(3), 1870-1884, https://doi.org/10.1093/gji/ggad172.

Mao S. et al. (2022) - Space-time monitoring of groundwater fluctuations with passive seismic interferometry. Nat. Commun., 13(1), 4643, https://doi.org/10.1038/s41467-022-32194-3.

Vassallo M. et al. (2022) - Peak Frequency Changes From HV Spectral Ratios in Central Italy: Effects of Strong Motions and Seasonality Over 12 Years of Observations. J. Geophys. Res. Solid Earth, 127(5), e2021JB023848, https://doi.org/10.1029/2021JB023848.

Spatial and vertical variability of potentially toxic elements in urban soils of Milano Zone C

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Keywords: urban geochemistry, soil contamination, Milan and Swabi.

Urban soils represent important archives of long-term anthropogenic contamination, particularly within densely populated metropolitan environments (Scalenghe & Ajmone-Marsan, 2009). This study investigates the geochemical characteristics, source apportionment, and vertical distribution of potentially toxic elements (PTEs) in shallow (0-20 cm) and deep (35-50 cm) soil horizons of Milano Zone C, the area subjected to the city's strictest traffic restrictions.

Composite soil samples were collected using a systematic 500 × 500 m sampling grid and analyzed for granulometry, pH, and concentrations of Pb, Cr, Cu, Cd, Co, Ni, Fe, As, Mn, and Zn by ICP-MS following aqua regia digestion. The results reveal localized enrichment of Cd, Pb, Cu, and Zn in both shallow and deep horizons, with several concentrations exceeding the threshold values established by Italian legislation (D.Lgs. 152/2006). Background concentrations were estimated using cumulative distribution curves and subsequently applied to calculate Enrichment Factors (EFs).

Spatial analysis of EFs highlights distinct contamination hotspots, with the highest enrichment associated with Zn and Pb. Pollution Load Index (PLI) values indicate stronger contamination signals in deep horizons (0.65-3.26) compared to shallow soils (0.79-1.71), suggesting that deeper layers preserve historical contamination signatures, whereas surface soils mainly reflect ongoing urban processes. Principal Component Analysis (PCA) and geospatial mapping identify two dominant geochemical associations: (i) Cr, Ni, Co, Mn, and Fe, mainly linked to lithogenic contributions, and (ii) Pb, Zn, Cu, and Cd, associated with anthropogenic activities including traffic and urban emissions. Hazard Index (HI) assessment indicates potential non-carcinogenic risks, particularly in deeper horizons under conditions of soil disturbance or excavation.

The results demonstrate the importance of integrated urban soil characterization for evaluating environmental quality, reconstructing contamination history, and supporting sustainable urban planning and environmental risk management strategies in metropolitan areas.

Scalenghe R. & Ajmone-Marsan F. (2009) - The anthropogenic sealing of soils in urban areas. Landsc. Urban Plan., 90(1-2), 1-10.

S30.

Active and Capable Faults and Risk Reduction: New Perspectives on Seismic Hazard in the Apennines and Southern Alps after the 1976 Friuli Earthquake

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A multi-parametric approach to the analysis of a moderate magnitude earthquake sequence in the Southern Alps

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Keywords: seismic sequence, multiparametric space-time analysis, southern Alps.

The Southern Alps are characterized by the highest seismicity of the Alpine chain, being 1976 Friuli earthquake the most recent and with instrumental recording of a long series of strong-moderated events (Rovida et al., 2016). They have been formed by the action of several tectonic phases with different orientations of the principal stress axes, implying significant mechanical heterogeneities that influence the distribution of seismicity (Bressan et al., 2012).

This study investigates the spatio-temporal pattern of seismicity preceding the M_D 4.6 (coda-duration magnitude) event that occurred on 27 March 2024 and its aftershock sequence, located in the Carnic Alps, an area previously affected by many destructive historical earthquakes, including the 1794 I0=VIII-IX and Mw=6.0 earthquake (Rovida et al., 2016).

To investigate the features of seismicity in this area, we use a multi-parametric approach first applied by Bressan et al. (2021), which we consider particularly suitable for quantifying time variations in seismic activity within the context of rock damage mechanics. The novelty of this study is the application of the same multi-parametric approach to a single sequence, examining the space-time variation of the parameters in the three-year period preceding it.

We analyse changes in seismicity characteristics using the b-value; the Nearest Neighbour Distance (η), which measures the correlation between events; the fractal dimension, to quantify variation in clustering; and the Shannon entropy, to measure the level of disorder in the seismic energy distribution (Bressan et al., 2021). The b-value remains low until the beginning of 2023, when a positive trend is detected. Subsequently, a negative trend in the b-value is observed before the main shock, during which the η parameter also decreases. The time variation of Shannon entropy and fractal dimension both show higher values in the year preceding the main shock, and lower values in the months across the sequence, indicating a temporary ordering of the seismicity.

Furthermore, Principal Component Analysis is performed to infer the planes along which hypocentres tend to align and the direction in which they propagate over time. The PCA reveals two distinct temporal plane orientations before and during the sequence: the former is related to tectonic lineaments produced by past tectonic phases, and the latter is associated with the activation of vertical rupture planes triggered by the mainshock of the sequence. The latter reflects the upward propagation of aftershocks, favoured by decreasing overburden pressure and unclamping induced by positive normal stress changes caused by the mainshock.

Bressan G. et al. (2012) - Sequential integrated inversion of tomographic images and gravity data: an application to the Friuli area (North-Eastern Italy). Boll. Geof. Teor. Appl., 53, 191-212.

Bressan G. et al. (2021) - Anatomy of seismicity clustering from parametric space-time analysis. Phys. Earth and Planet. Int., 320, 192-214, https://doi.org/ 10.1016/j.pepi.2021.106787.

Rovida A. et al. (2016) - CPTI15, the 2015 version of the Parametric Catalogue of Italian Earthquakes. Istituto Nazionale di Geofisica e Vulcanologia, https://doi.org/10.6092/INGV.IT-CPTI15.

Earthquakes of the northeastern Italian border at the beginning of the 20th century

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Keywords: Friuli, historical earthquakes, early 20th cent.

We present the first results of a systematic revision of the seismicity along the northeastern Italian border at the beginning of the 20th century.

In the period 1900-1929, as documented in the Italian Parametric Earthquake Catalogue - CPTI15 (Rovida et al., 2022), 94 events with magnitudes ranging from 3.93 to 6.02 occurred along the northeastern Italian border.

Some of the most significant events of this period have been well studied, whereas others require further revision. Moreover, most moderate events lack macroseismic data. In fact, only 17 events are supported by macroseismic information, and not all of them have been validated through historical seismological studies. Conversely, most records from this period provide Mw values derived from early instrumental data, later reprocessed by studies conducted at different times.

This work aims to reassess the seismic activity along the northeastern Italian border during the period 1900-1929. It is important to note that this region was a primary theatre of conflict during the First World War, a conflict that resulted in significant alterations to the political landscape. The upheavals caused by the war constituted a major obstacle to the recording and preservation of seismological data during these years.

A thorough analysis was conducted on three distinct kinds of sources, namely newspapers, seismological literature, and archival documents: 1) Austrian, Croatian, and Slovenian newspapers are accessible through the digital archives of their respective National Libraries, while Italian newspapers are available through various digital library collections. 2) We thoroughly reviewed relevant issues of seismological and geophysical society publications. 3) In addition, we examined documents from the Macroseismic Archive of the National Institute of Geophysics and Volcanology, particularly seismic postcards.

Through the utilisation of the aforementioned sources, it is possible to enhance the Macroseismic Data Set and thereby achieve a more comprehensive picture of Italian seismicity.

Rovida A. et al. (2022) - Catalogo Parametrico dei Terremoti Italiani (CPTI15), versione 4.0 [Data set]. Istituto Nazionale di Geofisica e Vulcanologia (INGV), https://doi.org/10.13127/cpti/cpti15.4.

Antithetic faults and their role in active fault systems. Lessons from the Paganica fault system (L'Aquila, central Italy) for surface faulting hazard assessments

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Keywords: antithetic faults, surface faulting hazard, central Italy.

Antithetic faults are often sidelined as secondary features with limited surface-faulting potential. However, the recent seismic sequences in central Italy, since the 2009 M_W 6.3 L'Aquila earthquake generated by the Paganica Fault (PF), highlighted the need to re-evaluate the role of these structures, especially in terms of surface faulting hazards associated with these secondary structures.

This study presents new data from the Bazzano and Pianola-Bagno faults, two primary antithetic structures of the PF system.

The Bazzano fault, a NW-SE trending NE-dipping structure, exhibited discontinuous and debated co-seismic surface ruptures in 2009 of up to few cm on the main fault plane (EMERGEO Working Group, 2010). Our palaeoseismological trenching across its northern part revealed a 40 m-wide deformation zone with evidence of at least two recent activation events. The most recent one (post-15th century CE) produced a minimum 40-50 cm vertical offset. Given that the 2009 M_W 6.3 event only generated - if it was actually surface faulting - a few cm of throw on the southern portion of this splay, we attribute the palaeoseismic displacement to a significantly more energetic event, likely the 1703 M_W 6.7 earthquake, supporting the hypothesis of the rupture involving the Mt. Marine, Mt. Pettino, and Paganica systems (Moro et al., 2013 and references therein).

The Pianola-Bagno fault - the southern antithetic splay of the PF - shows clear evidence of Holocene activity (Maceroni, 2022). New chronological constraints on displaced deposits confirm the Holocene activity of the antithetic fault. Although the urban setting prevented paleoseismological trenching from directly intercepting the fault plane, electric resistivity tomography confirmed deep structural discontinuities, and the probable occurrence of post Roman-age liquefaction episodes.

These findings demonstrate that antithetic faults are relevant for Italian surface faulting hazard estimates, conforming what has been observed with the 2016 M_W 6.5 Central Italy earthquake, owing to which up to 80 cm surface faulting occurred along the San Lorenzo antithetic fault, and the Mt. Serra antithetic fault damaged the San Benedetto tunnel with a 20 cm offset. Secondary structural features represent a critical element for surface faulting hazard since empirical scaling relationships, such as those of Wells & Coppersmith (1994) are typically calibrated for master faults. The systematic integration of surface faulting data on secondary faults into hazard models is an essential opportunity to refine displacement estimates.

EMERGEO Working Group (2010) - Evidence for surface rupture associated with the Mw 6.3 L'Aquila earthquake sequence of April 2009 (central Italy). Terra Nova, 22, 43-51, https://doi.org/10.1111/j.1365-3121.2009.00915.x.

Maceroni D. (2022) - Cartografia prototipale di faglie attive e capaci in relazione alla distribuzione di sorgenti sismogenetiche. Tesi di Dottorato, Università degli Studi di Cassino e del Lazio Meridionale, https://hdl.handle.net/20.500.14242/168447.

Moro M. et al. (2013) - Historical earthquakes and variable kinematic behaviour of the 2009 L'Aquila seismic event (central Italy) causative fault, revealed by paleoseismological investigations. Tectonophysics, 583, 131-144, https://doi.org/10.1016/j.tecto.2012.10.036.

Wells D.L. & Coppersmith K.J. (1994) - New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement. B. Seismol. Soc. Am., 84(4), 974-1002, https://doi.org/10.1785/BSSA0840040974.

Detection and hazard assessment of active and capable faults in the Florence Urban Area (Italy)

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Keywords: active and capable faults, seismic hazard, geophysical investigations.

The NW-SE-oriented Firenze-Pistoia Basin (FPB) represents an intermontane tectonic depression within the Northern Apennines of Italy. Although the basin has experienced only moderate historical seismicity, with catalogues attributing a maximum magnitude of approximately Mw 5.5 to the 1895 event, its recent active tectonic architecture has not been characterized in comparable detail to adjacent basins that generated earthquakes exceeding Mw 6.0.

This study focuses on the southeastern FPB, encompassing Florence and its surroundings. We applied a multidisciplinary workflow integrating tectonic geomorphology from remote-sensing datasets, particularly high-resolution LiDAR**,** geological field surveys to verify morphotectonic signatures, and targeted geophysical imaging including electrical resistivity tomography (ERT) and high-resolution shallow seismic reflection profiling. The combined datasets effectively verified their structural significance in urban areas and resolved subtle tectonic features obscured by combined low slip rates, high depositional rates and anthropogenic landscape modification (Piccardi et al., 2025).

Results identified three NE-SW striking normal faults transverse to the basin, the Peretola, Scandicci, and Maiano faults, showing evidence of Holocene activity and capability. These structures segment the southeastern FPB master fault, historically mapped as a continuous normal fault system bounding the eastern basin margin. Consequently, the NW-SE-oriented fault system appears active only along discontinuous segments and should not be regarded as a single continuous seismic fault.

Among these structures, the Scandicci Fault is the most significant in terms of length, slip potential, and cumulative vertical displacement. Within the basin, we constrain a fault length of ~9 km and estimate a Late Quaternary slip rate of ~0.2 mm/year from observed morphotectonic offsets. Published empirical magnitude-rupture scaling relationships indicate that a fault of this length and slip rate could generate earthquakes of Mw ≥5.5.

These findings have direct implications for seismic- and surface-faulting hazard assessment and urban risk mitigation in the FPB, particularly for Florence. The recognition of multiple active normal-fault strands with Holocene activity, capability, and significant slip potential indicates that seismotectonic models should be updated to incorporate these faults, improving seismic microzonation, guiding urban planning and structural mitigation, and better protecting the basin's built heritage.

Piccardi L. et al. (2025) - An Integrated Remote Sensing and Near-Surface Geophysical Approach to Detect and Characterize Active and Capable Faults in the Urban Area of Florence (Italy). Remote Sens., 17, 2644, https://doi.org/10.3390/rs17152644.

Comparative analysis of coseismic effects along strike-slip faults: Evidence from Sichuan (China) and Central Italy

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Keywords: geohazard, strike-slip faults, coseismic effects.

In the frame of the MoU between ISPRA, Geological Survey of Italy and the China Geological Survey (CGS), several cooperation projects focused on geohazards have been carried out over the last ten years. Among them, here we present the results of an ongoing project focused on the characterization of earthquake-induced geological effects associated with strike-slip events in Sichuan (China) and Italy. This aims to promote the collection, integration, harmonisation, and joint interpretation of available datasets, including inventories of capable faults, seismogenic structures, detailed mapping of primary and secondary coseismic effects, and morphotectonic indicators of active deformation. The collection and integration of different datasets will benefit from the well-structured Italian inventories of ITHACA and the EEE Catalogue, facilitating their harmonisation within a common framework and helping define empirical scaling relationships between the distinct geological and tectonic settings of China and Italy.

Initial field surveys in the Sichuan region led to the selection of three major strike-slip earthquakes along the main faults of the Xianshuihe fault zone: one historical event (the 1786 Mw 7.75 Moxi earthquake) and two recent events (the 1955 Mw 7.5 Kangding earthquake and the 2022 Mw 6.8 Luding earthquake). For these events, data on coseismic environmental effects were collected, enabling the assessment of seismic intensity using the ESI 2007 scale, based only on environmental effects.

Successively, we focused on the analysis of river-valley hazard chains, in which coseismic surface deformation and secondary effects interact with fluvial systems to generate cascading effects. These include river obstruction, transient or persistent damming, upstream inundation, downstream hydrological perturbations, and dam-break floods, which are particularly relevant in China. For example, a large landslide triggered by the 1786 earthquake dammed the Dadu River. Ten days later, sudden dam failure triggered catastrophic downstream flooding, with more than 100,000 fatalities. Such processes highlight a key interface between tectonics and surface processes, where primary rupture effects propagate into complex secondary hazard cascades with major implications for infrastructure and population safety.

Although Italy does not host active strike-slip fault systems with a seismic potential comparable to those identified in China, some of them deserve attention. Joint field surveys will be conducted in Italy in the Gargano area along the Mattinata Fault and on the eastern flank of Mount Etna, focusing on the Pernicana Fault.

Through this collaboration, ISPRA and CGS will promote the development of scenario-based modelling frameworks and integrated datasets that support comparative analyses of fault behaviour, reinforcing the importance of international cooperation in advancing earthquake hazard and risk mitigation at regional and global scales.

Local seismic response of intermontane basins under complex geological conditions: The Cassino Plain case study

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Keywords: local seismic response, seismic hazards, Cassino Basin.

Geological models are fundamental for an accurate seismic risk assessment, particularly in complex geological settings such as the Cassino Plain, an intermontane basin in central Italy characterised by significant seismic hazard and a high population density. The study presented here involves comprehensive geophysical, geological, hydrogeological and geotechnical analyses, combining borehole data, seismic ambient noise measurements, and advanced geostatistical techniques to delineate the bedrock's morphology and reconstruct a geological reference model.

The Cassino Plain, formed during Pliocene-Pleistocene tectonic activity, features a complex horst-and-graben arrangement with varying thicknesses of Quaternary alluvial sediments resting on carbonate and arenaceous bedrock (Saroli et al., 2020). During the past, the Cassino Basin has experienced severe seismic events with historical and instrumental data indicating macroseismic intensities reaching grade 9, highlighting the need for precise identification of the seismic bedrock to evaluate local amplification. Furthermore, the Atina-San Pietro Infine fault plays an essential role in the seismotectonic of the area, acting as a local source of potentially strong earthquakes, as it is considered active, with evidence of activity extending into the Upper Pleistocene-Holocene (Saroli & Moro, 2012).

A high-resolution 3D bedrock model of the Cassino Plain was reconstructed, integrating data from nearly 400 boreholes (reaching depths of 350 m b.g.l.) and over 260 seismic ambient noise measurements. By applying the Horizontal-to-Vertical Spectral Ratio technique, significant impedance contrasts were identified, and resonance frequencies were mapped, which correlated strongly with borehole-derived bedrock depths. Through advanced geostatistical interpolation and empirical frequency-thickness relationships, the study defines the seismic bedrock topography and sediment thickness. Furthermore, the Quaternary infill beneath the city centre was classified into four distinct lithological layers with specific geotechnical properties, and two primary aquifers were identified.

A seismic stratigraphic model was developed based on detailed geological cross-sections to simulate the basin's dynamic behaviour. Six seismic profiles were reconstructed and utilised for six 2D numerical simulations and 117 1D local seismic response analyses. The results were compared with the area's geological settings, and better correspondence between the 2D analyses was confirmed. A comparison was also performed with the results of the Level 3 Seismic Microzonation studies conducted in 1D mode on 4 seismostatigraphic vertical profiles; in this case, the 2D numerical simulations show better correspondence with the complex geological conditions of the Cassino Basin.

The proposed approach demonstrates the value of multidisciplinary geological modelling in reducing uncertainties and seismic risk in complex geological settings.

Saroli M. & Moro M. (2012) - San Pietro Infine Basin. Field-trip guidebook. In: the 16th Joint Geomorphological Meeting, 1-5 July, 2012, Rome.

Saroli M. et al. (2020) - Insights into bedrock paleomorphology and linear dynamic soil properties of the Cassino intermontane basin (Central Italy). Eng. Geol., 264, 105333, https://doi.org/10.1016/j.enggeo.2019.105333.

Paleoseismological insights into the Late Quaternary to historical activity along the outer thrust front of the eastern Southern Alps (Polcenigo, NE Italy)

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Keywords: microzonation, paleoseismology, Col Longone fault.

To better constrain the recent activity of the thrust systems propagating toward the Friuli Plain (NE Italy), this study integrates new geological and paleoseismological data acquired from the Pliocene-Quaternary front of the eastern Southern Alps (ESA). Investigations focused on the Polcenigo area, situated at the western boundary of the Carnic Prealps, which are defined by a system of arched SW-NE to WSW-ENE-trending, S-verging active thrusts (Poli et al., 2015).

The area is characterized by moderate to high seismic hazard and risk and has experienced several historical earthquakes with Mw ≥ 6, including the 1873 Alpago (Imax = X MCS and Mw = 6.3) and the 1936 Cansiglio (Imax = VIII MCS and Mw = 6.1) earthquakes (Rovida et al., 2022). Notably, Galadini et al. (2005) associated the Alpago event with the Polcenigo-Montereale seismogenic source and the Cansiglio event with the Cansiglio source.

Within the framework of the third-level Caneva-Polcenigo Seismic Microzonation Project, paleoseismological investigations were conducted along the Col Longone Fault. In the study area, this structure marks the tectonic contact between the Mesozoic carbonate succession and the Upper Miocene-Pliocene Molasse, with its Late Quaternary tectonic activity documented by displaced pre-LGM conglomerates (Poli et al., 2015). A trench, excavated across the boundary between the LGM Coltura fan slope deposits and the Upper Miocene-Pliocene Molasse of the Col del Cao hill, exposed a sharp tectonic contact between the sub-horizontal Lower Molasse (Cavanella Group, Lower-Middle Miocene) in the NW sector of the trench, and the sub-vertical Upper Molasse (Conegliano Unit, Pliocene) in the SE sector. This structure is consistent with the Col Longone fault, interpreted both as the transpressive left-lateral closure of the Caneva-Cansiglio thrust (dipping 280/65) (Galadini et al., 2005) and as a transfer zone connecting the Caneva-Cansiglio and the Polcenigo-Montereale thrusts (Monegato et al., 2023). The fault deformation extends into the uppermost trench units dated between the 17th and 19th centuries AD, suggesting that the co-seismic effects of a historical earthquake may have been recorded in the trench stratigraphy.

These results provide new evidence of Late Quaternary to historical activity along the outer ESA thrust front. Furthermore, they emphasize the seismogenic potential of the tectonic structures at the prealpine piedmont plain, carrying important implications for seismic hazard assessment in the Friuli Plain.

Galadini F. et al. (2005) - Seismogenic sources potentially responsible for earthquakes with M ≥ 6 in the eastern Southern Alps (Thiene-Udine sector, NE Italy). Geophys. J. Int., 161(3), 739-762, https://doi.org/10.1111/j.1365-246X.2005.02571.x.

Monegato G. et al. (2023) - LGM glacial and glaciofluvial environments in a tectonically active area (southeastern Alps). Geol. Field Trips Maps, 15 (2.2), 1-50, https://doi.org/10.3301/GFT.2023.07.

Poli M.E. et al. (2015) - D6/a2.1-Seismotectonic characterization of the western Carnic pre-alpine area between Caneva and Meduno (NE Italy, Friuli). DPC-INGV-S1 Project "Base-knowledge improvement for assessing the seismogenic potential of Italy."

Rovida A. et al. (2022) - Catalogo Parametrico dei Terremoti Italiani (CPTI15), versione 4.0. Istituto Nazionale di Geofisica e Vulcanologia (INGV), https://doi.org/10.13127/cpti/cpti15.4.

Active and capable faults in anthropized settings: Revising avoidance zones criteria through comparative scarp analysis and paleoseismology along the Mt. Marine fault system (Upper Aterno Valley - Central Apennines)

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Keywords: fault scarps, paleoseismology, seismic microzonation.

Rupture hazard assessment in densely anthropized areas of the central Apennines requires methodologies that can recognize and quantify fault scarps even where the original morphological signature has been deeply modified by agricultural activity, urbanization, and recent erosional/depositional processes. This work presents an integrated morphotectonic analysis of the south-western dipping Mt. Marine normal fault system (Upper Aterno Valley, central Apennines), to which the historical earthquake of 2 February 1703 (Mw ≈ 6.7) is attributed. The available scientific literature documents the presence of fault splays, generally in tectonic contact with Late Quaternary alluvial and slope deposits in the hanging wall of the main fault plane, which is not always observable in outcrop and is located within a large, strongly cataclastic deformation zone. The deposits preserved as deformation and coseismic scarps within the covering soils highlight fault activity in very recent times, yielding a minimum fault-slip rate of 0.25-0.43 mm/a throughout the system (Galli et al., 2011; Moro et al., 2016).

The study focuses on these active and capable faults in a ~3.5 km-long sector near the village of Pizzoli (L'Aquila) and is based on a high-resolution LiDAR DEM on which 215 topographic profiles were drawn across 28 candidate fault scarps. The analysis followed a multiscale approach (100-, 500-, and 1000-m-long profiles) and is combined with the semi-automatic SPARTA tool (Hodge et al., 2019) to estimate scarp height, width, and slope.

Of the 28 candidate scarps, 15 were confirmed as tectonic, 8 were reclassified as anthropogenic, and 4 were relocated. The along-strike throw distribution highlights a systematic partitioning of deformation: mountainward splays, developed on the carbonate bedrock, accommodate the larger offsets (up to 19-20 m on Upper Pleistocene deposits), whereas basinward splays, i.e., toward the Aterno valley, show offsets of 2-5 m involving Upper Pleistocene-Holocene deposits. Comparison with SPARTA yields a moderate positive correlation, confirming the usefulness of the automated approach for simple scarps and its limitations in zones of distributed deformation.

The results were finally compared with published paleoseismological data (Iezzi et al., 2023 , and references therein) for the area, where the trenches validate the morphotectonic classification and identify, in the Vallicella-Collemusino sector, a residual epistemic-uncertainty class, in which high Holocene aggradation and anthropogenic reworking completely mask active splays. The results suggest how the avoidance zones defined by the Italian Guidelines for Active and Capable Faults should be extended to the entire deformation area (≈500 m across-strike) and must necessarily integrate geophysical and paleoseismological investigations in anthropized contexts.

Galli P. et al. (2011) - Peleoseismology of the L'Aquila faults (central Italy, 2009, MW 6.3 earthquake): implications for active fault linkage. Geophys. J. Int., 187, 1119-1134, https://doi.org/10.1111/j.1365-246X.2011.05233.x.

Hodge M. et al. (2019) - A semi-automated algorithm to quantify scarp morphology (SPARTA): Application to normal faults in southern Malawi. Solid Earth, 10(1), 27-57.

Iezzi F. et al. (2023) - Slip localization on multiple fault splays accommodating distributed deformation across normal fault complexities. Tectonophysics, 868, 230075, https://doi.org/10.1016/j.tecto.2023.230075.

Moro M. et al. (2016) - New paleoseismic data across the Mt. Marine Fault between the 2016 Amatrice and 2009 L'Aquila seismic sequences (central Apennines). Ann. Geophys., 59, fast track 5, https://doi.org/10.4401/ag-7260.

Geological and geodetic study of the seismically active Belice Valley area (southwestern Sicily)

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Keywords: active tectonics, GNSS, seismogenic structures.

The study area is located in the SW sector of Sicily, identified as the outermost front of the Sicilian fold and thrust belt, with southward vergence. In particular, the research focuses on the Belice Valley. Although tectonic deformation is active in this sector, the low frequency of seismic events, combined with the predominantly clayey lithology of the outcropping rocks, complicates the understanding of the ongoing seismotectonic pattern. The most relevant seismic events striking the area include the one in Selinunte between 370 BC and 600 AD, the one near the town of Sciacca in 1578 (M≥5), and the 1968 seismic swarm in the Belice Valley (Guidoboni et al., 2002). Although the latter is considered the most violent earthquake in this sector, the available seismological and geological data do not allow for the identification of specific seismogenic structures. Therefore, the scientific debate regarding the possible seismogenic source responsible for the earthquake sequence, its geometry, and its kinematics remains open. Focal mechanisms do not provide unambiguous solutions, showing variations from pure strike-slip to pure reverse (Barreca, 2014; Orecchio et al., 2021). The area includes the Belice Basin to the north and the Menfi Basin to the south, separated by the NO-SE oriented ridge of M. Magaggiaro, composed of Meso-Cenozoic carbonates. To the north, the Belice Basin, that consists of Messinian-Lower Pliocene deposits and clays dated to the Upper Pliocene-Lower Pleistocene, is bounded by the Poggioreale ridge, whereas the Menfi Basin, that continues offshore in the Sicily Channel. Given these still unresolved uncertainties, an additional contribution to the understanding of the sector was planned through geodetic studies. A new geodetic network was installed, consisting of 23 benchmarks covering a WNW-ESE elongated area, crossing the main tectonic structures recognized in the literature. To increase the resolution of the deformation field over a wide area around the study zone, benchmarks of the geodetic network of the IGM were also re-occupied, for which high-quality GNSS measurements over the last 30 years are available. Benchmarks previously installed by other institutions within the study area were also re-surveyed, and data from available permanent GNSS stations were used. The acquired data will be integrated with information from geological-structural surveys to correlate possible current deformation patterns with neo-tectonic structures recognized in the field.

Barreca G. (2014) - Geological-structural outlines of the southern Madonie Mts. (Central Northern Sicily). J. Maps, 11(3), 432-443, http://dx.doi.org/10.1080/17445647.2014.977972.

Guidoboni E. et al. (2002) - A case study in archaeo-seismology. The collapses of the Selinunte Temples (Southwestern Sicily): two earthquakes identified. Bull. Seismol. Soc. Am., 92, 2961-2982.

Orecchio B. et al. (2021) - New Results for the 1968 Belice, South Italy, Seismic Sequence: Solving the Long- Lasting Ambiguity on Causative Source. Seismol. Res. Lett., 92, 2364-2381, https://doi.org/10.1785/0220200277.

Beyond standard site classification: Investigating unexpected seismic amplification at Monteluco di Roio Mountain, central Italy

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Keywords: local seismic response, 2D numerical simulation, in-bedrock structure role.

Current seismic regulations and territorial planning often rely on the assumption that rocky bedrock (Vs > 800 m/s) acts as a stable substrate, providing negligible local amplification. However, the severe damage observed in reinforced concrete structures during the 2009 L'Aquila earthquake at the Monteluco di Roio mountain (MRM) contradicts this paradigm. This research examines the geological drivers behind such anomalous seismic responses, moving beyond traditional 1D stratigraphic assessments to explore the role of complex 2D in-bedrock geometries.

By employing a series of numerical simulations conducted by use of LSR2D code across diverse scenarios, we isolated the specific effects of hill topography, weathered regolith, and internal geological discontinuities. Our findings demonstrate that while topographic features and thin surface layers have a marginal impact limited primarily to high-frequency ranges, the deep-seated internal structure of the carbonate basement is the primary source of amplification, where the spatial interaction between tilted strata and sub-vertical faults produces a significant broad-band response (2-14 Hz).

This evidence is congruent with previous experimental investigations conducted by Durante et al. (2017), who identified significant spectral ratios (SSR and HVSR) in the same frequency range (2-14 Hz) with a dominant peak at approximately 3 Hz. Our 2D numerical models successfully replicate these experimental results, showing that the amplification is not a localized surface phenomenon but is intrinsically linked to the deep geological architecture of the site. As a potential physical explanation for these recorded amplifications, we explored a model of geometric focusing (e.g., Motosaka & Nagano, 1996; Davis et al., 2000) through ray-tracing analysis. This interpretative hypothesis suggests that the convergence of refracted and direct seismic wave paths, induced by the specific velocity contrasts and dip angles of the internal bedrock layers, could lead to constructive interference and signal superposition.

This study highlights a critical warning regarding current seismic codes and safety assessments. The reliance on 1D models and the common practice of limiting geophysical investigations to the upper 30 meters (Vs30) may lead to an underestimation of seismic risk in complex orogenic environments. We demonstrate that internal bedrock discontinuities can generate unexpected site effects even where high-velocity materials outcrop, necessitating a shift toward more comprehensive 2D characterizations in territorial planning to ensure the resilience of the built environment.

Davis P.M. et al. (2000) - Northridge Earthquake Damage Caused by Geologic Focusing of Seismic Waves. Science, 289,1746-1750.

Durante F. et al. (2017) - A multidisciplinary approach to the seismic characterization of a mountain top (Monteluco, central Italy). Phys. Chem. Earth, 98, 119-135.

Motosaka M. & Nagano M. (1996) - Analysis of Ground-Motion Amplification Characteristics in Kobe City Considering a Deep Irregular Underground Structure Interpretation of Heavily Damaged Belt Zone during the 1995 Hyogo-ken Nanbu Earthquake. J. Phys. Earth, 44(5), 577-590.

Site amplification in North-East Italy: Empirical vs numerical estimates

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Keywords: site effects, amplification factors, empirical analyses.

The estimation of seismic site amplification at regional scale is a key challenge for hazard and risk assessment. In this study, we focus on the North-East Italy region, where a comprehensive dataset allows for a robust comparison between independent empirical approaches. Site amplification factors were derived using two complementary methods: (i) residual-based estimates (δS2S, Lanzano et al., 2025) obtained from ground-motion prediction models, and (ii) spectral amplification functions computed through the Generalized Inversion Technique (GIT, Andrews, 1986) applied to recorded earthquake data.

The site amplification factor (AF), adopted as a key parameter in this study and widely used in seismic microzonation, describes the average amplification level over three period intervals (ΔT_1 = [0.1-0.5] s, ΔT_2 = [0.4-0.8] s, ΔT_3 = [0.7-1.1] s), representative of the characteristic periods of the Italian building stock. The comparison, performed at 21 stations across the region, shows a remarkably high level of consistency between the two approaches. Spearman's correlation coefficients exceed 0.9 for all the considered period bands, indicating that both methods capture coherent amplification patterns among sites.

To further investigate the reliability of simplified modeling strategies, empirical estimates (in terms of δS2S) are compared with amplification factors derived from 1D numerical simulations recently developed for the Italian territory (Falcone et al., 2021). The analyses indicate that 1D simulations fail to reproduce the full variability of observed amplification, which spans a significantly wider range. This discrepancy is primarily attributed to the inability of 1D approaches to account for complex site effects, such as 2D/3D wave propagation, basin effects, and local geological heterogeneities. In particular, 1D simulations tend to overestimate amplification at rock and stiff sites and underestimate it in softer or structurally complex environments. These results are consistent with those obtained within a broader research framework on site amplification at the national scale, which highlights the limitations of simplified numerical approaches when compared with empirical observations.

These findings indicate that empirical approaches provide reliable and consistent estimates of site amplification at regional scale, while simplified 1D simulations may fail to capture its full variability, especially in complex settings. As a consequence, empirical site amplification estimates should be prioritized for regional applications, supported by suitable proxies to ensure spatial extrapolation, whereas numerical simulations require careful validation and integration with observations.

Andrews D.J. (1986) - Objective determination of source parameters and similarity of earthquakes of different size. In: Das S., Boatwright J., Scholz C.H. (Eds), Earthquake Source Mechanics, Geophysical Monograph Series, American Geophysical Union, Washington, D.C., 37, 259-267, https://doi.org/10.1029/GM037p0259.

Falcone G. et al. (2021) - Seismic amplification maps of Italy based on site-specific microzonation dataset and one-dimensional numerical approach. Eng. Geol., 289, 106170, https://doi.org/10.1016/j.enggeo.2021.106170.

Lanzano G. et al. (2025) - Estimation of the seismic microzonation amplification factors from the GMMs site-to-site residuals: an application to the Italian strong-motion stations in ITACA 4.0. Bull. Earthq. Eng., 23, 5229-5257, https://doi.org/10.1007/s10518-025-02249-z.

Multiscale fault geometry and slip-rate consistency in the Northern Matese Fault System (Southern Apennines): Implications for seismic hazard assessment

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Keywords: active faults, structural geology.

Fault slip-rates are key parameters for characterizing regional deformation patterns and assessing fault-based seismic hazard. However, slip-rates commonly vary across timescales and depend on the spatial resolution and temporal scale of the applied method. Reconciling these discrepancies is essential to understand how faults accommodate deformation through time. Here, we apply a multidisciplinary, multi-timescale approach to the Northern Matese Fault System (Southern Apennines, Italy) to quantify slip-rate variability and improve the reliability of slip-rate constraints. We combine geological mapping, postglacial fault scarp analysis, geophysical imaging, paleoseismological trenching and geodetic data to reconstruct the fault system geometry and to constrain fault throw-rates from geological to geodetic timescales.

Throw-rates measured over long-term (~500 ka), post-LGM (~15 ka), and geodetic (tens of years) timescales are mutually consistent, indicating persistent strain localization during the entire evolution of the fault system, despite small-scale fluctuations. This consistency implies that the Northern Matese Fault System accommodates deformation at a stable average rate over its lifetime, and that strain accumulation and release have occurred at comparable rates through time.

Our findings show that apparent discrepancies between slip-rates derived from individual methods may arise when rates are extrapolated beyond the spatial or temporal scales they directly sample. A multiscale approach helps to identify whether such discrepancies reflect persistent or transient variations in fault behavior, and to what extent slip-rate fluctuations can affect the long-term fault activity. When constrained at structurally representative locations, geological and geodetic slip-rates can be reconciled, providing a robust framework for evaluating fault activity and for selecting slip-rate estimates appropriate for specific tectonic or hazard-related applications.

Paleoseismic characterization of active and capable faults in the Rieti Basin (Central Apennines, Italy): Implications for seismic microzonation

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Keywords: active and capable faults, microzonation, Apennines.

The Rieti Basin (Central Apennines, Italy) is a fault-bounded intramontane depression characterized by an orthogonal system of Quaternary normal faults and documented historical seismicity. Despite this, the basin has long lacked a comprehensive paleoseismological framework suitable for identifying active and capable faults, a key requirement for Seismic Microzonation (SM) studies. This contribution presents the first basin-scale reconstruction of surface-faulting earthquakes over the last ~20 kyr, providing new constraints for the identification and characterization of seismogenic fault sources.

Investigations focused on the northern, eastern, and southern basin-bounding fault zones and followed an integrated approach consistent with SM guidelines. High-resolution geophysical surveys, including electrical resistivity tomography and ground-penetrating radar, were combined with extensive paleoseismological trenching. A total of 17 trenches were excavated, 13 of which yielded clear stratigraphic evidence of surface faulting. Fifty-two radiocarbon samples were collected and calibrated using the IntCal20 curve, providing robust chronological constraints and enabling correlation with previously published datasets.

The paleoseismological record documents up to 15 surface-rupturing earthquakes over the last ~20 kyr. Seven events are sufficiently constrained to define recurrence patterns on a millennial timescale. The evidence indicates repeated activation of multiple fault segments, with some events involving rupture of the entire ~21 km-long Rieti Basin Fault, consistent with maximum expected magnitudes of about Mw 6.5. Spatiotemporal correlations suggest clustered earthquake sequences, with rupture commonly initiating along the eastern basin-bounding fault and subsequently propagating to the northern and/or southern faults.

These results demonstrate that the Rieti Basin hosts active and capable faults characterized by documented surface displacement, long recurrence intervals, and complex interaction patterns. The study provides essential input for Level 3 SM analyses, including fault-zone identification and fault-related hazard zoning, and highlights the key role of paleoseismology in supporting reliable seismic microzonation and land-use planning in intramontane basins.

Recent and active tectonics of the southern margin of Central High Atlas (southern Morocco)

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Keywords: active tectonics, high atlas, Morocco.

The Moroccan High Atlas is an intracontinental chain roughly trending ENE-WSW, developed since the Mesozoic as a consequence of Africa and Europe convergence. The chain is currently delimited by two complex fault systems, namely the Northern and the Southern Atlas Fault Systems (NAFS and SAFS, respectively). The widespread seismic activity indicates that deformation is still ongoing as the Mw 6.8, 8-9-2023 Al Houz earthquake suggests. Along the southern margin of the Central High Atlas the wide Ouarzazate basin, to the south-west and the ErRachidia - Boudenib basin to the NE, correspond to foreland area filled by Miocene-Pleistocene continental sediments. Moreover, widespread Late Pleistocene-Holocene terraced deposits cover older sediments. Previous works report dating of the terraced sediments, based on radiometric methods, and suggest that at least six orders of terraced surfaces developed since middle Pleistocene. Analysis of recent and active deformations are limited and local. The aim of this study is to fill this gap integrating structural data on the recent deformations with the available dating of sediments to suggest a possible reconstruction of the current state of stress of this sector of the High Atlas. We have extended the analysis of terraces in the Ouarzazate Basin correlating to the whole basin the six orders of locally dated terraced sediments. For the Er Rachidia-Boudenib basin no dating is available. A preliminary morphotectonic analysis based on remote-sensing techniques was carried out with the aim of identifying areas where the more recent deposits filling the basins could have been involved in deformation. This preliminary analysis has revealed many points of interest that were controlled through field studies, confirming the presence of widespread deformation involving all the terraced sediments and locally the Holocene first order terraced surface. The structures mainly consist of open folds, locally overturned, and reverse faults that in general correspond to structures affecting Miocene - Pliocene basin fill succession and likely emanate from the deeper Mesozoic succession. The structures show a general ENE-WSW trend, that is roughly subparallel to the SAFS. The work has been further integrated with the analysis of seismicity of both the High Atlas chain and the Ouarzazate and Er Rachidia - Boudenib basins, compiling a seismotectonic map of the area reporting a tentative relative dating of the detected structures.

New data on active fault segmentation in the L'Aquila basin: A seismotectonic and surface faulting hazard perspective

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Keywords: active and capable fault, central Apennines, seismic microzonation.

This study focuses on active and capable faulting in the L'Aquila basin area. Capable faulting, that is the ability of active faults to rupture the ground surface, is a primary earthquake-related geological hazard. After the April 6, 2009, earthquake, which produced surface faulting along the causative Paganica Fault (PF), guidelines for managing territories affected by active and capable faults were introduced (Commissione Tecnica, 2015). Besides the PF, other normal faults strands NW-SE striking and SW dipping, controlled the Quaternary evolution of the basin. One of these structures is known as the Pettino active fault (PeF). Previous paleoseismological investigations documented Holocene activity of the PeF (Galli et al., 2011). Our new investigations focus on this tectonic structure, specifically on its northern and possibly southern sectors. The northern sector affected the southeastern slope of Caliglio Hill, in the San Vittorino village area. Our geological and paleoseismological investigations confirm the late Quaternary activity of the PeF. In particular, we first found evidence of activation of the PeF segment during the last millennium.

The southern sector of the PeF outcrops N of the L'Aquila city. The possible prolongation towards the SE of the fault trace was supposed by previous studies to affect the northern sector of the L'Aquila town, supposedly responsible for the displacement of the Middle Pleistocene L'Aquila breccias (Tallini et al., 2019 and references therein). The inferred fault trace could affect a sector of the town where several school buildings are also located. Therefore, assessing the presence and capability of the PeF in this part of L'Aquila was of particular relevance. Structural, geological, paleoseismological and geophysical analyses revealed no evidence of extensional faulting in the area where the fault branch had been hypothesised. Shear planes and faults affecting pre-Quaternary bedrock are exclusively associated with reverse and strike-slip faulting, related to a compressive and transpressive tectonic phase, currently inactive.

Overall, our study confirmed the late Holocene activity of the PeF and casts new light on the possibility that the PeF activated during the February 2 1703 seismic event (MW 6.7) (Rovida et al., 2022), together with other active fault strands, among wich the PF. Our study also cofirms the possibility that the active faults of the L'Aquila basin are able to produce both MW ~6 earthquakes, such as the 2009 one, with the activation of a single segment, as well as 6.5-7 earthquakes, as occurred on the, when the entire fault system was activated.

Commissione tecnica per la microzonazione sismica (2015) - Linee guida per la gestione del territorio in aree interessate da Faglie Attive e Capaci (FAC), versione 1.0, Conferenza delle Regioni e delle Province Autonome - Dipartimento della protezione civile, Roma.

Galli et al. (2011) - Palaeoseismology of the L'Aquila faults (central Italy, 2009, Mw 6.3 earthquake): implications for active fault linkage. Geophys. J. Int., 187, 1119-1134, https://doi.org/10.1111/j.1365-246X.2011.05233.x.

Rovida et al. (2022) - Italian Parametric Earthquake Catalogue (CPTI15), version 4.0. Istituto Nazionale di Geofisica e Vulcanologia (INGV), https://doi.org/10.13127/cpti/cpti15.4.

Tallini et al. (2019) - High-resolution seismic reflection exploration for evaluating the seismic hazard in a Plio-Quaternary intermontane basin (L'Aquila downtown, central Italy). Quat. Int., 532, 34-47, https://doi.org/10.1016/j.quaint.2019.09.016.

Seismic hazard assessment in Italy: Testing a new probabilistic model linking the seismic cycle to the dynamics of Adria and Apulia microplates

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Keywords: seismic cycle, Adria and Apulia microplates.

Most large earthquakes occur along tectonic plate margins, where relative plate motions fuel the slow, decade-to-century long loading and abrupt release of stress referred to as seismic cycle. The Mediterranean region comprises several microplates that accommodate the convergence between the African and Eurasian plates, including Adria and Apulia. The interactions of these microplates make Italy one of the most seismically active countries in the area, with significant events nucleating along seismogenic faults in the Apennines and Alps. Most models for seismic risk assessment are purely statistical and rely on observations gathered in the vicinity of known faults. This study aims at testing the feasibility of a novel approach for probabilistic assessment of seismic risk that relies on inferences of microplate motion-changes derived from Global Navigation Satellite Systems (GNSS) and observations gathered relatively far away from seismogenic faults.

The test revolves around the contemporary dynamics of the Adria and Apulia microplates: recent studies (Iaffaldano et al., 2022; Iaffaldano & Kalum, 2024) have linked changes in the motions of these microplates (inferred from publicly available GNSS position time-series) over periods of a decade or so to the interseismic phases of large earthquakes that have occurred along their margins. Specifically, these studies have shown that the torque-variations required to change the Adria and Apulia microplate motions in the years immediately before the 2009 L'Aquila and 2019 Durrës earthquakes, respectively, are compatible with those imparted to the microplates by stress variations preceding these seismic events.

On the basis of these results, here we set up a procedure that compares torque-variations required to justify observed changes of the motions of Adria and Apulia to torque-variations imparted to these microplates by putative interseismic stress variations along faults included in the Database of Individual Seismogenic Sources (DISS; Basili et al., 2008), which is a georeferenced repository of fully parameterised fault geometries. This comparison aims at assigning to each DISS element a probability that it is the most-likely current source of the torque-variation responsible for the observed microplate motion change, and thus that it is the most-likely one to feature ongoing, significant temporal variations of interseismic stress.

Basili R. et al. (2008) - The Database of Individual Seismogenic Sources (DISS), version 3: Summarizing 20 years of research on Italy's earthquake geology. Tectonophysics, 453(1-4), 20-43, https://doi.org/10.1016/j.tecto.2007.04.014.

Iaffaldano G. & Kalum W.K. (2024) - Variations of whole-Adria microplate motion during the interseismic phase preceding the MW 6.3, 6 April 2009 L'Aquila (Italy) earthquake. J. Geophys. Res. Solid Earth, 129, e2023JB028245, https://doi.org/10.1029/2023JB028245.

Iaffaldano G. et al. (2022) - Decadal change of the Apulia microplate motion preceding the MW 6.4, 26 November 2019 Durrës (Albania) earthquake. Earth Planet. Sci. Lett., 584, 117505, https://doi.org/10.1016/j.epsl.2022.117505.

Seismotectonic model of the epicentral area of the 1976 Friuli earthquake: The interplay between strike-slip fault systems and transpressive fronts controlling seismogenesis

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Keywords: seismotectonics, transpressive fault systems, eastern southern Alps.

The Friuli Venezia Giulia region (in north-eastern Italy) is one of the areas with the highest seismic hazard in the country. Located at the northeastern edge of the Adria microplate, the study area represents the junction between the SSE-verging polyphase thrust front of the eastern Southern Alps and NW-SE dextral strike-slip systems of the western Slovenia-eastern Friuli domain. It is currently affected by about N-S compression, with a shortening rate of about 2 mm/yr estimated from geodetic data (Serpelloni et al., 2022). In particular, eastern Friuli has been struck by four Mw>6 destructive earthquakes over the past 700 years: the 1348 Mw 6.6 earthquake, the 1511 Mw 6.3 seismic event, and the May and September 1976 Friuli earthquakes (Mw 6.5 and 6.1, respectively).

Different seismotectonic interpretations have been proposed for the 1348 and 1511 historical events. Most studies agree on the activation of right-lateral strike-slip systems of western Slovenia and northern-eastern Friuli, while also assessing the involvement of south-verging transpressive fronts. Concerning the source mechanism for the 1976 strongest earthquakes, numerous models presented in the literature support the activation of low-angle, south-verging reverse planes with small strike-slip component (Slejko et al., 2018 and references therein), and the mainshock of May is referred to the Susans-Tricesimo source (Galadini et al., 2005).

In this work, we present the seismotectonic model of the 1976 epicentral area, developed through a multidisciplinary approach that integrates the 3D structural model with the distribution of seismicity recorded between May 1976 and December 1977. The aim is to relate the main tectonic structures to the most significant seismic events, and to assess how interaction between fault-systems with different kinematics controls seismogenesis in eastern Friuli. We elaborated the 3D structural model integrating subsurface data from ENI seismic lines with surface geological and morphotectonic data. We constructed a series of parallel sections across the main fault surfaces and we populated them with earthquake hypocenters of the 1976-1977 sequence. Coulomb stress change analysis was used to evaluate the role of interacting fault systems and their influence on stress distribution during the early stages of the sequence (Patricelli et al., 2022).

The presented seismotectonic model identifies the geometry of the active fault system of the area and define the crustal volume involved in the 1976 earthquakes, highlighting a transpressive kinematics. The results support the interpretation that the seismic sequence was controlled by the interaction between strike-slip fault systems propagating NW-ward in the Italian territory and inherited S-verging transpressive fronts, emphasizing the need for integrated approaches to improve the seismic hazard assessment and risk mitigation in the eastern Southern Alps.

Galadini F. et al. (2005) - Seismogenic sources potentially responsible for earthquakes with M > 6 in eastern Southern Alps (Thiene-Udine sector, NE Italy). Geophys. J. Int., 161, 739-762, https://doi.org/10.1111/j.1365-246X.2005.02571.x.

Patricelli G. et al. (2022) - Structural Complexity and Seismogenesis: The Role of the Transpressive Structures in the 1976 Friuli Earthquakes (Eastern Southern Alps, NE Italy). Geosci., 12, 227, https://doi.org/10.3390/geosciences12060227.

Serpelloni E. et al. (2022) - Surface Velocities and Strain-Rates in the Euro-Mediterranean Region From Massive GPS Data Processing. Front. Earth Sci., 10, 907897, https://doi.org/10.3389/feart.2022.907897.

Slejko D. (2018) - What science remains of the 1976 Friuli earthquake? Boll. Geof. Teor. Appl., 59(4), 327-350.

Spatiotemporal variations in b-value suggest an evolving mechanical state of the crust in the southeastern Alps

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Keywords: b-value, crustal strength evolution, seismic hazard.

Understanding whether and how the mechanical state of the crust evolves is a central challenge in intraplate regions. We investigate the southeastern Alps region by analyzing the frequency-magnitude distribution of ten years of seismicity (14776 earthquakes) with magnitudes in the range $0 \leq M_L \leq 4.5$. We analyze the spatio-temporal evolution of the b-value, a proxy for crustal stress and strength. Using the b-positive method and Singular Spectrum Analysis, we observe a persistent b-value decrease since 2020 in the Friuli region, which we interpret as evidence of the evolving stress state of the system towards crustal weakening. By linking b-value trends to the Hoek-Brown failure criterion, we interpret the crustal stress evolution in terms of rock mass disturbance. Our results suggest that, even under low loading rates, distinct crustal volumes may evolve differently over time, with some potentially approaching critical conditions while others remain stable. Whitin this framework, b-value variations may provide a physically grounded approach to monitor fault weakening and assess seismic hazard in slowly deforming continental regions.

Seismic energy from small earthquakes maps fault segmentation in the Southeastern Alps

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Keywords: earthquake, seismic risk, southern Alps.

Fault strength spatial variability controls how earthquakes initiate, propagate, and arrest, yet remains poorly resolved in complex tectonic settings. The southeastern Alps constitute one of the most seismically hazardous regions in Central Europe, with active fault systems, a history of damaging earthquakes, and ongoing tectonic deformation. We analyze more than 9,200 small-to-moderate earthquakes ($0 \leq M_L \leq 4.5$) recorded between 2016 and 2025 to image lateral variations in crustal stress using the Energy Index (EI), a moment-energy parameter sensitive to rupture efficiency. By extending the RAMONES framework to this region, we detect pronounced east-west contrasts in fault mechanical behavior: high EI values in the west mark zones of reduced frictional strength, whereas low EI in the east suggests mechanically stronger, segmented fault domains. These spatial patterns align with independent geophysical indicators (V_P/V_S, Q_p), indicating a strong link between mechanical segmentation, material properties, and permeability structure. Our results demonstrate that small earthquakes carry diagnostic signatures of fault-zone strength and segmentation, providing a scalable tool to resolve stress heterogeneity and refine seismic hazard models in structurally complex regions.

Friuli 1976: A story map tells the stories of a community reborn

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Keywords: storymaps, map tour, earthquakes stories.

On May 6, 1976, at 9:00 pm, Friuli was struck by a ML 6.5 (Mw 6.5) earthquake, representing the most powerful seismic event recorded in Northern Italy during the instrumental era. Fifty years after those tragic events, INGV and OGS have released the story map titled: "That night, a single piece of news. Friuli 1976: stories of a community reborn" (https://arcg.is/1Gm5em1). Structured into five chapters, the story map illustrates the seismic sequence and the community's resilience through seismological analyses, historical cartography, archival imagery, videos and interactive maps.

The first chapter describes the seismic sequence that started with the event of May 6. This was the first Italian earthquake to be rigorously analyzed through extensive instrumental recordings. Following a period of relative seismic quiescence during the summer, the seismic activity resumed in September, culminating on the 15th with a ML 6.1 event. The seismic sequence had over 1200 earthquakes within the first year ending with the ML 5.2 event in September 1977 (Rebez et al., 2018). The second chapter illustrates the impact of the earthquakes. The mainshock reached a intensity of IX-X on the EMS-98 scale and was felt across a very large area, extending across Central and Northern Italy, as well as European countries (Tertulliani et al., 2018). Photographic evidence documenting the devastating effects on the towns of Friuli is organized within an interactive map (tour map) and also through a "before and after" comparative analysis.

The third chapter is dedicated to the emergency phase. From the very first hours, the role of journalists proved crucial. Furthermore, the collaboration between scientists from OGS and Messaggero Veneto gave rise to a pioneering form of data journalism (Carbonetto, 2018). The emergency in Friuli marked the end of the makeshift responses with the appointment of Parliament Giuseppe Zamberletti as Special Commissioner. His approach, known as the "Zamberletti Method", transformed local mayors into the "institutional heart" of emergency management.

The fourth chapter examines the reconstruction process through the "Friuli Model", summarized in the motto "where it was, as it was". In just ten years, Friuli rose again thanks to the implementation of new anti-seismic technologies and a philological respect for history. In less than a year, over 90% of the 450 affected businesses were fully operational again (Baiutti & Micelli, 2016). The final chapter explores how the people of Friuli processed the trauma by returning to ancestral myths: the earthquake was personified as the Orcolat, a mythological ogre or dragon. The poet Leonardo Zanier emerged as the voice of cultural resistance. Alongside folk and literary narratives, the chapter gathers the stories of many people, such as survivors and scientists, into an interactive map (tour map) featuring both text and multimedia interviews.

Baiutti G. & Micelli F. (2016) - Friuli-1976-2016: dalla ricostruzione a un nuovo modello di sviluppo, Forum editrice, Regione Friuli Venezia Giulia, 256 pp., ISBN:978-88-8420-951-1.

Carbonetto P. (2018) - The 1976 Friuli earthquake in the newsroom. Boll. Geofis. Teor. Appl., 59(4), 385-398, https://doi.org/10.4430/bgta0215.

Rebez A. et al. (2018) - Misunderstood "forecasts": two case histories from former Yugoslavia and Italy. Boll. Geofis. Teor. Appl., 59(4), 481-504, https://doi.org/10.4430/bgta0244.

Tertulliani A. et al. (2018) - The 6 May 1976 Friuli earthquake: re-evaluating and consolidating transnational macroseismic data. Boll. Geofis. Teor. Appl., 59(4), 417-444, https://doi.org/10.4430/bgta0234.

Is the Colle Villano North Thrust the possible causative source of the May 6th 1976 Friuli earthquake? Some consideration on geological, morphotectonic, geophysical and paleoseismological evidence

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Keywords: Friuli earthquake, seismogenic source, eastern southern Alps.

Located at the northeastern edge of the Adria microplate, where about N-S compression originates a shortening rate of about 2 mm/yr, the Friuli region is one of the most seismically active area in Italy. Here, a complex tectonic regime joins the SSE-verging polyphase thrust front of the eastern Southern Alps (Miocene to Present in age) with the Pliocene to Present NW-SE dextral strike-slip fault systems of the western Slovenia.

Over the past 700 years, some Mw≥6 destructive earthquakes affected central-eastern Friuli: the 1348 (Mw 6.6) Carinthia-Val Canale, the 1511 (Mw 6.3) Julian Prealps and the 1928 (Mw 6.0) Tolmezzo-Verzegnis earthquakes. In 1976, the Friuli region was hit again by two destructive earthquakes which caused a thousand of fatalities and a severe damage to many Friuli villages: the first on May the 6th (Mw6.5; Io9-10), and the second on September the 15th (Mw6; Io8-9).

Although the Friuli 1976 earthquakes could be considered the starting point for the modern seismological investigation in Italy (Slejko et al., 2018), the causative sources of the earthquakes (both May and September) are still under debate. In particular for the first mainshock, different interpretations were proposed: the Gemona Kobarid reverse fault (Pondrelli et al., 2001); the Bernadia-Buia-Tricesimo Thrust (Aoudia et al., 2000), the Susans Tricesimo Thrust (Galadini et al., 2005).

In this work we show some evidence of recent deformation along the Colle Villano North (CVN) thrust, a WNW-ESE trending, S- verging splay of the Susans Tricesimo thrust-system: the results of geological, morphotectonic, geophysical and paleoseismological investigation, made it possible to believe that the CVN can be the causative source of the 1976 May the 6th.

Aoudia A. et al. (2000) - The 1976 Friuli (NE Italy) thrust faulting earthquake: a reappraisal 23 years later. Geoph. Res. Lett., 27, 573-576.

Galadini F. et al. (2005) - Seismogenic sources potentially responsible for earthquakes with M > 6 in eastern Southern Alps (Thiene-Udine sector, NE Italy). Geophys. J. Int., 161, 739-762, https://doi.org/10.1111/j.1365-246X.2005.02571.x.

Pondrelli S. et al. (2001) - Seismotectonic re-evaluation of the 1976 Friuli, Italy, seismic sequence. J. Seismol., 5, 73-83.

Slejko D. (2018) - What science remains of the 1976 Friuli earthquake? Boll. Geofis. Teor. Appl., 59(4), 327-350.

A combined structural, geomechanical, and passive seismic approach to assess fracture-driven site effects along an active normal fault zone (Mt. Morrone Fault, Central Apennines)

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Keywords: near-fault fracture characterization, amplification effects on MS study.

In this study, we present the results of a multidisciplinary investigation aimed at characterizing fault-zone site effects along the Mt. Morrone fault system, a major Quaternary normal fault bounding the eastern margin of the Sulmona intramontane basin (Central Apennines, Italy).

A passive seismic survey was conducted at four sites located along the central sector of the fault (Roccacasale and Sulmona). The selected sites are structurally located within the fault core and damage zone, across both the footwall and hanging wall blocks of the Mt. Morrone fault system, which is characterized by intense deformation and pervasive fracturing. Ambient noise data were acquired and processed using the Horizontal-to-Vertical Spectral Ratio (H/V) technique to investigate resonance frequencies and potential directional amplification effects. Where suitable reference conditions were identified, the data were further analyzed using the Standard Spectral Ratio (SSR) technique to provide a more robust estimate of relative amplification.

Geophysical observations were integrated with detailed structural and geomechanical field measurements. These include fault architecture mapping, fracture density and orientation analyses, and in-situ rock mass characterization through Schmidt hammer rebound measurements. The combined dataset highlights significant lateral variations in seismic response between the investigated sites, which can be directly related to the internal features of the fault zone, damage intensity, and rock mass stiffness. Directional amplification patterns observed in the H/V curves are consistent with the dominant orientation of fault-related discontinuities, suggesting a strong structural control on the local seismic response.

Our results align with previous studies documenting fault-controlled site effects and directional amplification within active fault zones in the Central Apennines (Pischiutta et al., 2017; Vignaroli et al., 2022; Pischiutta et al., 2023), and further emphasize the role of fault-core properties and damage-zone architecture in modulating seismic ground motion. Furthermore, they suggest that fault cores and associated damage zones should be treated as mechanically distinct domains, characterized by stiffness contrasts and velocity anisotropies capable of modifying the amplitude, frequency content, and directionality of seismic ground motion.

From an applied perspective, the multidisciplinary dataset presented here provides further evidence of the importance of correctly representing fault zones in two-dimensional subsurface models for numerical simulations of local seismic response. Explicitly considering the internal architecture of faulted rock masses, rather than assuming uniform "bedrock" conditions, can significantly improve ground motion modeling and help reduce uncertainties in seismic microzonation studies in tectonically active regions.

Pischiutta M. et al. (2017) - Structural control on the directional amplification of seismic noise (Campo Imperatore, central Italy). Earth Planet. Sci. Lett.., 471, 10-18, https://doi.org/10.1016/j.epsl.2017.04.017.

Pischiutta M. et al. (2023) - Directional Amplification at Rock Sites in Fault Damage Zones. Appl. Sci., 13, 6060, https://doi.org/10.3390/app13106060.

Vignaroli G. et al. (2022) - Middle Pleistocene fluid infiltration with 10-15 ka recurrence within the seismic cycle of the active Monte Morrone Fault System (central Apennines, Italy). Tectonophysics, 82, 229-269, https://doi.org/10.1016/j.tecto.2022.229269.

NITRO: A multiparametric near-fault observatory in Northeastern Italy

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Keywords: near fault observatory, earthquake-monitoring systems, southeastern Alps.

Within EPOS (European Plate Observing System), Near Fault Observatories (NFOs) constitute a distributed multidisciplinary infrastructure devoted to the integrated observation and long-term monitoring of active fault systems and earthquake processes. Situated in areas experiencing complex deformation and often located near densely populated regions, NFOs enable detailed monitoring of microseismicity, transient deformation and fault mechanics that regional networks cannot fully capture. Their limited geographic extent and well-constrained geological setting make them ideal for deploying dense, multidisciplinary sensor arrays and maintaining long-term observational strategies. NFOs aim to enhance understanding of earthquake nucleation, rupture propagation, and the structure of seismogenic faults. Achieving these goals requires continuous acquisition of high-quality, high-density, multi-parameter data combined with robust, standardized processing techniques. Fifty years after the 1976 Mw 6.5 Friuli earthquake, we present NITRO (Northeastern Italy Thrust Faults Observatory), a multidisciplinary geophysical observatory designed to monitor active faults. Northeastern Italy represents one of the most structurally intricate and seismically relevant regions in Europe. Located at the junction between the eastern Southern Alps and the external Dinarides, the area accommodates ongoing deformation associated with the convergence between the Adria microplate and the European plate. This tectonic setting is characterized by the coexistence of thrust, strike-slip, and transpressive fault systems, which interact over short spatial scales and generate heterogeneous patterns of seismicity. The 1976 Mw 6.5 Friuli earthquake sequence, along with historical events in 1348 and 1511, demonstrated the capability of these systems to produce damaging earthquakes affecting densely populated valleys and plains.

Through a dense network of seismic, geodetic, optical and geochemical instrumentation, the observatory seeks to improve understanding of seismicity patterns, fault geometries, crustal deformation, fluids and environmental parameters in the Southeastern Alps. A central objective is to integrate advanced machine-learning capabilities into operational workflows, fostering active collaboration with Regional Civil Defense and other key stakeholders. This approach will address long-term sustainability and governance challenges while supporting the development of resilient, innovative, and forward-looking earthquake-monitoring systems in Northeastern Italy.

Integrated assessment of surface faulting and paleoliquefaction in the Plio-Quaternary L'Aquila basin: Implications for seismic microzonation and seismotectonics of central Italy

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Keywords: surface faulting potential, paleoliquefaction, seismic microzonation.

Surface faulting and liquefaction are two critical earthquake-related phenomena that must be addressed in geological hazard assessments, particularly when siting or reconstructing strategic infrastructure. The former is directly linked to coseismic surface ruptures along active and capable faults, while the latter is triggered by seismic ground shaking, primarily affecting silty-sandy deposits with shallow water tables. This study presents the results of multi-methodological investigations conducted at Pagliare di Sassa site, west of L'Aquila within a Seismic Microzonation project granted by Abruzzo Region (Department of Government of the Territory and Environmental Policies-Risk Prevention Service of Civil Protection) and L'Aquila Municipality (Tallini et al., 2025). The primary goal was to evaluate a hypothesized active and capable fault at a site designated for the construction of a new school. By integrating geological and geomorphological fine-scale surveys, paleoseismological trenches, geophysical (ERT surveys and microtremor measurements), and borehole data, this research successfully ruled out the presence of this active and capable fault within the immediate school area. However, the investigation identified several soft-sediment deformation structures and sand dykes, interpreted as seismites resulting from two distinct earthquake-induced paleoliquefaction events. Through a combination of ceramic and radiocarbon dating, these paleoseismites were correlated with large magnitude earthquakes that struck the L'Aquila basin in historical times. The penultimate event was likely triggered by an earthquake originating from the Middle Aterno Valley-Subequana Valley fault system and constrained to the 2nd-1st century BC (Falcucci et al., 2011; Falcucci et al., 2015). The most recent event was likely triggered by an earthquake originating from the Upper Aterno Valley-Paganica fault system and constrained to the 4th-6th century AD (Moro et al., 2013). Identifying the likely date, seismogenic source, and magnitude of these events has contributed significantly to the broader understanding of the seismotectonic framework of central Italy. Ultimately, the assessment of these local seismic instabilities highlights the necessity of paleoseismological techniques as a best practice in urban planning. Such methodologies are invaluable for mitigating seismic risk and ensuring the safety of strategic buildings, such as schools, in seismically active regions.

Falcucci E. et al. (2011) - The 2009 L'Aquila earthquake (Italy): what's next in the region? Hints from stress diffusion analysis and normal fault activity. Earth Planet. Sci. Lett., 305 (3-4), 350-358, https://doi.org/10.1016/j.epsl.2011.03.016.

Falcucci E. et al. (2015) - Deep reaching versus vertically restricted Quaternary normal faults: implications on seismic potential assessment in tectonically active regions: lessons from the middle Aterno valley fault system, central Italy. Tectonophysics, 651, 186-198, https://doi.org/10.1016/j.tecto.2015.03.021.

Moro et al. (2013) - Historical earthquakes and variable kinematic behaviour of the 2009 L'Aquila seismic event (central Italy) causative fault, revealed by paleoseismological investigations. Tectonophysics, 583, 131-144, https://doi.org/10.1016/j.tecto.2012.10.036.

Tallini M. et al. (2025) - Multi-methodological approach for assessing surface faulting and paleoliquefaction history in central Italy: applicative implications for seismic microzonation studies in the Quaternary L'Aquila basin. Front. Earth Sci., Sec. Geohazards and Georisks, 13, https://doi.org/10.3389/feart.2025.1523730.

Seismotectonic framework and paleoseismological investigations of the Farneto-Roggiano Gravina Fault (Northern Calabria, Italy)

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Keywords: active and capable fault, paleoseismology.

This study presents a comprehensive seismotectonic characterization and paleoseismological assessment of the Farneto-Roggiano Gravina Fault, an active extensional structure located in northern Calabria (Crati Valley/Esaro River region). Constraining the behavior of this fault is crucial for evaluating the regional Fault Displacement Hazard (FDH) and understanding the deformation patterns of active extensional structures in the southern Apennines. The structural framework was reconstructed by integrating detailed geological and geomorphological mapping, geophysical analysis (ERT profiles), dating and Paleoseismology. This integrated approach identified a WNW-dipping normal fault displacing both the Pleistocene marine substratum (Serra dell'Ospedale Marine Conglomerates, VSR4) and the overlying continental deposits. To constrain long-term slip rates, Infrared Stimulated Luminescence (IRSL) was performed at the top of the VSR4 unit, yielding an age of 252.6 ± 28.1 ka. This result allows correlation of the summit pedogenized paleosurface (bn3) with the Marine Isotope Stage 7 (MIS 7, ~215 ka), providing a chronological marker for cumulative vertical displacement rates.

To assess recent activity and surface faulting capability, three paleoseismological trenches were excavated across the fault trace. Trench T1 exposed a sub-vertical main fault plane putting the VSR4 conglomerates into contact with Middle Pleistocene continental deposits, accompanied by secondary pseudo-reverse structures caused by near-surface fault refraction and colluvial-filled tension cracks. Trench T2 showed the main contact between the substratum and younger colluvial units (Middle Pleistocene), including fault related colluvial wedges. Trench T3 crosscut a 10-meter-high morphological fault scarp; at this site, an Electrical Resistivity Tomography (ERT) profile successfully imaged the subsurface continuation of the fault zone directly beneath the slope. Subsequent trenching confirmed that, although the fault is sealed by recent organic soils (~2500-2864 BCE), it clearly deforms the underlying Pleistocene-Holocene succession.

In conclusion, the paleoseismological investigations confirm that the Farneto-Roggiano Gravina Fault could be an active and capable structure. Although characterized by low slip rates and long recurrence intervals, the clear evidence of Middle-to-Late Pleistocene and Holocene surface faulting underscores the necessity of accounting for distributed and principal displacement in site-specific probabilistic fault displacement hazard analyses (PFDHA).

S31.

Understanding provenance, processing and decay of geomaterials in archaeological Heritage through mineralogy and petrography: from microscope and geochemistry to AI

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Crafting the Roman provinces: Ceramic technology in *Noricum* and *Regio X* (40 BC - AD 50)

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Keywords: Roman pottery, technology, Noricum and Regio X.

The Roman expansion into southern central Europe, a region that would later form the provinces of *Noricum* and *Regio X* (respectively present-day Austria and Slovenia), marked a period of profound political and socio-economic change. This seems to have gone hand in hand with the emergence of throwing coarse ware pottery on the fast wheel, a technological change made possible by the transfer of knowledge between craft communities.

This study investigates the technology of coarse ware tripod bowls, combining macroscopic observation of forming techniques with a materials science approach, including thin section petrography, stable isotope, X-ray powder diffraction (XRPD), and scanning electron microscope (SEM) analyses. A total of 60 tripod bowls from four sites are examined, including Magdalensberg and Gurina (in modern-day Austria), and Nauportus and Kranj (in modern-day Slovenia). These sites play an important role during the Roman expansion in the studied area, but fell into decline or disappeared completely by the middle of the 1st century AD.

The results of the macroscopic observations suggest that all tripod bowls are coil-built and finished on a rotating device. Most of these bowls are further defined by coarse, poorly sorted carbonate inclusions (e.g., sparry calcite, speleothems, marble) and a grey colour resulting from reducing firing conditions. Carbonate grains are further examined using stable isotope analysis and compared with data from the reference collection of the University of Padua (Maritan et al., 2021). Only a minority of the tripod bowls studied appear to be characterised by coarse sand inclusions. Comparison of all data with geological maps confirms that the analysed bowls might have been produced locally near the sites.

The findings of this study have two important implications: i) given the limited variation in the *chaîne opératoire* of the tripod bowls analysed, it seems plausible that potters in *Noricum* and *Regio X* shared knowledge about their technology; this suggests that pre-existing supra-regional organisational networks persisted during the Roman expansion; ii) however, the knowledge tranmission about coil-building tripod bowls appears to decline from the middle of the 1st century AD in favour of expertise in throwing them on the fast wheel (Borges et al., 2023) - something that seems to go hand in hand with the emergence of Roman monumental architecture at numerous settlements in the study area.

Borgers B. et al. (2023) - Production and Distribution of Greyware Tripod-bowls in the 1st and 2nd centuries AD Noricum (Austria). OAJAA,4(3), 1-10, https://doi.org/10.33552/OAJAA.MS.ID.000588.

Maritan L. et al. (2021) - What kind of calcite? Disclosing the origin of sparry calcite temper in ancient ceramics. J. Archaeol. Sci., 129, 105358, https://doi.org/10.1016/j.jas.2021.105358.

Using Digital Imaging Models for heritage stone decay quantification: the M3DEA approach

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Keywords: stone heritage, surface recession, 3D metrology.

Stone monuments transcend their role as physical structures, serving as tangible links to the artistic, technological, and social achievements of past civilizations. Today, anthropogenic climate change poses unprecedented challenges to their conservation, threatening both the material integrity of historic surfaces and the narratives they preserve.

The M3DEA project introduces an innovative diagnostic framework based on the Digital Imaging Model (DIM), a 3D imaging approach designed to quantify climate-driven deterioration across complex architectural surfaces. The methodology integrates: i) a comparative metrological analysis between high-resolution 3D reconstructions of original monuments and their historical replicas; and ii) laboratory aging tests on lithic samples engineered to simulate specific architectural elements and epigraphy. Trajan's Column (Rome, 113 AD) serves as the primary case study due to the exceptional availability of historical casts produced between the 16th and 19th centuries, which act as past chronological benchmarks. High-resolution structured light scanning was performed using an Artec3D Spider II scanner to detect micro-morphological changes on the original monument at the Parco Archeologico del Colosseo and on casts held at the Victoria & Albert Museum (London), Villa Medici (Rome), National History Museum of Romania (Bucharest), and Pinacoteca Ambrosiana (Milan). Preliminary 3D comparisons between the original surfaces and the casts reveal heterogenous recession levels, influenced by cardinal orientation and height-dependent environmental exposure.

To ensure broader applicability, M3DEA utilizes controlled environmental chambers to simulate climatic stressors (e.g. wet-dry cycles, acid rain, salt mist) on five representative Mediterranean carbonate rocks (Carrara, Sivec, and Red Verona marbles, Nanto stone, and Istrian stone). To assess how geometry influences decay, samples were modeled according to Vignola's The Five Orders of Architecture. Results (obtained through SEM, contactless optical profilometry, and 3D modeling) demonstrate that surface degradation processes and recession rates vary significantly based on the interplay between stone textural features and surface morphology.

By focusing on differential degradation and geometric complexity, M3DEA aims to quantify the loss of a monument's readability and legacy, establishing a new data-driven approach for assessing cultural heritage at risk.

This research is conducted within the framework of the M3DEA project, funded by the Marie Skłodowska-Curie Actions programme.

Beyond Magna Graecia: Insights on Technological Evolution in Ceramic Production from Medieval to Modern Age in Calabria Region (Southern Italy)

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Keywords: characterization, pottery, technology.

The Calabria region in southern Italy is famous for its past linked to the Magna Graecia Period and to the intense ceramic production with renowned stylistic and technological features. Nevertheless, also in the subsequent periods, Calabria continues to be not only a crucial productive centre but also a crossroad for trade routes. Three areas rich in ceramic finds and dislocated from the North to the South of the region were selected: Cleto (Cosenza), Soriano (Vibo Valentia), Bagnara (Reggio Calabria). The research aims to define the technological production processes, their evolution over time, and the probable provenance of the materials. Overall, 87 samples dated back between the XII and XIX centuries were considered. They consist of daily use polychrome, glazed, and sgraffito ceramics, such as tableware pottery. The samples underwent complementary archaeometric analyses, some still in progress. In this contribution, a polarising optical microscope (POM) and scanning electron microscopy (SEM) coupled with EDS microanalysis results were reported. POM and SEM-EDS provided, respectively, textural features and data on the morphological aspect of the microstructure and chemical composition of the ceramic body and glaze. The preliminary results indicate technological processes rather similar in all the samples: the use of a weakly marly clay as raw materials; predominant inclusions of granitoids and schists fragments comparable with the Palaeozoic basement outcropping widely in Calabria, suggesting a probable local provenance of the raw materials. In this regard, eight samples contain volcanic fragments that surely require further analytical insights. The glazes are often applied over a caolinitic engobe and are constituted mainly by silica and lead, and chromophore components such as CuO for blueish and greenish pigments, FeO for ochres and MnO for black and brownish colours (Ricca et al., 2019). Finally, some of the samples with volcanic inclusions show lead-silica glazes with the addition of SnO_2 as a probable opacifier. The research was carried out with the authorization by Superintendency of Archaeology, Fine Arts and Landscape of Calabria and funded by Research project Prin pnrr 2022, Calabria Unit (AI: A. Coscarella, F.C. Papparella; PI: C. Ebanista) TYPO project. Forms, Decorations and Production of Tyrrhenian Area Pottery from the Middle Ages to the Contemporary Age.

Ricca M. et al. (2019) - Archaeometric Characterisation of Decorated Pottery from the Archaeological Site of Villa dei Quintili (Rome, Italy): Preliminary Study. Geosci., 9(4), 172, https://doi.org/10.3390/geosciences9040172.

From marble to lime: Archaeometric and experimental investigation of historical lime production in Rorà, Waldensian Valleys, NW Italy

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Keywords: lime production, archaeometry, Waldensian Valleys.

The Waldensian Valleys of Piedmont, in the Dora-Maira Massif of the Cottian Alps, preserve a long history of carbonate raw-material exploitation, including ornamental marbles and rocks burnt for lime production. This contribution focuses on the carbonate lenses historically quarried around Rorà, where lime production represented a distinctive local activity, closely associated with the traditional identity of the *brusapère*, the "stone burners" of Rorà (Tourn & Zanella, 2003; Vola, 2025). The study aims at distinguishing these materials from the better-known ornamental marbles and associated lithotypes of the Waldensian Valleys and the Dora-Maira Massif (Sandrone et al., 2001; Vola et al., 2022; Vola, 2025), and to evaluate how mineralogical and petrographic features controlled their behaviour during lime burning. About twenty samples were collected from five quarrying and kiln-related sites: Fournais, Poza di Mort, Monte Volatia, Piccolo Tibet and Rio Fucine. The dataset includes carbonate rocks, slags and refractory fragments. The analytical protocol combines optical petrography, XRPD quantitative phase analysis by the Rietveld method, SEM-based mineral chemistry, WD-XRF/ICP-MS geochemistry, stable C-O isotope analysis, cathodoluminescence microscopy, and carbon speciation/TOC analysis. Selected samples were also submitted to laboratory calcination tests at 1050 and 1150°C, overburning tests at 1300°C, slaking tests and available lime index measurements. The studied rocks are mainly silicate-bearing dolomitic marbles and calcschists, with subordinate calcitic marbles. They are fine-grained, whitish to grey-yellowish or brownish, and display variable amounts of silicate impurities. Insoluble residues are low in most marbles but much higher in calcschists, reflecting marked lithological heterogeneity at deposit scale. This variability strongly affects firing behaviour: several dolomitic marbles show limited sticking tendency under overburning conditions, whereas impure calcschist-rich samples develop partial melting and cohesive agglomerates. Fragmentation during calcination is also highly variable and, in several samples, severe enough to compromise permeability in vertical kilns. Slaking behaviour confirms that dolomitic compositions and silicate impurities may delay hydration and produce heterogeneous lime products. The Rorà carbonate lenses therefore represent a distinct archaeometric and technological group within the Waldensian Valleys marbles. Unlike the Val Germanasca ornamental marbles, they were mainly exploited as local lime raw materials and show limited ornamental potential. The integration of mineralogical, petrographic, geochemical and experimental data provides a robust framework for reconstructing provenance, processing choices and technological constraints in historical lime production.

Sandrone R. et al. (2001) - La Pietra di Luserna. In: Alciati L. & Sandrone R. (Eds), Guida alle escursioni. Atti del Seminario Internazionale "Le Pietre Ornamentali della Montagna Europea", Luserna San Giovanni-Torre Pellice, 10-12 giugno 2001, 347-355.

Tourn G. & Zanella D. (2003) - Rorà. Il paese dei brusapere. Claudiana, 68 pp.

Vola G. et al. (2022) - Archaeometric characterization of historical-contemporaneous marbles from Waldensian Valleys of Piedmont. J. Archaeol. Sci. Rep., 45, 103562, https://doi.org/10.1016/j.jasrep.2022.103562.

Vola G. (2025) - La Pietra di Luserna. LAReditore, 330 pp.

Preliminary archaeometric characterization of ceramic materials from the Tamara mining area (Southwest Sardinia, Italy)

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Keywords: archaeometry, archaeometallurgy, Southwest Sardinia.

This contribution is framed within the 'Landscape Archaeology of Southwest Sardinia' (LASS) project, a research initiative focused on the implementation of non-invasive archaeological investigations in the Sulcis region (Southwest Sardinia, Italy) and working in close collaboration with the Pani Loriga Archaeological Mission (Murphy et al., 2019). The project adopts an integrated diachronic and multidisciplinary methodological approach aimed at reconstructing long-term patterns of landscape use, settlement organization, and resource exploitation, including extractive industries, forestry, and agricultural activities.

Among the investigated contexts, the Tamara mining district of Nuxis has yielded archaeological evidence not only of mining activities dating to the late 19th and early 20th centuries, but also of much earlier human occupation. Systematic surface survey campaigns documented a substantial assemblage of ceramic materials from prehistory to the Phoenician-Punic period, with a marked predominance of Bronze Age productions. Several ceramic fragments exhibit features potentially related to metallurgical processes, namely hearth / furnace fragment, vessels with litharge, vessels with copper prills, and severely burnt ceramics.

This contribution reports preliminary archaeometric data derived from an ongoing analytical investigation conducted on a selected group of ceramic samples. The research, carried out in collaboration between Florida State University and University of Catania, is aimed at the compositional and technological characterization of ceramic fabrics, raw materials, and possible surface metal residues associated with early mining and metal-processing activities at the site.

The analytical workflow integrates optical microscopy observations on thin sections, X-ray diffraction (XRD), X-ray fluorescence spectroscopy (XRF), Raman spectroscopy, and scanning electron microscopy coupled with microanalytical investigation (SEM-EDS). Preliminary results reveal significant compositional and technological variability within the ceramic assemblage and provide initial evidence indicative of metallurgical activities in the investigated area.

These data contribute to a more comprehensive understanding of the relationship between prehistoric settlement dynamics and mineral resource exploitation in Southwest Sardinia, while representing a preliminary step toward the reconstruction of technological practices and production processes associated with ancient mining landscapes.

Murphy E.A. et al. (2019) - The Landscape Archaeology of Southwest Sardinia Project: New data and method from the insular Mediterranean. J. Field Archaeol., 44(6), 367-82.

Integrated non-destructive methodologies for the geophysical and geomorphological characterisation of historical quarry fronts in the Punic necropolis of Tuvixeddu (Cagliari, Italy)

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Keywords: geoheritage, photogrammetry, historical quarries.

The Punic necropolis of Tuvixeddu, located in Cagliari, represents one of the most significant archaeological and geoheritage contexts of the Mediterranean region, where funerary structures coexist with historical extractive fronts exploited from the Punic age to the modern period (Careddu et al., 2025). These quarry landscapes constitute an important testimony to the long-lasting interaction between human activities, geomaterials, and landscape evolution, contributing to the territorial identity and cultural memory of the area.

This study focuses on the integrated characterization of one of the historical quarry fronts preserved within the Tuvixeddu site through the application of non-destructive and multi-scale investigation techniques. The main objective was to assess the conservation state of the geomaterials, reconstruct the morphology of the extractive surface, and estimate the extracted rock volumes in order to support future geoheritage enhancement and conservation strategies.

The adopted methodological framework combines geophysical investigations, mechanical diagnostic techniques, and high-resolution digital surveying. Ultrasonic pulse velocity measurements performed with Pundit instrumentation were used to evaluate the physical integrity and compactness of the rock masses, while Schmidt hammer tests provided information on the superficial mechanical properties of the exposed materials. In parallel, an aerial photogrammetric survey was carried out using a pole-mounted camera system to generate a high-resolution three-dimensional model of the quarry front.

The integration of geophysical and geomatic datasets allowed the extraction of detailed geomorphological information, enabling the mapping of weathering and degradation forms affecting the rock surface and the quantitative estimation of extracted volumes. The obtained 3D reconstruction also represents a valuable digital tool for documentation, monitoring, and dissemination purposes within geoheritage management practices (Akoglu et al., 2020). Furthermore, ultrasonic investigations proved effective for evaluating the physical and mechanical properties of carbonate geomaterials in cultural heritage contexts (Vasanelli et al., 2015).

The results highlight the effectiveness of integrated non-destructive approaches in the study of historical extractive landscapes, demonstrating how advanced diagnostic and digital surveying techniques can contribute to the conservation, interpretation, and valorisation of complex geoarchaeological contexts. The proposed methodology provides a replicable framework for the sustainable management of historical quarry sites and urban geoheritage areas characterized by strong interactions between geological resources and human activities.

Akoglu K.G. et al. (2020) - Combined use of ultrasonic pulse velocity (UPV) testing and digital technologies: A model for long-term condition monitoring memorials in historic Grove Street Cemetery, New Haven. Journal of Cultural Heritage, 41, 84-95, https://doi.org/10.1016/j.culher.2019.07.015.

Careddu N. et al. (2025) - Virtutes Materiae: Cagliari, the City of Stone. Innovative Geo-tourist Itineraries Promoting the Use of Stone Resources Throughout Time. Geoheritage, 17, 45, https://doi.org/10.1007/s12371-025-01099-0.

Vasanelli E. et al. (2015) - Ultrasonic pulse velocity for the evaluation of physical and mechanical properties of a highly porous building limestone. Ultrasonics, 60, 33-40, https://doi.org/10.1016/j.ultras.2015.02.010.

Towards interpretable deep learning in ceramic petrography with dynamic vision transformers

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Keywords: ceramic petrographic classification, deep learning, dynamic ViT.

The application of artificial intelligence (AI) in materials science is rapidly expanding, offering new opportunities for automated classification and analysis (Fiorucci et al., 2020; Greenacre & Wood, 2024). However, the complexity of deep learning (DL) models often limits their interpretability and practical applicability (Freeman et al., 2025). In archaeometry, and particularly in the study of ancient ceramics, only a limited number of studies have explored the potential of advanced DL architectures for petrographic classification.

In this study, we apply an attention-based architecture, a dynamic vision transformer (D-ViT), to classify thin sections of Levantine ceramics dating from the Late Chalcolithic to the Iron Age into their corresponding petrographic groups. D-ViT extends the standard vision transformer framework through a trainable token-selection mechanism, enabling adaptive token pruning that improves both computational efficiency and model interpretability (Rao et al., 2021). Beyond predictive performance, this work focuses on understanding the internal decision-making process of the model through explainable AI (XAI) techniques. We investigate model uncertainty using entropy and confidence metrics, analyse hierarchical token pruning and sparsification patterns, and visualize token-selection dynamics to identify the most informative image regions for classification. In addition, exit-depth mapping and token influence (Δprob) analyses are employed to evaluate how specific regions contribute to the final prediction.

The proposed model achieved strong performance on the test set, reaching 91.00% accuracy and 91.54% precision. The pruning analysis revealed structured and semantically meaningful token-selection patterns, highlighting petrographically relevant regions within the ceramic micrographs.

To further evaluate robustness and generalization, we performed an out-of-domain (OOD) assessment by excluding at least one sample from each petrographic group during training and using these unseen samples as a dedicated OOD test set. The model maintained performance comparable to the in-domain evaluation, demonstrating strong reliability and generalization capability.

Greenacre M. & Wood J.R. (2024) - A comprehensive workflow for compositional data analysis in archaeometry, with code in R. Archaeological and Anthropological Sciences, 16(10), 171, https://doi.org/10.1007/s12520-024-02070-w.

Fiorucci M. et al. (2020) - Machine learning for cultural heritage: A survey. Pattern Recognition Letters, 133, 102-108, https://doi.org/10.1016/j.patrec.2020.02.017.

Freeman L. et al. (2025) - Beyond black boxes: Enhancing interpretability of transformers trained on neural data. arXiv preprint arXiv:2506.14014, https://arxiv.org/abs/2506.14014.

Rao Y. et al. (2021) - Dynamicvit: Efficient vision transformers with dynamic token sparsification. Advances in neural information processing systems, 34, 13937-13949, https://doi.org/10.48550/arXiv.2106.02034.

Evaluation of the interactions between water and materials at the Mnajdra Megalithic Temples, Malta (UNESCO World Heritage Site)

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Keywords: limestone deterioration, water dynamics, multidisciplinary research project.

The megalithic temples of Mnajdra (Malta, ~3600-2500 BC), inscribed on the UNESCO World Heritage List (1992), are built of the local Globigerina and Coralline limestones and have been the subject of extensive conservation research in recent decades. The progressive deterioration of the stone, caused by salt crystallization, hydrocapillary processes, and exposure to marine aerosols, has been extensively documented, leading to the installation of protective cover in 2009 (Cassar, 2002; Cassar et al., 2011; Faieta et al., 2024; Roussel et al., 2021). Long-term environmental and material monitoring programmes, conducted by Heritage Malta, the Agency which cares for the temples, and the University of Malta, have provided crucial data on degradation dynamics and helped inform conservation strategies for these exceptional prehistoric structures. In order to complete the understanding of the factors influencing the long-term preservation of the site, and to complete this body of work, the site's water dynamics, including surface runoff, subsurface moisture distribution, and capillary rise pathways need to be addressed through a comprehensive and integrated approach. The hydrogeological role and conservation implications of an adjacent abandoned modern quarry, and of the nearby Misqa tanks (a rainwater collection system that may date from the Neolithic), also remain largely unexplored. To address these gaps, the University of Siena, the University of Malta, and Heritage Malta are jointly developing a multidisciplinary research project, with fieldwork scheduled to begin in summer 2026. The project will combine geomatics, geophysics, hydrogeology, in situ diagnostics, and laboratory material characterization to reconstruct the site's water dynamics and develop a hydrogeological model to support evidence-based preventive conservation strategies.

Cassar J. (2002) - Deterioration of the Globigerina Limestone of the Maltese Islands. In S. Siegesmund, T. Weiss & A. Vollbrecht (Eds), Natural stone, weathering phenomena, conservation strategies and case studies,17-43.

Cassar J. et al. (2011) - Shelters over the megalithic temples of Malta : debate, design and implementation. Environmental Earth Sciences, 43(7), 1849-1860.

Faieta R. et al. (2024) - The multidisciplinary studies of the Megalithic Temples of Malta leading to their sheltering, and beyond. 2024 IEEE International Conference on Metrology for Archaeology and Cultural Heritage (MetroArchaeo 2024), Valletta.

Roussel E. et al (2021) - Quantifying 450 years of limestone weathering induced by salt crystallization on fortifications in Malta and Gozo. Geomorphology, 378, 107614.

Petrographical and mineralogical approach for reading Building Practices through Mortars: Raw materials and construction technology in the Late Antique Villa of Negrar (Verona, Italy)

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Keywords: Negrar, mortars, petrography.

The research focuses on investigating the production techniques and raw material choices of structural mortars from a Late Antique *villa* near Negrar (Verona, Italy). The study comprises both bedding mortars and floor beddings layers sampled and investigating the binders used in the residential spaces, and in the later, added productive area of the *villa*. The petrographical and mineralogical characterization, aimed to investigate potential chronological discontinuities between the villa's main sectors, also provided valuable information regarding binder production techniques and the raw materials used in the construction of the *villa*.

The analytical workflow combined Transmitted-Light Polarized Optical Microscopy (TL-OM) and Scanning Electron Microscopy with Energy Dispersive X-Ray Analysis (SEM-EDS). Sample description followed the UNI 11176:2006 guidelines (Pecchioni et al., 2006).

All the mortars examined, including both bedding mortars and floor beddings, consist of a natural hydraulic lime binder, derived from the calcination of marly limestone rocks, the *Scaglia Rossa Veneta* limestone formation. Petrographic analysis of the samples from the *villa* highlighted the presence of two main groups of organogenic carbonate rocks: one can be associated with the limestone formation known as *Scaglia Rossa Veneta*, a local variety found in the Valpolicella area (Dilaria et al., 2024; Bridi et al., 2026) and the other corresponds to Nummulitic Limestone.

The bedding mortars consist of an aggregate mainly composed of organogenic rocks; based on this data, two distinct groups can be identified: one features only *Scaglia Rossa Veneta*, while the other also shows the presence of *Nummulitic limestone*. The remaining fraction of the aggregate mainly consists of quartz and polycrystalline quartz, mica, silicate-rich slag, and rock fragments such as chert and volcanic rocks (basalts); a smaller percentage of schist fragments and occasional pyroxenes were also observed. This fraction is interpreted as sand, excluding silicate-rich slags, added to the matrix. The petro-mineralogical composition of the sand is compatible with the sediments of the Adige River, which flows 5-6 km south-east of the villa (Dilaria et al., 2024).

Regarding the mortars from the floor beddings, *cocciopesto* fragments were chosen as the main component of the aggregate, with a lower concentration of fragments from the two previously identified organogenic limestone rocks.

Regarding the potential distinction between the villa's different rooms and their construction chronologies, the study found no correlation between the mortar mixtures and the building phases of the complex.

Although no clear correlation emerged between mortar composition and construction phases, the study provides important insights into raw material procurement strategies, local resource exploitation, and technological choices in Late Antique building practices in northern Italy.

Bridi E. et al. (2026) - From Quarries to Urban Construction Sites: Middle-Late Mesozoic Limestones int he Public Architecture of Roman Verona, Italy, Geoarchaeology, 41(1), 1-22, https://doi.org/10.1002/gea.70045.

Dilaria S. et al. (2024) - Production technique and multi-analytical characterization of a paint-plastered ceiling from the Late Antique *villa* of Negrar (Verona, Italy), Archaeological and Anthropological Sciences, 16(74), 1-21, https://doi.org/10.1007/s12520-024-01983-w.

Pecchioni E. et al. (2014) - Atlante delle malte antiche in sezione sottile al microscopio ottico, Nardini Editore, 78 pp.

Tracing Mediterranean connectivity through Greek cooking ware: Petrographic and geochemical evidence from Spina

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Keywords: Spina, Greek cooking ware, petrography.

The Etruscan city of Spina, founded during the VI century BCE in the Po river delta, representing one of the main commercial hubs of the northern Adriatic and maintained strong connections with the Greek world, particularly Athens.

Spina is mostly renowed for the wide presence of Attic black-gloss pottery imported from Athens, primarly found in the necropolis area as part of the grave goods. Besides that, excavations within the settlement have revealed a significant assemblage of Greek cooking ware, a ceramic class rarely documented in northern Etruria outside major port settlements.

This particular class of material started to be produced in Greece during the VI century BCE and is quickly spread throughout Mediterranean coastal cities, especially to the largest *emporia* and port cities. Unlike this, Greek cooking ware diffusion is not as common in Etruscan and Italic communities, except for a few port cities along Tyrrhenian coast and in the city of Spina (Cassai et al., 2009).

Since Spina was founded, all the principal forms composing the variety of Greek cooking ware have been present in the settlement.

Among all the Etruscan cities located in Northern Italy, Spina is the only one showing such a large presence of this class, highlighting the fact that this particular category was not meant to be traded as a commercial good. The widespread presence of these vessels suggests that their circulation was not exclusively related to trade dynamics, but also connected to the adoption of Greek culinary practices and domestic traditions within the multicultural environment of Spina. (Zamboni, 2016).

This study presents an integrated petrographic and geochemical investigation of selected group of Greek cooking ware samples from the settlement area. The thin-section petrography through Transmitted-Light Polarized Optical Microscopy (TL-POM) follows the descriptive model proposed by P. S. Quinn (Quinn 2021), combined with XRF elemental analyses and Loss on Ignition (LOI) analyses employed to characterize ceramic fabrics and identify potential production districts.

Preliminary indicate the prevalent use of non-calcareous clay matrices associated with volcanic temper components. The heterogeneity observed in the ceramic fabrics can be attributed to a variety of production centers, characterized by different local fabrics and techniques.

Petrographic variability and geochemical heterogeneity together with typological-archaeological study suggest the coexistence of different manufacturing traditions and supply networks, likely connected to production centers such as Athens, Corinth, and, during later phases, (IV-III century BCE), Magna Graecia (Zamboni, 2016).

In conclusion, the archaeometric data contribute to reconstructing the complexity of Mediterranean exchange systems involving Spina and highlight the circulation not only of ceramic goods, but also cultural practices during the Classical period.

Cassai C. et al. (2009) - Spina. Scavi nell'abitato della città etrusca. 2007-2009, Cooperativa archeologia, 208 pp.

Quinn P.S. (2021) - Thin Section Petrography, Geochemistry and Scanning Electron Microscopy of Archaeological Ceramics, Archaeopress, 466 pp.

Zamboni L. (2016) - Spina città liquida. Gli scavi 1977-1981 nell'abitato e i materiali tardo-arcaici e classici, Verlag Marie Leidorf GmbH . Rahden/Westf, 392 pp.

Preserving Earth's memory in ancient urban quarry fronts: stratigraphic, petrographic and paleontological insights from the Miocene Cagliari limestone succession (Sardinia, Italy)

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Keywords: geoheritage, urban geology, geological monument.

The urban area of Cagliari preserves important remnants of the Miocene carbonate successions traditionally known as the 'Calcari di Cagliari', exposed in historical quarry fronts and natural rock walls distributed within the city landscape. Sites such as the Punic necropolis of Tuvixeddu, the hill of San Michele, and the coastal sector of Calamosca represent significant geological monuments where stratigraphic, sedimentological, paleontological, and historical values coexist within highly anthropized urban contexts. However, the progressive expansion of the urban fabric has led to the partial obliteration and fragmentation of many geological outcrops, increasing the scientific and cultural importance of the remaining exposures and highlighting the urgent need for their conservation, digital archiving, and sustainable valorisation as irreplaceable records of Earth's memory.

This study presents an integrated stratigraphic, petrographic, and paleontological investigation conducted on selected quarry fronts and carbonate outcrops within the urban area of Cagliari. The research aimed to reconstruct the local stratigraphic architecture of the Miocene carbonate deposits and improve the geological characterization of the exposed lithofacies through detailed field surveys and high-resolution laboratory observations, implementing non-destructive protocols to preserve rock face integrity. The investigated successions were analyzed through non-invasive stratigraphic logging, macroscopic petrographic description, and detailed paleontological characterization of fossil assemblages preserved within the carbonate units. The comparison among the different urban outcrops allowed the reconstruction of lateral and vertical stratigraphic relationships among the lithological units composing the 'Calcari di Cagliari' succession. In addition, the application of these advanced, non-destructive diagnostic methodologies led to the identification of previously undescribed sedimentary and paleoenvironmental features not yet recognized in the existing geological literature, contributing to a more detailed interpretation of the depositional evolution of the Cagliari Miocene basin without requiring destructive sampling. The results highlight the exceptional scientific, educational, and geotouristic value of these urban quarry fronts as highly accessible open-air archives of the geological history of southern Sardinia. Their integration within archaeological, historical, and urban landscapes strengthens their role as geoheritage sites and natural monuments, emphasizing the importance of innovative multidisciplinary approaches and non-destructive enhancement techniques for their documentation, protection, conservation, and public dissemination. The preservation of these geological exposures is particularly relevant in densely urbanized areas, where anthropogenic transformations increasingly threaten the visibility and physical integrity of the original geological record.

Tracking first farmer community in Southeastern Italy: Chert and pottery provenance data as proxies for the neolithization of Apulia and Matera area

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Keywords: neolithization, chert, pottery.

Apulia has long represented an exceptional laboratory for understanding the process of Neolithization in southeastern Italy and, more generally, across the Italian Peninsula. Absolute dating undoubtedly constitutes the main framework upon which any reconstruction concerning the arrival and spread of the first farming communities in this area must be based. However, which other indicators can be effectively analyzed to reconstruct in detail the routes followed by Early Neolithic groups during their penetration into the territory?

This contribution presents preliminary data from provenance analyses of cherts used for knapped lithic production and ceramics from some of the earliest Neolithic sites in the Tavoliere, Bari, and Matera areas. These materials provide useful evidence for reconstructing raw material procurement strategies, contact networks, and mobility patterns of the first Early Neolithic groups settled in these territories, thus contributing to the definition of the possible routes and mechanisms through which the Neolithization process spread across southeastern Italy.

Early Neolithic lithic industries, both in the Tavoliere and in the Matera area, are generally made by exploiting locally procured polygenic pebbles as well as cherts from primary Gargano outcrops, the latter being used mainly for blade production. Petrographic and geochemical analyses carried out according to the parameters defined by the non-destructive NM-PCI protocol show different supply patterns among the sites of the Matera area. At Giavarra, a site dated to the end of the 7th millennium BCE, the clear predominance of exogenous cherts, essentially deriving from Gargano formations, possibly reflects pioneer communities involved in the earliest colonization of the Matera area. At Murgia Timone and Trasanello, entrenched villages whose earliest phase of occupation dates to the first half of the 6th millennium BCE, the picture is completely different. Indeed, at these sites, lithic production is mainly based on local pebbles deriving from the outer geological units of the Southern Apennines, suggesting communities already well integrated into the territory. Trasano, chronologically positioned between these contexts, shows a more balanced exploitation of local pebbles and exogenous Gargano cherts.

The petrographical, mineralogical and chemical data of pottery samples of the same periods from the Tavoliere and Murge area provided strong similarities in technological processes at different sites clearly show a broad network of middle-distance exchange of formal and technological production techniques between many Neolithic communities located in different geographical areas of south-eastern Italy, who shared many other common behavioral features. Although the hypothesis of the circulation of finished ceramic pots was not confirmed, all data confirm a more complex social mode of production that might have evolved from a ‘domestic mode of production’ to an ‘incipient-specialization stage’.

The toolkit of the first Neolithic communities that arrived in the Matera area therefore seems to suggest a very strong connection with northern Apulia, if not even the origin of these groups from these areas. As early Neolithic groups became more stably settled in the Matera area, their increasing knowledge of local environments and resources progressively reduced their dependence on exogenous raw materials from the Gargano area.

Pottery Production and Specialization in Early Rome and Its Neighbors investigated via a combined Neutron Activation Analysis of regional sssemblages and a mineralogical-petrographic study of Impasto Chiaro-Sabbioso

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Keywords: pottery production, early Rome, multi-analytical approach.

This research investigates ceramic production and signs of specialization in Rome and the surrounding region during the early first millennium BCE. Pottery production plays a central role in this study because it constitutes the most abundant quantitative archaeological source of information. This study addresses the problem by examining all pottery production between the 8th and 6th centuries BCE, with the aim of identifying, where possible, evidence of specialization through the integration of traditional archaeological and archaeometric methods, and by reconstructing elements of the *chaînes opératoires* (D'Acri 2024a, 2024b).

A total of 274 ceramic samples from six archaeological sites —four in Rome (Sant'Omobono, Caesar's Forum, Regia, and Palazzo Canevari), Gabii, and San Giovenale—were analyzed using NAA to reconstruct regional compositional patterns and production networks from the 8th to the 6th centuries BCE. Within the NAA dataset, a subset of 15 samples belonging to a particular production, namely Impasto Chiaro-Sabbioso pottery, one of the most characteristic and readily identifiable productions of the period, was further investigated using a multi-analytical approach. For this production, mineralogical (X-ray powder diffraction - XRPD), petrographic (polarizing light microscopy - PLM), and morphostructural (Field Emission Scanning Electron Microscopy - FESEM) analyses were also carried out to assess whether the chemical patterns identified through NAA are reflected at the mineralogical and microstructural levels. This approach aims to provide a better understanding of the technological choices underlying production and to refine interpretations of raw material selection, paste preparation, and firing technologies.

Ultimately, the goal is to assess whether emerging forms of specialization can be detected, and, if so, when and how they begin to materialize within the broader trajectory of early urban craft production. Prevailing theories hold that specialized ceramic production was already established by the 8th century BCE; yet our results suggest that it only emerged at the very beginning of the 6th century BCE, when clear evidence for widespread standardized recipes and specialized production strategies appears. This suggests that early ceramic production in central Italy was characterized by flexible, overlapping technological traditions rather than by rigid specialization.

D'Acri M. (2024a) - Pottery Production and Social Complexity in Archaic Rome and Latium. Ph.D. Dissertation, University of Missouri-Columbia.

D'Acri M. (2024b) - Reconstructing Pottery Production in Archaic Rome and Latium: Integrating Traditional Approach and Archaeometry. In Technology, Crafting and Artisanal Networks in the Greek and Roman World (eds. D. Elia, E. Hasaki, and M. Serino), 183-192, De Gruyter.

Beyond the Vitruvian Standard: Local pozzolanic aggregates from the Euganean Hills Magmatic District in Roman mortars from Padova and Montegrotto

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Keywords: provenance study, mortar, volcanic pozzolans.

This paper investigates the provenance of volcanic aggregates used in Roman lime-based mortars from the theatre-bath complex at Via Scavi in Montegrotto Terme (ancient Fons Aponi, northeastern Italy) and the Amphitheater of Padova, dated to the Early Imperial period. An integrated stepwise archaeometric approach combining petrographic observations via Transmitted Polarized Light-Optical Microscopy (TPL-OM), mineralogical analyses via Quantitative Phase Analysis-X-Ray Powder Diffraction (QPA-XRPD), bulk geochemical data via X-Ray Fluorescence (XRF), microchemical analyses via Scanning Electron Microscopy coupled with Energy-Dispersive Spectroscopy (SEM-EDS), and μ-Raman Spectroscopy were applied to characterize the volcanic components of the mortars and assess their hydraulic behaviour. The results show that the mortars incorporate angular trachytic to trachyandesitic (latitic) volcanic breccias displaying well-developed reaction rims and extensive pozzolanic reactivity, leading to the formation of calcium-aluminosilicate hydrate phases typical of pozzolanic lime mortars. Comparison with a comprehensive reference database of volcanic rocks from the Euganean Hills Magmatic District (Veneto, Italy) indicates that these aggregates are consistent with explosive diatreme breccias exposed in the eastern sector of the district, from specific quarry districts. The identification of these volcanic materials in mortars from Aquileia (northeastern Italy, approximately 150 km north-east of the Euganean Hills) further suggests that such “Euganean pozzolans” were not used exclusively at a local scale but were traded over longer distances. These findings provide new archaeometric evidence for the exploitation of non-Vitruvian volcanic pozzolans in Roman construction and illustrate the potential of integrated petrographic and geochemical approaches for provenance studies of these mortar aggregates (Dilaria et al., 2026).

Dilaria S. et al. (2026) - Discovery of a Roman Quarry for Pozzolanic aggregates in the Euganean Hills Magmatic District, Northeast Italy: A stepwise archaeometric approach. PLOS ONE 21(4): e0347202, https://doi.org/10.1371/journal.pone.0347202.

Archaeometric analyses of Western Greek amphorae from metro line contexts in Naples

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Keywords: Western Greek Amphorae, Naples, provenance.

The research focuses on the archaeometric analysis of thirty-seven fragments of Western Greek amphorae dating from the 6th to the 4th centuries BCE, classified according to Sourisseau's typological characteristics and Gassner's rim shape variants (Gassner, 2003; Sourisseau, 2011). The samples were found during construction work on lines 1 and 6 of the Naples metro line; more specifically, they were taken from Piazza Municipio, Piazza Nicola Amore, and Piazza Santa Maria degli Angeli. The Western Greek amphorae were manufactured in several centres across Magna Graecia, Sicily, the Ionian-Adriatic region, the Aegean, and Massalia, indicating their wide distribution throughout the central-southern Mediterranean. The distribution of production across numerous ateliers makes it difficult to attribute the amphorae to specific workshops.

The archaeometric analyses carried out on the fragments include thin-section polarised light microscopy (PLM) and X-ray fluorescence (XRF) analysis, thereby providing a petrographic and chemical characterisation of the samples. Thin section analysis identified seven petrographic groups with homogeneous characteristics. The chemical data, examined through binary diagrams and Hierarchical Cluster Analysis (HCA), confirmed the petrographic results. The samples exhibited two main clay compositions: mostly high-CaO (CaO > 6 wt.%) and fewer low-CaO clays. Trace elements, especially chromium and nickel, were key in identifying differences in raw materials, with some groups showing significantly higher concentrations of these elements.

Integrating petrographic and chemical data with those from previous studies has enabled more precise identification of potential production areas. The study confirms the presence of locally produced amphorae in the investigated contexts and also documents the discovery of Western Greek amphorae that can be traced to Paestum, Calabria, and the Aegean/Ionian-Adriatic area (Scoppetta et al., in press).

Gassner V. (2003) - Materielle Kultur und kulturelle Identität Eleas in spätarchaisch-frühklassischer Zeit. Untersuchungen zur Gefäss-und Baukeramik aus der Unterstadt (Grabungen 1987-1993). Velia-Studien 2. Vienna.

Scoppetta E. et al. (in press) - Le anfore dai contesti arcaici. In Parthenope e Neapolis: nuovi dati e prospettive di ricerca. In Atti del 62° Convegno Internazionale di Studi sulla Magna Grecia (Taranto, 28 settembre - 1 ottobre 2023). Taranto: Istituto per la Storia e l'Archeologia della Magna Grecia.

Sourisseau J. C. (2009) - La diffusion des vins grecs d'Occident du VIIIe au IVe s. av. J.-C., sources écrites et documents archéologiques. In La vigna di Dioniso: vite, vino e culti in Magna Grecia, atti del quarantanovesimo Convegno di studi sulla Magna Grecia (Taranto, 24-28 settembre 2009), 145-252.

Earthen defences in Magna Graecia: The mudbricks of the Late Archaic fortification of Rhegion (Calabria, 6th-5th century BCE)

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Keywords: mudbrick, Magna Graecia, fortification.

The use of unfired earthen materials and building techniques during the Archaic and Classical period played a significant role in the rapid urbanisation and monumentalisation of the cities of Magna Graecia. Within this framework, the Chalcidian city of *Rhegion* (today Reggio Calabria), between the late 6th and the early 5th century BCE, was provided with a defensive circuit delimiting the eastern side of the urban settlement and representing one of the earliest examples of *geländemauer*. The defensive wall, today documented for approximately 300 m and about 4 m thick, is preserved at Collina degli Angeli and Collina del Trabocchetto. Unlike more common mixed buildings, the structure lacks a stone foundation and was built entirely of mudbricks from its foundation levels upwards.

Although the two preserved sectors belong to the same building programme, traditionally associated with the political project of the tyrant Anaxilas, they display significant differences in the selection of raw materials, in the morphology and dimensions of the bricks and in the accuracy of construction. This technological heterogeneity makes the fortifications of *Rhegion* a privileged case study for integrating metrological and statistical analysis with geoarchaeological and mechanical approaches. The study combines archaeological and architectural observation of the wall faces with grain-size, petrographic and chemical analyses, as well as mechanical compression tests. The aim is to reconstruct the production of earthen building materials - mudbricks and mortars - and to understand the organisation of the construction site, from the selection of procurement areas to the preparation of mixtures, the moulding of the bricks and the sequence of building operations.

The results reveal the presence of several mudbrick production, differentiated by raw-material provenance, mixture recipes and morpho-dimensional features. The variations observed between the two sectors reflect a complex management of the building site, involving multiple production units and adapted to locally available resources. This study offers a new opportunity to assess the role of unfired earth in the development of public architecture in Magna Graecia during one of the most dynamic phases in the history of the Greek colony.

Archaeometric study of bronze coins from the Santa Maria Veterana medieval church (Apulia, Italy)

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Keywords: bronze coins, xrf, microscopy.

This study presents the archaeometric investigation of 24 bronze coins recovered from the medieval church of Santa Maria Veterana in Triggiano (Apulia, Southern Italy), an archaeological context that provides valuable evidence for reconstructing the settlement history and socio-economic role of the site within regional and wider Mediterranean exchange networks.

The coin assemblage spans different chronological periods, offering a unique opportunity to investigate technological practices, circulation dynamics and patterns of use over time. To achieve this goal, a multi-analytical methodology was employed, integrating digital microscopy and portable X-ray fluorescence.

The analytical results reveal significant differences in alloy composition and manufacturing technology among the examined coins, suggesting diversified production traditions and possible provenance groups. Moreover, the compositional patterns contribute to reconstructing circulation phenomena and economic interactions connected with the church across different historical phases. The integration of archaeometric data with the archaeological context provides new insights into the role of Santa Maria Veterana as a place involved in long-term regional and extra-regional connections.

New insights on hydraulic mortars from Central Italy

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Keywords: Roman mortars, hydraulicity, geomaterials.

This study provides a comprehensive analysis of mortars from the archaeological sites of Narni and Carsulae, located in the Umbria region of Italy. Mortars originating from the Bridge of Augustus (27 BCE), in Narni, and from the Arch of San Damiano and a cistern in Carsulae (1st century CE), were analyzed. To ascertain the composition and provenance of the stones utilized in both the binders and aggregates, minero-petrographic and geochemical analyses were undertaken, including XRPD, OM, TGA, SEM-EDS analyses. Furthermore, Focal Plane Array Fourier-transform infrared spectroscopy (FPA-FTIR) and synchrotron radiation X-ray diffraction (SR-XRD) analyses were conducted on selected samples to identify the compounds influencing the hydraulic properties of the mortars. Distinct mortar formulations were identified based on specific structural roles. In the case of Augustus Bridge, the mortars employed in the upper sections of the pier present compositional differences from those utilized in the lower sections. Here, an attempt was made to enhance the mortars hydraulicity by incorporating volcanic aggregates according to Roman recipes. Likewise, mortars from Carsulae present the deliberate addition of tuffs and volcanic aggregates to improve the hydraulic performance of the structure, while these materials are absent in San Damiano Arch, which contains only limestone and chert fragments as aggregates. Compositional analyses indicated the presence of binders with elevated silicon content in all the mortars analyzed in Narni and Carsulae, thereby facilitating hydraulic setting even in the absence of pozzolanic materials. A comprehensive geological survey of both the areas surrounding Carsulae and Narni was undertaken to identify potential sources of geomaterials compatible with those employed in ancient mortar production. The volcanic aggregates were determined to be compositionally heterogeneous yet locally sourced. For Narni, they derived from volcanic complexes in Lazio, specifically Vulsini and Vico. The same products also covered the Carsulae area, with the addition of volcanites from monogenic ULUD (Umbria-Lazio Ultra-alkaline District) volcanoes. The limestone utilized in binder production was found to be compatible with particular silicified limestones linked to a Jurassic aborted rifting event, which are exposed in both study areas, the Narni thrust and the Martani Mounts (Cipriani et al., 2019; Asti et al., 2024).

Asti R. et al. (2024) - Reconciling post-orogenic faulting, paleostress evolution, and structural inheritance in the seismogenic northern Apennines (Italy): insights from the Monti Martani Fault System. Solid Earth 15, 1525-1551, https://doi.org/10.5194/se-15-1525-2024.

Cipriani A. & Bottini C. (2019) - Unconformities, neptunian dykes and mass-transport deposits as an evidence for Early Cretaceous syn-sedimentary tectonics: new insights from the Central Apennines. Italian Journal of Geosciences, 138, 333-354, https://doi.org/10.3301/IJG.2019.09.

Behind the Colors: Technology of the Roman wall painting in the Casa del Tiaso, Pompeii

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Keywords: pigments, multi-analytical approach, Pompeii.

Roman wall paintings are an important resource for understanding ancient construction techniques and artistic methods through the examination of original materials. This study focuses on two adjoining rooms of significant importance located in the *Casa del Tiaso* (Regio IX, Insula 10). One room serves as a *sacrarium*, decorated in the Fourth Pompeian Style with a prominent blue background, while the neighboring *oecus corinthius* features a monumental Dionysiac megalography painted in the late Second Pompeian Style. The exceptional preservation of these wall paintings allows for a thorough analysis of the artistic and technological choices involved in their creation.

The research includes chemical, mineralogical, and microstructural analysis of the painted layers and plaster supports, employing methods such as Polarized Light Microscopy (PLM), Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM-EDS), Synchrotron Radiation micro-X-ray Diffraction (SR-μXRD), and Fourier-Transform Infrared Spectroscopy (FPA-FTIR). This integrated approach reveals a sophisticated decorative practice.

The rooms feature a multi-layered plaster system, including a carefully prepared arriccio enriched with volcanic aggregates and topped by a lime-based *intonachino* made of fine *marmorino*. The pictorial layers utilize high-quality pigments, such as Egyptian blue in the *sacrarium* and cinnabar in the Red Room, reflecting the prestige of the decorative program.

In the Blue Room, the pictorial layer consists of pigment particles embedded in a Mg-carbonate medium, topped with an additional layer of very fine-grained aragonite, indicating refined finishing techniques. In the Red Room, stratigraphic evidence reveals a complex and evolving decorative scenario that reflects ongoing repainting activities at the time of the eruption. The analysis identified various pigments, including cinnabar and hematite, sometimes mixed with red lead, along with rarer oxides containing lead, manganese, and iron. Additional materials, such as earth pigments, carbon black, calcite, and Egyptian blue, were also discovered, contributing to the room's color palette. Stratigraphic analysis is crucial for interpreting these findings, as it highlights pigment-dependent painting techniques and offers valuable insights into repainting practices and the successive decorative phases within the same workshop.

The long journey of Veja at its beginning: from prohibition to promotion

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Keywords: cave excavation, palaeoenvironment, local heritage.

The Lessinia Regional Natural Park represents an exemplary case where high population density and local economic activities are closely connected with outstanding geological spots and significant *Lagerstätten* (e.g. Valle delle Sfingi and Bolca). Within this context, the Veja site is famous as one of the largest European natural rock bridges and for the several karstic caves that open just beneath it. Because it is located just within the park's protected boundaries, it is heavily frequented by tourists and surrounded by private properties and small settlements. Therefore, it embodies both the challenges of sustainable management and opportunities for development aimed at preserving its value as geoheritage site.

Historically, the numerous caves in the Veja Valley, which preserve valuable palaeontological, archaeological, and environmental records, were exploited for guano extraction and ochre mining, while the bridge was used by speleologists for training purposes. EU regulations and local heritage authorities have introduced legal protection for endangered mammal fauna and restrictions. These measures have led to the closure of cave access, triggering conflicts among the stakeholders.

In 2021, we initiated systematic investigations within the main cavity (Cave A), where previous unauthorized excavations had exposed a depositional sequence spanning the last ~40ky. Fieldwork has been carefully designed and monitored to minimize environmental impact; we used only lithium battery systems, activities were restricted to the winter season to avoid disturbance to bat populations, and sediments were initially washed in the nearby stream and then moved out of the valley using pack animals to the laboratories of the University of Padova.

Our approach includes taxonomic identification of faunal remains, aDNA and C and N isotopes, reconstruction of vegetational change through anthracological remains, stratigraphic analysis supported by micromorphology, microdiagenetic characterization and chemical profiling of the sediments, radiocarbon dating, speleothem analyses, and LiDAR surveys of the valley. The goal of these integrated methods is to reconstruct the sequence of depositional events and to correlate the internal cave record with the external geomorphological evolution of the valley. Furthermore, the project aims to strengthen the relationship between the cave system and the local community, raising awareness of its geological heritage and supporting future conservation, education, and sustainable development strategies. In addition, within the framework of the HYPERPAST Project, we are investigating ochre deposits and cave graffiti using hyperspectral imaging, with the aim of characterizing their mineralogical composition and tracing the temporal evolution on the cave walls.

All research activities are non-destructive and minimally invasive, preserving the integrity of the geological features and the aesthetic value of the bridge and caves, also with a view to future musealisation of the research process. At the same time, we seek to quantify the value of the Veja valley as a key ecosystem service and cultural asset within the Lessinia region.

(Geo)chemical study of two coats of arms stained glass windows in the Chapel of St. Pietro Martire (Capella Beccai, early 15th century) of the Basilica of San Petronio, Bologna, Italy

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Keywords: lime-potassium medieval glass, HR-ICP-MS-LAM, colour recipes.

This work studies two small stained glass windows made around 1400 and restored in 2009. The windows come from the San Pietro Martire chapel of San Petronio Basilica of Bologna (Italy). The sampling performed includes 8 representative fragments of glass (blue and deep blue, red, green, amber and yellow glass) and 2 fragments from the framework constituted by the lead structure mixed with glass fragments. The chemical analyses were conducted by microablation craters with a HR-ICP-MS-LAM instrument.

The main chemical components of glass show a composition of lime-potassium silica glass of centeeuropean affinity (all except one in the 17-24% CaO range; while the K2O contents are more variable (most - 6 - range between 19-24%) and relatively low silica content (just over 50% in SiO2). A first group of three fragment of glass are of the low-lime high-magnesia (LLHM group), while a second set of four glass fragments can be classed in the high-lime low-magnesia (HLLM) group of medieval lime-potassium glass. Also, the LLHM set of glass present MgO values much higher than those that would be expected for a medieval glass simply formed from silica sand as a vitrifier and wood ash (even higher than using birch ash or bracken ash). An alternative Mg source is (calcined) dolomite from dolostone or a mixture with another Mg rich mineral or ash not yet considered. On other hand, if we consider the CaO/Sr ratio the source of calcium all the set of glass is compatible with (diagenized) limestone, except in sample CT06 (yellow silver) that suggest Ca and Sr introduction via aragonitic molluskan shells. These compositional characteristics (lime-potassium silica glass) are consistent with a state of preservation which, although generally good, includes the presence of corrosion micropitting in the yellow samples, as well as widespread surface (gypsum and syngenite) growths of sulfates in most of the fragments.

Also, the chemical study allows for understanding the color recipes used (Co with Ni-Cu fingerprint in blue, Fe-Cu for green, Cu for red-plaqué). REE elements content (attributable to the silica content in the formulation of uncoloured glass) is homogeneous for most glass fragments coinciding with the main group, which is relatively homogeneous in terms of its major element components. Trace element metals allow to explain the colour recipe used, providing information on the characteristic geochemical fingerprint of the metallic salts used in each case. The yellow colours are variated: silver yellow in a clearly precedent glass used in the ancient restoration of the stained glass window, while in the other yellow sampled and analysed we can invoke the classical medieval recipe of control of the redox conditions of the kiln, noticed since the classical work the monk Theophylus (early XII century). HR-ICP-MS-LAM and geochemical background makes possible to establish whether the glass has a medieval composition, and the raw materials used for uncoloured glass and the colour recipes.

Building materials characterization and structural evaluation of ancient coastal watchtowers in Southern Calabria (Italy): A conservation and valorisation project

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Keywords: valorization, 3D model, interactive watchtower.

Calabria preserves a valuable heritage of over 130 coastal watchtowers, of which about 70 remain today, dating from the Angevin period to the Spanish Viceroyalty, and present varying degrees of structural and conservation status (Valente, 1960). A QGIS - based map enabled the identification of the main natural hazards affecting the remaining Calabrian watchtowers, including coastal erosion and hydrogeological risk, but above all landslides and earthquakes, which are closely interconnected. Consequently, this cultural heritage is highly vulnerable to natural hazards and marine-induced degradation. This study focuses on three ancient coastal watchtowers in Calabria (Southern Italy): the Saracena Tower in Palmi (Reggio Calabria), the Marrana Tower in Ricadi (Vibo Valentia), and La Rocchetta in Briatico (Vibo Valentia), with the aim of applying innovative methodologies to support their conservation and sustainable valorisation. Minero-petrographic analyses using Polarized Optical Microscopy (POM) and X-Ray Diffraction (XRD) were carried out to characterize the building materials of the watchtowers, including rocks, mortars, and bricks, as well as their main degradation forms, predominantly *flos tectorii*. The study areas are characterized by high seismic hazard, as also confirmed by historical earthquake records reported in the CFTI5Med catalogue of earthquakes in Italy (461 BC - 1997) and in the Mediterranean area (760 BC -1500). In particular, the Palmi area has experienced events reaching intensities up to XI on the Mercalli-Cancani-Sieberg (MCS) scale (Guidoboni et al.,2018; Guidoboni et al., 2019). Within this context, the HVSR (Horizontal-to-Vertical Spectral Ratio) technique was employed to identify the predominant frequencies of both the foundation soil and the structures. This approach allows the detection of possible double resonance effects, providing a qualitative assessment of the structural integrity of the watchtowers in relation to seismic activity. Finally, the study will include the creation of a three-dimensional model of each watchtower, generated through laser scanner surveys, with the dual objective of integrating the data obtained from minero-petrographic characterization and HVSR measurements within Heritage Building Information Modeling (H-BIM) techniques or similar digital tools, while also promoting the watchtowers to a broad and diverse audience. The models will be integrated into local digital heritage and tourism platforms, allowing users to explore them by scanning a QR code placed in front of each watchtower (Solima & Izzo, 2018). Through the interactive model, visitors will also be able to access information related to HVSR measurement points, as well as the characterization of building materials and observed degradation forms. This study is part of a PhD project developed within TEACH PhD course - University of Calabria. The project is co-funded by the CNR institutes ICAR, ITM, IIT.

Guidoboni E. et al. (2018) - CFTI5Med, Catalogo dei Forti Terremoti in Italia (461 a.C.-1997) e nell'area Mediterranea (760 a.C.-1500). Istituto Nazionale di Geofisica e Vulcanologia (INGV), https://doi.org/10.6092/ingv.it-cfti5.

Guidoboni E. et al. (2019) - CFTI5Med, the new release of the catalogue of strong earthquakes in Italy and in the Mediterranean area. Scientific data, 6(1), 80, https://doi.org/10.1038/s41597-019-0091-9.

Solima L. & Izzo F. (2018) - QR codes in cultural heritage tourism: New communications technologies and future prospects in Naples and Warsaw. Journal of Heritage Tourism, 13(2), 115-127, https://doi.org/10.1080/1743873X.2017.1337776.

Valente G. (1960) - Le torri costiere della Calabria. Eredi Serafino.

Finding the sources of Pompeiian colors: From mines to the walls

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Keywords: coloring pigments, provenance, Pompeii.

In the ancient and complex society of Pompeii, pigments became entangled with broader economic and technological systems: they had to be extracted from specific geological settings, transported across landscapes, and processed in workshops that understood how to stabilise, modify, or intensify their properties. Due to the earthquake(s) that shook Pompeii since 62 BCE, many rooms with their wall paintings have been under renovation, awaiting repair by the artists who were actively working on corrections when the Vesuvian eruption in 79 BCE preserved their work in progress. In this research, funded by The American Institute for Roman Culture under the Ancient Rome Live program, we analyzed the coloring pigments in their original bowls, found and conserved within the rooms, before applying them to the walls. Going from traditional techniques such as light microscopy, μXRF, μFTIR, and μRaman spectroscopy to advanced analyses such as synchrotron-based 2D-μXRD mapping of samples in microgram quantities, we have created fingerprints of the most used colouring materials in Pompeii, with the aim of identifying their geological sources. Our results indicate that some pigments were sourced locally, while others were mined, traded, and transported from distant regions of the Roman World and the wider Mediterranean region. This new perspective situates Pompeian pigments within a broader socio-economic context, demonstrating that color functioned not only as decoration but also as an indicator of access to resources, trade networks, and social status. Such an approach provides a novel framework for reconstructing patterns of wealth distribution and neighbourhood organisation within Pompeii.

Geoheritage under Pressure: Low-Cost preventive monitoring of stone decay at Pomposa Abbey (Italy)

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Keywords: geoheritage conservation, preventive monitoring, Po Delta coastal environment.

Pomposa Abbey, located in the Po Delta coastal plain of northeastern Italy, represents an outstanding example of medieval architectural geoheritage and a UNESCO cultural landscape shaped by the interaction between geological setting, environmental dynamics, and human activity. The monument, built using heterogeneous lithotypes and ceramic materials sourced from the surrounding Po Basin and Ravenna area, is strongly influenced by the geomorphological and climatic conditions typical of lowland coastal environments (Stefani, 2017).

This study investigates the conservation state of two architecturally significant sectors of the Abbey, namely the bell tower and the Basilica atrium, through a low-cost and non-destructive visual assessment integrated with geoheritage risk-analysis protocols. Field surveys conducted in summer 2020 followed the ICOMOS-ISCS glossary of stone deterioration patterns (ICOMOS, 2008) and included macroscopic observations, photographic documentation, and semi-quantitative decay scoring. The methodology was designed as a rapid, replicable, and economically sustainable tool for preventive conservation and geoheritage monitoring.

The results highlighted widespread and spatially differentiated deterioration phenomena affecting both natural stone and ceramic materials. The bell tower exhibited the highest vulnerability, particularly on the north and west façades, where biological colonisation, granular disintegration, alveolarization, exfoliation, fracturing, material loss, and black crust formation were identified. In the atrium, degradation mainly affected decorative calcarenite and terracotta elements, showing biological patinas, fractures, granular disruption, and localised detachments. The observed decay patterns are closely linked to geoenvironmental factors such as marine aerosol transport from the nearby Adriatic coast, rising damp, salt crystallisation, humidity fluctuations, wind exposure, and atmospheric pollution (Morillas et al., 2020).

The integration of visual inspection with a Risk Indicator (RI) framework (Kioussi et al., 2013) allowed qualitative observations to be transformed into measurable vulnerability parameters, improving the reproducibility of conservation assessment and supporting long-term geoheritage management strategies. The study demonstrates how geological context and environmental processes play a fundamental role in the deterioration of built heritage materials, particularly in fragile coastal landscapes such as the Po Delta.

Pomposa Abbey, therefore, represents a significant case study for the application of preventive conservation within geoheritage research, showing how low-cost visual monitoring can effectively support the preservation of cultural landscapes, material authenticity, and sustainable geotourism. The proposed approach offers a practical methodology for identifying early-stage decay processes before severe structural damage occurs, contributing to the long-term resilience and valorisation of historical geoheritage sites.

ICOMOS ISCS (2008) - *Illustrated Glossary on Stone Deterioration Patterns*. Monuments and Sites XV.

Kioussi A. et al. (2013) - Documentation protocols to generate risk indicators regarding degradation processes for cultural heritage risk evaluation. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 40, 379-384, https://doi.org/10.5194/isprsarchives-XL-5-W2-379-2013.

Morillas H. et al. (2020) - Decay processes in buildings close to the sea induced by marine aerosol: Salt depositions inside construction materials. Science of the Total Environment, 721, 137687, https://doi.org/10.1016/j.scitotenv.2020.137687.

Stefani M. (2017) - The Po Delta Region: Depositional Evolution, Climate Change and Human Intervention Through the Last 5000 Years. In: Soldati, M., Marchetti, M. (eds) Landscapes and Landforms of Italy. World Geomorphological Landscapes. Springer, Cham, https://doi.org/10.1007/978-3-319-26194-2_16.

Multi-analytical investigation of glazed and overpainted ceramics from Pyrgi (Santa Severa, Rome): Insights into raw material processing and provenance

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Keywords: Etruscan glazed ceramics, raw materials, pigments.

This study reports the petrographic and mineralogical characterisation of glazed and overpainted ceramic samples from the Southern Sanctuary of Pyrgi (Santa Severa, Rome), dating to the 4th century BCE. The research aims to reconstruct both the manufacturing techniques and the provenance of raw materials. Optical microscopy (OM) and quantitative grain-size analysis reveal a highly standardised production characterised by a fine-grained fabric with well-sorted, silt-sized inclusions. X-ray powder diffraction (XRPD) identifies quartz, alkali feldspars, plagioclase, clinopyroxene, and hematite as the main mineralogical phases. SEM-EDS analyses show frequent Ba-rich feldspars, together with Na-plagioclase, fluorapatite, Fe-Ti oxides, and sphene. This assemblage supports the use of local volcanic-sedimentary clay sources associated with the Quaternary alkaline volcanic districts of northern and central Latium, particularly the Sabatini and Vulsini volcanic complex (De Rita et al., 2012; Peccerillo, 2017). The only fragment initially interpreted as a Greek production displays slight chemical and mineralogical differences, including the lowest CaO content in the ceramic matrix, the absence of Ba-rich feldspars and fluorapatite, and the presence of monazite-(Ce-La) and zircon inclusions. The mineralogical assemblages indicate firing temperatures between 850 and 950°C under stable oxidising conditions. SEM-EDS further characterises the glaze layers as Fe- and K-rich sintered clay suspensions. Micro-Raman spectroscopy identifies magnetite and amorphous carbon in black glazes, indicating a reducing firing stage. The red-brown glazes, dominated by hematite, may reflect intentional oxidation, incomplete reduction, or long-term glaze alteration processes. Overpainted decorations were produced using hematite- and carbon-based pigments.

De Rita D. et al. (2012) - Fluorine in the rocks and sediments of volcanic areas in central Italy: total content, enrichment and leaching processes and a hypothesis on the vulnerability of the related aquifers. Environmental Monitoring and Assessment, 184, 5781-5796, https://doi.org/10.1007/s10661-011-2381-3.

Peccerillo A. (2017) - Cenozoic Volcanism in the Tyrrhenian Sea Region. Springer International Publishing, Cham, https://doi.org/10.1007/978-3-319-42491-0.

A geoarchaeological reconstruction of stone exploitation in the Euganean Hills: An integrated remote sensing, field survey, and archaeometric approach

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Keywords: LiDAR, geoarchaeology, quarries.

The Euganean Hills (Colli Euganei, NE Italy) represent a geologically diverse volcanic complex with a well-documented history of stone procurement, yet the full extent and character of their exploitation during the Roman period remains poorly understood. The EuQuGeA (Geoarchaeology of Euganean Quarrying) project presents a multi-disciplinary framework for reconstructing the quarried landscape of this volcanic district through integrating remote sensing, geoarchaeological survey, and archaeometric provenance analysis.

High-resolution UAV LiDAR surveys covering 8.5 km of the eastern hill system enabled the identification of 89 candidate quarry features, of which 84.9% were field validated as quarries or anthropogenic cuts (Olah et al., 2026). Microtopographic analysis and multivariate morphometric clustering provided a robust methodological basis for quarry landscape interpretation, subsequently extended to a regional 1m resolution ALS dataset through a confidence analysis of LiDAR visualization techniques for quarry identification. Preliminary results from this regional assessment, currently ongoing across the full volcanic complex, indicate that previous surveys and historical cartography significantly underestimated the spatial extent and overall locations of extraction across the Euganean Hills. Additionally, this project will produce the first estimate for the minimum quantity of quarried materials in the region, providing a meaningful attribute for the comparison of features and their impact on the natural landscape.

Targeted geological sampling and petrographic-geochemical characterization combining optical microscopy, SEM-EDS, XRF, and XRPD established geochemical fingerprints for quarry source areas and demonstrated strong compositional correspondence between Euganean volcanic breccias and pozzolanic aggregates identified in Roman opus caementicium at a nearby archaeological site (Dilaria et al., 2026). Both the geological sampling campaign and archaeometric characterization of materials are ongoing, with the aim of expanding the existing reference database to newly identified quarry locations across the regional survey area.

The integrated dataset produced by EuQuGeA offers an ideal basis for addressing questions of Roman material selection behavior distinguishing between quality-driven and accessibility-driven procurement strategies and for positioning this regional case study within broader discussions of resource exploitation and supply chain organization in the Roman world. The project's multi-methodological approach, combining non-invasive remote sensing with stone material characterization, illustrates the potential of integrated Earth Science and archaeological frameworks for reconstructing cultural and Geoheritage landscapes.

Dilaria S. et al. (2026) - Discovery of a Roman Quarry for Pozzolanic aggregates in the Euganean Hills Magmatic District, Northeast Italy: A stepwise archaeometric approach. PLoS ONE, 21(4), e0347202, https://doi.org/10.1371/journal.pone.0347202.

Olah J. et al. (2026) - Enhancing quarry landscape interpretation with UAV LiDAR and morphometric clustering: A case study from the Euganean Hills, Italy. J. Archaeol. Sci., 186, 106478, https://doi.org/10.1016/j.jas.2026.106478.

Multi-analytical charaterization and multivariate analysis of Spina slags: Insights into polymetallic production and furnace conditions

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Keywords: multi-analyses, slags, Spina.

The Etruscan harbor of Spina (Ferrara, Italy) was a major Adriatic trading center during the 5th - 4th century BCE in the Mediterranean, whose technological activities remain only partially understood. Although its commercial role is well-documented, the organization, scale, and technological features of local metallurgical dynamics activities remain poorly constrained (Sassatelli & Govi, 2013). This study presents a multi-analytical archaeometric characterization of slags recovered during the 2023 excavation, aimed at reconstructing key steps of the site's "chaîne opératoire" (Rehren & Pernicka, 2008). A representative set of samples was investigated through an integrated protocol combining digital microscopy for morphological screening (Hirox), extensive portable XRF (pXRF) chemical mapping, and microstructural analysis of polished thin sections. Mineral phases were identified using Optical Microscopy, SEM-EDS, and Micro-Raman Spectroscopy.

The investigated assemblage points to a complex polymetallic production system, documented by the co-occurrence of iron-rich slags containing magnetite and hematite and residues related to copper-processing residues (Chiarantini et al., 2018). The occurence of well-developed, idiomorphic mineral phases within the glassy matrix, suggests specific cooling histories and poits to a degree of control over melt properties during both ferrous and non-ferrous operations. Relict quartz and K-feldspar crystals may reflect contributions from furnace linings ceramic materials, or fluxing agents, whereas the vitrification of associated ceramics supports the attainment of high-temperature conditions. From a preservation perspective, the widespread calcite infilling observed within pore spaces are interpreted as a secondary post-depositional product related to the hydromorphic conditions of the Po Delta environment. Distinguishing these secondary alteration phases from the primary mineralogical assemblage is therefore essential to avoid misinterpretations of the original smelting recipes and fluxing strategies.

In conclusion, the results point to a high degree of metallurgical expertise at Spina, including the ability to manage furnace atmosphere and redox conditions. The dataset, integrating mineral chemistry and microstructural descriptors, is currently being explored through principal component analysis (PCA) to identify "technological patterns" and assess possible links with raw material selection and provenance. This approach provides a refined framework for interpreting metallurgical practices the Po Valley's archaeological heritage.

Chiarantini L. et al. (2018) - Copper merallurgy in ancient Etruria (southern Tuscany, Italy) at the Bronze-Iron Age transition: a lead isotope provenance study. Journal of Archaeological Scienze: Reports, 19, 11-23, https://doi.org/10.1016/j.jasrep.2018.02.005.

Rehren T. & Pernicka E. (2008) - Coins, artefacts and isotopes—archaeometallurgy and archaeometry. Archaeometry, 50, 232-248, https://doi.org/10.1111/j.1475-4754.2008.00389.x.

Sassatelli G. & Govi E. (2013) - Etruria on the Po and the Adriatic Sea. In: Turfa J.M. (Ed.), The Etruscan World, Routledge, 281-300, https://doi.org/10.4324/9780203526965.

Preserving stone cultural heritage against climate change through geochemical modelling approaches

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Keywords: cultural heritage, weathering, geochemical modelling.

The conservation of stone cultural heritage is increasingly threatened by climate change, whose stress factors accelerate the degradation processes already underway and can also lead to new forms of deterioration (Sesana, 2021). This research aims to apply geochemical modelling, integrated with traditional diagnostic investigations, to simulate the processes involved in the weathering of stone materials in cultural heritage sites under specific environmental conditions, in order to contribute to understanding the impact of climate change on cultural heritage. Geochemical modelling is a method based on the use of software capable of providing reliable results, grounded in the principles of thermodynamics and chemical kinetics. It is used to quantitatively predict the formation and/or dissolution of minerals, as well as other processes that occur during both reversible and irreversible reactions between minerals and aqueous solutions (Apollaro, 2025). The research applies geochemical modelling to two types of rock widely used in the cultural heritage context: granitoid stone (GS) and carbonate stone (CS). The methodological framework comprises: (i) the selection of four pilot sites in the Calabria region (Italy) constructed with GS and CS; (ii) diagnostic analyses to characterise the samples and identify forms of degradation, defining the solid phases for the geochemical simulations; and (iii) the collection and processing of environmental data (temperature, precipitation and CO_2 concentrations) from local monitoring stations. Two kinetic models have currently been developed: one for the Soriano Calabro site, characterised by granitoid stone (GS), and one for the carbonate stone of Prestarona (CS), which is used locally as a building material, as in the case of the Chapel of the Madonna dell'Itria in Gerace, one of the pilot sites. Kinetic models were developed using the EQ3/6 software package version 8.0a (Wolery & Jarek, 2003) employing site-specific environmental parameters, including temperature, precipitation and CO_2 concentration, and assuming a water-rock interaction time of one day. The results quantified the dissolution of calcite in Prestarona and, in the case of the Soriano Calabro granite, the dissolution of minerals and the formation of secondary phases, as also confirmed by analyses of the samples. By relating the results to the average annual number of rainy days, it was possible to estimate the annual dissolution of the stones and assess their vulnerability under current environmental conditions. The models will be extended to future climate scenarios and different CO_2 emission levels, in order to employ geochemical modelling as a tool for predicting the deterioration of stone heritage, thereby supporting long-term conservation strategies.

Apollaro C. et al. (2025) - Climate change effects at basin-scale: Weathering rates and CO_2 consumption assessment by using the reaction path modelling. Environmental Modelling & Software,187, 106398, https://doi.org/10.1016/j.envsoft.2025.106398.

Sesana E. et al. (2021) - Climate change impacts on cultural heritage: A literature review. WIREs Climate Change, 12(4), e710, https://doi.org/10.1002/wcc.710.

Wolery T.W. & Jarek R.L. (2003) - Software User's Manual. EQ3/6. Sandia National Laboratories e U.S. Dept. of Energy Report. Version 8.0.

Asbestos in cultural heritage: a risk-oriented framework from geomaterial characterization to heritage management

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Keywords: asbestos, cultural heritage, risk management.

Asbestos and asbestos-containing materials of historical, artistic, and scientific significance represent a largely overlooked category of geomaterials within cultural heritage. From prehistoric pottery and ancient textiles to Byzantine wall paintings, industrial architecture, and twentieth-century design objects, asbestos has been intentionally or unintentionally incorporated into a wide range of artefacts and heritage assets. Despite its historical and technological significance, the presence of asbestos in cultural heritage has received limited attention in conservation practice, particularly regarding material characterisation, degradation processes, documentation, and risk assessment.

This work examines asbestos-containing cultural heritage items (ACCHI) as a complex conservation issue at the intersection of geomaterials science, heritage management, and occupational safety. An overview of the occurrence of asbestos in archaeological, architectural, artistic, and industrial heritage is provided, highlighting the variability of asbestos-bearing matrices and their different states of preservation and degradation.

Based on an interdisciplinary approach integrating mineralogy, conservation science, and asbestos risk assessment, a structured and risk-oriented framework for the identification, characterization, and long-term management of ACCHI is proposed. The workflow is supported by dedicated documentation tools, including an Asbestos Survey Report (ASR) and a dynamic ACCHI Registry, designed to facilitate the systematic classification of heritage objects by material composition, conservation condition, and potential exposure risk.

The proposed methodology also addresses the conservation challenges posed by asbestos as an integral component of heritage objects and architectural materials. Unlike conventional asbestos-containing building materials, asbestos embedded within artworks, archaeological artefacts, decorative surfaces, or historical and scientific objects often cannot be removed without compromising their authenticity and material integrity. Consequently, preventive conservation strategies, condition assessment, monitoring procedures, and site-specific management protocols are required to balance heritage preservation with health and safety requirements.

By framing asbestos as both a geomaterial and a conservation concern, this work contributes to current discussions on the sustainable management of hazardous heritage materials and promotes the integration of material characterization, diagnostic investigation, and risk-oriented conservation practices within cultural heritage institutions.

ER-FTIR Spectroscopy and deep learning for non-invasive characterization of ancient wall paintings

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Keywords: wall paintings, ER-FTIR, deep learning.

Wall paintings are among the oldest art forms, executed throughout history using various pictorial techniques, including *fresco*, *mezzo fresco* and *secco* (Jiménez-Desmond et al., 2024). Given the immobility of wall paintings and the necessity to acquire a large set of measurements for their characterization, in-situ non-invasive analytical methods are highly required. Among FTIR instruments, portable external reflectance spectroscopy (ER-FTIR) is particularly suited for heritage science, as it meets the requirements of portability, non-invasiveness, and sensitivity under various working conditions. However, the interpretation of reflection spectra acquired on inhomogeneous surfaces, such as those of wall paintings, is challenging and time consuming due to the presence of distortions in the spectral features and the limited availability of reference database (Milani et al., 2012). In recent years, Deep Learning (DL) has emerged as powerful tool in the cultural heritage field, offering new possibilities for the analysis of complex spectral datasets (Towarek et al., 2024).

The aim of the present project is to develop a DL model capable of identifying pictorial materials in wall paintings based on ER-FTIR spectra. In order to develop the model, pictorial mock-ups have been prepared to simulate the variety of historical wall painting techniques, using different binder formulations and a range of mineral, earth-based and historical synthetic pigments. The mock-ups have been analysed using a portable ER-FTIR spectrometer to collect a large set of labelled spectra, capturing the variability of materials and techniques. Subsequently, the DL model will be trained to automatically identify pigments and materials used in the mock-ups, integrating explainable AI (XAI) methods to interpret the model's predictions and highlight the most relevant spectral features for the classification. In the final phase of the project, the model will be tested on real case studies to assess its performance in complex, real-world scenarios.

Jiménez-Desmond D. et al. (2024) - The fresco wall painting techniques in the Mediterranean area from Antiquity to the present: A review. Journal of Cultural Heritage, 66, 166-186, https://doi.org/10.1016/j.culher.2023.11.018.

Miliani C. et al. (2012) - Reflection infrared spectroscopy for the non-invasive in situ study of artists' pigments. Applied Physics A, 106(2), 295-307, https://doi.org/10.1007/s00339-011-6708-2.

Towarek A. et al. (2024) - Machine learning in analytical chemistry for cultural heritage: A comprehensive review. Journal of Cultural Heritage, 70, 64-70, https://doi.org/10.1016/j.culher.2024.08.014.

Multi-analytical approaches for the characterization, decay assessment of stone materials and monitoring in Magna Graecia archaeological sites

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Keywords: Magna Graecia Archeological sites, stone materials, degradation, monitoring.

The study of geomaterials in archaeological contexts requires the integration of mineralogical, petrographic, and geochemical analyses to reconstruct provenance, technological features, and decay processes affecting Cultural Heritage. Within the ATEMA project (Advanced Technologies to preserve and promote the Calabrian Magna Graecia Archaeological sites), a multidisciplinary workflow has been developed to investigate stone materials from key archaeological areas in Southern Italy, including Locri Epizefiri and Kaulon.

An important aspect of the project concerns the integration of analytical data with environmental and microclimatic monitoring. Dedicated sensor networks installed in the archaeological sites continuously collect environmental parameters, providing crucial information for interpreting material decay processes and evaluating site vulnerability. These datasets are integrated with historical and archaeological information to develop hazard indices and predictive models aimed at supporting conservation planning.

The project also includes the implementation of a digital platform and application for the management accessibility. Furthermore, the development of new visualization tools and digital environments for the exploration of cultural heritage datasets is foreseen, together with the testing of innovative methods for content accessibility and user interaction.

Ancient ceramic production and clay raw materials in the Bay of Naples: An integrated archaeometric and geological approach

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Keywords: clay-source discrimination, core-derived sediments, ceramic production systems.

The Bay of Naples is one of the most complex and long-lasting ceramic production areas of the Mediterranean. Volcanic activity, alluvial processes, coastal sedimentation and human occupation created a heterogeneous geological and archaeological landscape. From the Greek period to the Roman age and beyond, fine wares, common wares, cooking wares, amphorae and building ceramics were produced and circulated in this region (De Bonis et al., 2013). Yet the exploitation of clay raw materials, paste preparation strategies, and the relationship among geology, technology, and ceramic function remain only partly understood.

This study aims to identify the clayey raw materials in the area and understand how they influenced ancient production practices. The main questions are raw material availability, function-related selection and processing, origin and significance of low-CaO clays, and diachronic change in shaping technological choices.

The research combines the study of archaeological pottery, production indicators (wasters, kiln furniture), and ceramic building materials from production contexts, including *Neapolis, Cumae*, and *Pompeii*, with the characterization of clays and temper sources. These contexts are relevant because previous studies have highlighted typical local traditions and production practices, as well as unresolved questions about certain aspects of raw material procurement and processing (i.e. De Bonis et al., 2016; Morra et al., 2013; Grifa et al., 2021).

Sampling of raw materials is carried out through surface survey and targeted core drilling to access clayey levels in the alluvial plains (Volturno and Sarno rivers). The analytical approach includes petrography, XRPD, SEM-EDS, XRF, and grain-size and consistency limits to assess raw materials' workability. Preliminary analysis on selected core samples from different areas revealed compositional variability. XRF data indicate differences in CaO, SiO_2, Al_2O_3 and Fe_2O_3, while mineralogical and thin-section observations highlight variations in phase composition and fabric. These results suggest that some deposits may have been more suitable than others for ceramic paste preparation and provide a basis for assessing whether buried or inaccessible clay sediments could have served as sources of raw materials in the past.

Isotopic analyses will be explored as an additional tool to discriminate among clay resources. An experimental approach will involve the preparation of ceramic replicas from selected raw materials. These will be tested to assess physical properties and evaluate how clay composition and mix design influence ceramic performance.

The expected results include a refined attribution of clay raw materials, the identification of technological recipes, and a clearer understanding of resource-technology-function relationships. The study will contribute to the reconstruction of production systems and raw-material circulation in one of the key ceramic landscapes of southern Italy.

De Bonis A. et al. (2013) - Raw Materials for Archaeological Pottery from the Campania Region of Italy: A Petrophysical Characterization. Geoarchaeology, 28, 478-503, https://doi.org/10.1002/gea.21450.

De Bonis A. et al. (2016) - Distinctive volcanic material for the production of Campana A ware: The workshop area of Neapolis at the Duomo Metro Station in Naples, Italy. Geoarchaeology, 31, 437-466, https://doi.org/10.1002/gea.21571.

Grifa C. et al. (2021) - A pottery workshop in Pompeii unveils new insights on the Roman ceramics crafting tradition and raw materials trade. Journal of Archaeological Science, 126, 105305, https://doi.org/10.1016/j.jas.2020.105305.

Morra V. et al. (2013) - Minero-petrographic study of cooking ware and Pompeian Red ware (Rosso Pompeiano) from Cuma (Southern Italy). Archaeometry, 55, 852-879, http://dx.doi.org/10.1111/j.1475-4754.2012.00710.x.

Technology and raw materials of an enthroned terracotta deity from Anxa-Angitia (Central Italy): An integrated archaeometric and thermographic analysis

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Keywords: terracotta technology, volcaniclastic sediments, infrared thermography.

This study presents the first integrated archaeometric and conservation investigation of an enthroned terracotta deity statue, likely a maternal figure, made of pinkish-brown clay, from the archaeological site of *Anxa-Angitia* (Luco dei Marsi, Abruzzo, Italy). The artefact, stylistically dated to the late 3rd-early 2nd century BC, was discovered in 2003 during a stratigraphic excavation by the Superintendence for Archaeological Heritage of Abruzzo within a sanctuary dedicated to the goddess Angitia, venerated by the Marsi. The statue measures 87 cm in height (72.5 cm excluding base and footrest) and 43 cm in depth. The artefact belongs to the group of enthroned female terracotta divinities, exemplified by the votive deposit of Ariccia, and recalls the so-called *tripedaneae* (c. three feet high) (Liberatore, 2007; Zevi, 2012). It can be placed within the Etrusco-Latial coroplastic tradition of the late 3rd-early 2nd century BC, in continuity with southern Etruscan, Tiberine and Latial productions of the 4th-3rd centuries BC. The study aims to characterise raw materials, reconstruct forming and firing technologies, and assess whether production reflects a local or non-local origin. A multi-analytical approach was adopted, including thin-section petrography, XRPD, FESEM, micro-Raman, ATR-FTIR and LA-ICP-MS on clinopyroxenes. Active infrared thermography was also applied to detect subsurface features and restoration-related anomalies (Maldague, 2001). Petrographic observations revealed a mineral assemblage dominated by volcanic components (clinopyroxene, leucite and feldspars), with accessory phases such as biotite, and garnet, suggesting the use of volcaniclastic sediments with rare occurrences of metamorphic lithics. FESEM analysis indicates incipient glass bridge formation within the ceramic matrix, consistent with early-stage sintering, while mineralogical constraints indicate firing temperatures of ~850 °C under prevailing oxidizing conditions (Maniatis & Tite, 1981). Infrared thermography revealed subsurface heterogeneities and structural discontinuities, highlighting internal features not visible at the surface and areas affected by restoration.

LA-ICP-MS analyses of clinopyroxenes, supported by multivariate statistics and trace element ratios, indicate a clear geochemical affinity with the Colli Albani volcanic district (Southern Latium). When integrated with petrography, these data evidence the presence of reworked sediments incorporating a volcanic component rather than primary volcanic deposits. More specifically, the occurrence of metamorphic inclusions suggests the use of locally available raw materials from the Fucino basin. The technological features are consistent with production practices documented in Southern Latium, suggesting circulation of technical knowledge across regions.

Liberatore D. (2007) - Statuaria di età repubblicana dal Nemus Angitiae, Fortuna e Prosperità. Dee e maghe dell'Abruzzo antico, Synapsi Edizioni, ISBN 88-88457-25-9, pp. 75-91, 2006 e Liberatore 2007: D. Liberatore, Statuaria di età repubblicana dal nemus Angitiae, in D. Liberatore, M. J. Strazzulla, Fucino. Studi sulla cultura figurativa, Bari 2007, pp. 7-56.

Maldague X.P.V. (2001) - Theory and Practice of Infrared Technology for Nondestructive Testing, John Wiley & Son, New York, ISBN: 978-0-471-18190-3.

Maniatis Y. & Tite M.S. (1981) - Technological examination of Neolithic-Bronze Age pottery from central and southeast Europe and from the Near East. Journal of Archaeological Science, 8(1), 59-76, https://doi.org/10.1016/0305-4403(81)90012-1.

Zevi F. (2012) - Il santuario demetriaco di Valle Ariccia. Ostraka 141-159.

Micro-invasive XRD and XRF analyses of pottery from Nuraghe Candelargiu (SW Sardinia): tracing technological and cultural transitions from the Nuragic to Punic periods

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Keywords: pottery, XRD, XRF.

The excavation of Nuraghe Candelargiu (SW Sardinia) yielded a large number of ceramic fragments (Rodríguez Azogue, 2020) enabling the archaeometric investigation of apx 100 non-musealizable samples. The study aims to address a major archaeological question: whether pottery production can record technological and social changes across the Bronze Age, Iron Age, and Punic periods in Nuragic society.

Micro-invasive analyses were authorized by the Archaeological Superintendence and about 0.4 g of material was powdered for analytical characterizations. Synchrotron micro-X-ray diffraction (Elettra, Trieste) was performed on powdered material loaded into glass capillaries. XRD were collected using a Pilatus detector, integrated with Dioptas, analysed qualitatively and quantitatively with HighScore Plus and GSAS-II softwares. Laboratory XRF was carried out with a Rigaku Supermini200 spectrometer on lithium borate fused beads prepared from 0.2 g of sample after LOI determination and 9.8 g of flux. Calibration was based on 15 certified rock standards with comparable compositions. The strong dilution minimized matrix effects.

The mineralogical assemblage mainly consists of plagioclase, K-feldspar, quartz, pyroxene, amphibole, mica/illite, and hematite. Petrographic observations indicate that feldspars, pyroxene, amphibole, and quartz represent the main temper components, generally occurring as subangular crystal fragments. In contrast, a subgroup of Punic pottery is characterized by rounded quartz temper and distinct textural features.

Quantitative XRD data, excluding the largely amorphous clay matrix non-quantified, provided a robust dataset for multivariate cluster and PCA analyses. The results reveal two main compositional groups: one dominated by Punic pottery, and another including Bronze and Iron Age ceramics together with a minor Punic subset. Major, minor, and selected trace-element XRF data reproduce the same clustering pattern observed from XRD data alone. Bronze and Iron Age ceramics differ significantly in P2O5 content, ranging from 0.5-2 wt.% in Bronze Age to 2-6 wt.% in Iron Age ceramics, suggesting modifications in manufacturing technology, possibly related to the intentional addition of organic material.

The results support the hypothesis of predominantly local ceramic production during the Bronze and Iron Ages, further reinforced by crystal-chemical similarities between temper minerals and nearby andesitic-dioritic outcrops (electron microprobe analyses). Punic pottery appears texturally and compositionally distinct, indicating a non-local provenance. Ongoing microtomography and automated image analyses are aimed at further constraining porosity and textural parameters.

From a methodological perspective, the study demonstrates that synchrotron micro-XRD and laboratory XRF on extremely diluted samples can provide reliable quantitative datasets suitable for the discrimination and comparative investigation of large archaeological ceramic assemblages

Rodríguez Azogue A. et al. (2020) - Le ricerche archeologiche del Proyecto Nuraghe (San Giovanni Suergiu, SU). Notizie & Scavi della Sardegna Nuragica, 209-217.

From the black bottoms of vases to the light of the screens

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Keywords: multi-analytical approach, serious game, communicating archeological sciences.

This contribute presents the results of an innovative teaching project aimed at involving students from all fields in the results that can be obtained from an archaeometric study.

The black deposits, frequently found inside ceramic containers, represent a sort of time capsule, offering valuable evidence of daily activities in the past. In-depth study of these residues, as well as the ceramic objects themselves, conducted through laboratory analysis (photogrammetry, petrographic, mineralogical, chemical, spectroscopic (Raman and FT-IR), and electron microscopy analyses, as well as dating), revealed little-known details about the daily life of ancient communities, leading students to discover fascinating stories that took place within the home and beyond, involving trade and contact between peoples.

Communicating the results of archaeological research is never an easy task; the experience focuses on creating an exploratory narrative where the player, virtually entering the ‘dark depths’ as if in a cave, must learn to find their way out of the darkness and discover the results of scientific research.

The synergy between archaeology and computer science students and professionals in the audiovisual sector has given rise to a 2D online video game in which players can delve into these “black funds” as if they were a dark cave. Users can therefore “emerge from the darkness” by finding the right path: learning and finding their way, or getting lost in the dark.

Black Glazed Wares from the colony of Ariminum (Rimini): An archaeometric study

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Keywords: black glazed pottery, Ariminum, archaeometry.

The black-glazed pottery from the Latin colony of Rimini (founded in 264 BCE) constitutes a significant case study for examining the phenomenon of Roman colonization in ancient Italy. This research provides critical insights into the transmission of specialized practical knowledge, the training and organization of artisans within the colony, and the evolving interactions between Rome and its colonial settlements from the 4th to the 2nd century BCE. The production of black-glazed pottery during this period was characterized by extensive technical experimentation, fostering the development of innovative solutions tailored to the demands of mass serial production, which necessitated both high-quality standards and large-scale output. An archaeometric investigation was conducted on ceramic bodies and their respective black glazes. Analytical techniques including X-ray powder diffraction, X-ray fluorescence, and both optical and electron microscopy were employed on the ceramic bulk. Selected black-glazed samples, chosen for their distinctive chromatic appereance, were subjected to SEM-EDS, synchrotron radiation-based micro-X-ray diffraction (SR-based μ-XRD), and X-ray absorption spectroscopy (XAS) analyses. These advanced methodologies were utilized to elucidate the chemical composition of the glazes, the mineralogical phases and their spatial distribution, as well as the concentration, distribution, and oxidation states of the transition element Fe. To assess potential compositional variations between the near-surface region (few nanometers) and the bulk material, XAS measurements were performed in both Conversion Electron Yield (CEY) and Fluorescence Yield (FY) modes, utilizing point analysis and mapping approaches.

Distinct ore sources for copper blades and rivets: The Eneolithic daggers of Buca del Corno (northern Tuscany)

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Keywords: Eneolithic, archaeometallurgy, copper provenance.

The development of human society is closely linked to access to natural resources. One of the major turning points in human history was the rise of metallurgy with production of metal artefacts and the gradual replacement of stone tools. In this context, metal provenance represents a key issue for understanding resource exploitation, technological choices, and exchange networks in ancient societies.

This contribution investigates the Cu artefacts recovered from Buca del Corno, an Eneolithic funerary site located in Camaiore (northern Tuscany). The analyzed objects include two Cu blades and their rivets, currently preserved at the Civico Museo Archeologico di Camaiore. The artefacts were characterized through chemical analyses (FP-XRF, ICP-MS) and Pb isotope composition (MC-ICP-MS) to investigate the provenance of the ores exploited for metal production.

The analytical results reveal clear compositional differences between blades and rivets. The blades are made of arsenical copper, with As contents up to 2.5 wt%, whereas the rivets consist of nearly pure copper with a characteristics Se anomaly. Lead isotope data further support this distinction, showing that blades and rivets display two separate isotopic signatures indicating the use of distinct ores for their production.

These data suggest a deliberate technological choice in ore selection during the Eneolithic. Arsenical copper, with improved hardness and mechanical properties, was selected for blade production, whereas purer and more malleable Cu, was used for the rivets.

Overall, this study evidences that the manufacture of functional daggers involved intentional selection of Cu from different sources, highlighting an “advanced” knowledge of ore resources in Eneolithic communities.

Powdered Olive Stone (POS) as a sustainable additive in lime-based mortars for the conservation of Cultural Heritage

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Keywords: lime-mortars, agro-wastes, olive stone powder.

The construction sector exerts a considerable influence on the environment, primarily due to the extensive consumption of natural resources associated with building activities (Alengaram & Muhit, 2013). The continuous depletion of these resources has generated growing environmental concerns, highlighting the urgent need for more sustainable construction strategies.

As the global demand for construction materials rises, increasing attention has been directed toward the adoption of eco-friendly practices and alternative materials capable of reducing environmental issues and preserving natural resources for future generations. In this context, the incorporation of waste materials and industrial or agricultural by-products as admixtures or additives in mortars has emerged as a promising approach, owing to its potential to decrease both raw material consumption and the embodied energy of the final product (Maravelaki et al., 2023).

The present study explores the potential application of Powdered Olive Stone (POS), an agricultural by-product, in lime-based mortars for the conservation of historic buildings This study investigates the use of Powdered Olive Stone (POS), an agricultural by-product, in lime-based mortars used for the conservation of historical buildings. A lime-to-aggregate ratio of 1:3 by volume was adopted in this study, while POS was incorporated as a partial volumetric replacement of sand at substitution rates of 5%, 10%, and 15%. In addition, the effect of nanosilica incorporation within the mortar mixtures was also investigated.

Following specimen curing, a comprehensive experimental campaign was carried out to evaluate the physical and mechanical properties, including colorimetric characterization, optical and electron microscopy observations, capillary water absorption measurements, ultrasonic pulse velocity analysis, bulk density determination and mechanical testing. Their durability to salt crystallization was investigated as well.

The findings indicate that the incorporation of POS induces substantial changes in both the physical and mechanical behavior of the mortars, allowing the material properties to be adjusted according to specific conservation requirements. In particular, the addition of POS was found to increase the capillary porosity of the mixtures. Such enhanced porosity may promote greater moisture penetration and facilitate the migration of soluble salts, potentially enabling the mortar to act as a sacrificial material and thereby reducing deterioration phenomena affecting the original substrates. Ongoing research is focused on further assessing the long-term applicability and performance of these mortar formulations in conservation contexts.

Alengaram U.J. & Muhit B.A.A. (2013) - Utilization of oil palm kernel shell as lightweight aggregate in concrete - a review. Constr. Build. Mater., 38, 161-172, https://doi.org/10.1016/j.conbuildmat.2012.08.026.

Maravelaki P. et al. (2023) - RILEM TC 277-LHS report: additives and admixtures for modern lime-based mortars. Mater. Struct.,56, 106, https://doi.org/10.1617/s11527-023-02175-z.

S32.

Living in volcanic areas and coastal environments: Risks, anthropogenic impacts and cultural heritage

CONVENERS & CHAIRPERSONS:

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Rolled, tumbled and rounded, then used. A preliminary approach to the polished stone industry of the early Bronze age site of S. Vincenzo, Stromboli

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Keywords: bronze Age, stone tools, use-wear.

Resting for millennia on the steep beaches of Stromboli, vast quantities of volcanic pebbles have for centuries provided the inhabitants of the village of S. Vincenzo with an excellent and abundant source of raw material. The pebbles have been used for light and heavy striking percussion, for perforation, for abrasion of hard substances and grinding of food. Thus, they retained on their surfaces negative interfaces that remain hard to detect, as well as difficult to document and interpret. The presentation aims at sharing our first efforts at providing a functional classification of the important but still elusive class of prehistoric artifacts.

Effusive rocks do pottery better

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Keywords: WikiPottery, Bronze age, Aeolian Islands, pottery.

Extensive petrographic investigations of Central Mediterranean prehistoric pottery underline a recurrent preference for effusive components in ceramic pastes.

Here we consider data reported in WikiPottery, a systematic classification specifically developed by our team at the University of Modena and CNR-ISPC, which analyzed more than 2000 prehistoric pots from almost 100 sites and identified approximately 200 different fabrics. Effusive components, present as clasts in the clay-rich groundmass, are further distinguished into basaltic, andesitic, trachytic, dacitic-rhyolitic, and phonolitic types.

Considering the samples attributed to the Bronze Age, almost 40% of fabrics contain sedimentary components and/or grog, representing the most common choice, in line with the general geology and lithology of the Italian peninsula and Sicily. Effusive rock clasts occur in ~30% of the fabrics (alone or in combination with other components), representing the second most frequent composition. If monolithological compositions are considered, their relative abundance is: sedimentary 30%, effusive 20%, intrusive 6%, metamorphic 10%, and grog 10%.

Effusive ceramic fabrics are the obvious choice for potters' recipes in volcanic landscapes, such as the Aeolian Islands, but are also abundant in areas with mixed lithologies, for example in many Tyrrhenian regions of the Italian peninsula. In such mixed settings, pottery with effusive components is consistently preferred and widely distributed toward areas with different lithologies. Regions characterized by widespread sedimentary outcrops show a significant presence of imported pots with effusive components (or raw materials), whereas pots with sedimentary fabrics are absent in effusive areas.

We summarize here selected case studies on potters' choices and discuss their possible cultural and technical implications.

Which Volcano? Chance and necessity in prehistoric Aeolian Islands

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Keywords: volcanic risk, human volcano relationship, prehistory.

We address the long-lasting human prehistoric presence on the Aeolian Islands, the archipelago with active volcanoes in the Southern Tyrrhenian Sea, Italy.

The Aeolian Islands are extremely significant for the prehistory of the Mediterranean, for the central strategic position (in control of the Strait of Messina), the natural resources and the abundance of archaeological data. The islands have been extensively investigated, including by our team which has an ongoing main excavation at Stromboli and other interdisciplinary projects across the Archipelago.

A conceptual model has been built to explore the human presence and abandonment in the various Islands from the Neolithic to the Bronze Age (VI-I millennium BCE). We consider geography, morphology, natural resources and volcanism along with the archaeological data.

Archaeological data include the number and location of the villages and the connectivity between the Islands and other Mediterranean areas as outlined by the import - export patterns. For example, the Islands exported raw obsidian (abundant in Lipari) and imported pottery and other exotic prestigious goods. Our extensive project of pottery analyses has identified numerous ceramic compositions reflecting different origins and circulation networks. Circulation was not confined to the final product but included also people: the local production of exotic pottery was likely linked to interregional marriages. The importance of the sea is also reflected in the decorations, where an apparent abstract style of incised motifs clearly represents the seascape.

Furthermore, the human response to volcanic environments, to risk and to insularity is discussed. We propose a complex narrative where a combination of geological, socio-economic, and psychological factors influenced people's choices suggesting that human presence is related more to the volcanic (and island) environment (and opportunities) than to volcanic activity.

Tracing sea-routes and terrestrial paths of volcanic millstones trade linking source regions to final destinations by the archaeological (and petrological) data from the "intermediate" sites

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Keywords: archaeology, grinding stones, volcanic provenance.

One of the aims of the archaeometric studies on volcanic millstones is to determine the provenance of raw materials through the rigorous application of igneous petrology methods, i.e. thin section petrography combined with major and trace element geochemistry, and the subsequent comparison of artefacts with geologically, mineralogically and geochemically-compatible volcanic rocks (mainly lavas). This classical approach has been systematically applied to millstones from several well-known terrestrial archaeological sites across the Mediterranean (e.g., Megara Hyblaea, Santi et al., 2022), allowing the identification of volcanic source regions over a broad geographic scale. However, petrological and geological matching alone can only highlight the source region (volcano or volcanic area) and the final destinations of the artefacts (archaeological sampling sites). Precise sea-routes or overland paths cannot be reconstructed unless "intermediate" archaeometric data for the same volcanic lithotype are identified along the hypothetical distribution corridor.

When volcanic millstones of the same chronological period and the same volcanic source are discovered at both terrestrial sites and in shipwreck cargoes across the Mediterranean, a coherent distribution pattern can be unravelled. The case of Pantelleria Island exemplifies this approach: it can be identified as one of the most important production areas for lava grinding stones at least from the 7th to the 4th centuries BCE, on the basis of Pantelleria basalts documented in both shipwreck cargoes (Williams-Thorpe & Thorpe, 1990; Renzulli et al., 2019) and terrestrial sites up to 1,500 km away, i.e. the westernmost Phoenician settlement of Cadiz (Spain).

For terrestrial distribution networks, the reconstruction of transport routes can be further advanced through least-cost path (LCP) analysis. By applying slope-dependent, cost-surface algorithms to a digital elevation model, as demonstrated in the study of Final Bronze Age grinding tools from Monte Croce Guardia (Arcevia, central Italy; Santi et al., 2023), it is possible to simulate the most plausible overland corridors between a volcanic source area and a distant archaeological site. Crucially, such simulated routes frequently pass through settlements coeval with both the source and destination sites. This observation opens a clear and testable research programme: the systematic archaeometric analysis of volcanic grinding tools from intermediate sites along LCP-defined corridors could either confirm or falsify the existence of structured, recurrent exchange routes. The integration of igneous petrology, geospatial modelling, and targeted sampling at nodal intermediate sites thus represents a robust and increasingly feasible methodological framework for reconstructing ancient terrestrial trade and mobility networks at a sub-regional to regional scale.

Renzulli A. et al. (2019) - Pantelleria Island as a centre of production for the Archaic Phoenician trade in basaltic millstones: New evidence recovered and sampled from a shipwreck off Gozo (Malta) and a terrestrial site at Cádiz (Spain). Jour. Arch. Sci.: Reports, 24, 338-349, https://doi.org/10.1016/j.jasrep.2019.01.019

Santi P. et al (2022) - Petrological footprints of the millstones of Megara Hyblaea (Sicily Island, Italy) highlight the human interactions with Mediterranean volcanoes. Scientific Reports, 12:12494, https://doi.org/10.1038/s41598-022-16784-1

Santi P. et al (2023). Tracing the human movements of three thousand years ago by volcanic grinding tools in the Final Bronze Age settlement of Monte Croce Guardia (Arcevia-Marche Region, central Italy). Scientific Reports 13, 7022, https://doi.org/10.1038/s41598-023-34033-x.

Williams-Thorpe O. & Thorpe R.S. (1990) - Millstone provenancing used in tracing the route of a fourth-century BC Greek merchantship. Archaeometry 32(2), 115-137.

Cultural heritage and volcanoes: The role of knowledge dissemination in awareness raising and volcanic risk mitigation

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Keywords: Osservatorio Vesuviano, Cultural Heritage.

The dissemination of scientific knowledge on natural hazards represents a fundamental strategy for risk reduction and the enhancement of community resilience. Effective risk communication, supported by accurate and accessible scientific information, contributes to the development of public awareness and sustainable environmental management. Educational institutions, particularly schools, play a crucial role in promoting a long-term culture of risk by fostering scientific literacy and awareness among younger generations. In parallel, scientific organizations are increasingly integrating research activities with outreach and educational programs aimed at broader public engagement. Recently, Science Museums and Science Centers became vital actors in this mission. Evolving from traditional exhibition spaces into interactive learning environments, they now engage a wide and diverse public through digital and multimedia tools. This transformation made scientific knowledge more accessible and appealing, supporting a deeper public understanding of natural processes and associated risks. Within this framework, the Vesuvius Observatory of the INGV, stands as an exemplary case (Di Vito et al., 2023). Founded in 1841 by King Ferdinand II of Bourbon, it is the world's oldest volcano observatory. Its primary mission is the monitoring of the active volcanoes of the Neapolitan area through an advanced surveillance network. Its historic building on the western slope of Vesuvius also houses a museum that preserves valuable scientific and artistic collections, including early instruments, minerals, rocks, paintings, photographs, and films documenting volcanic eruptions. Permanent exhibitions and multimedia installations lead visitors through the history of Vesuvius and the origins of volcano monitoring, making the museum both a scientific archive and a tool for public education. The Observatory also contributed to other cultural initiatives, such as: the geological section of the Archaeological Museum of Villa Arbusto (Ischia, Naples) (de Vita et al., 2021), the Museum of the Vesuvius National Park in Boscoreale (Naples), the Lapis Museum, in the underground of Naples, the Terzigno exhibition, including a quarry along the eastern Vesuvio slopes and, finally, the Museo Vesuviano of the Pontifical Sanctuary in Pompeii (Naples), established by the renowned prelate and volcanologist Giovan Battista Alfano. By integrating scientific, historical, and cultural perspectives (Costa et al., 2022), these initiatives transform museums into permanent centers for education and volcanic risk mitigation, fostering public awareness, promoting respect for the environment, and contributing to a more informed and resilient society.

Costa A. et al. (2021) - The long and intertwined record of humans and the Campi Flegrei volcano (Italy). Bulletin of Volcanology, 84(1), 5, https://doi.org/10.1007/s00445-021-01503-x.

de Vita S.et al. (2021) - Disseminating the knowledge on the complex interactions between humans and volcanoes: the geological section of the Villa Arbusto Archaeological Museum at Lacco Ameno (Ischia, Naples - Italy). Ann. Geophys., 64(5), VO544-VO544, https://doi.org/10.4401/ag-8666.

Di Vito M.A. (2023) - The Museum of the Osservatorio Vesuviano: inviting the public to explore the geoheritage of the world's first volcano observatory. Bull. Volcanol., 85(8), 45, https://doi.org/10.1007/s00445-023-01658-.

Morphodynamic evolution and impacts of coastal armouring along the Punta Penna-Punta Pietre Nere Physiographic unit (Central Adriatic Coast, Italy)

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Keywords: coastal morphodynamics, coastal armouring, shoreline changes.

Sandy beach-dune systems are highly vulnerable coastal environments, increasingly affected by anthropogenic pressure, reduced sediment supply and climate-change-related forcing. This contribution investigates the impact of coastal armouring on beach-dune morphodynamics and shoreline dynamics along the 60 km coastal sector of the Punta Penna (Abruzzo) - Punta Pietre Nere (Apulia) physiographic unit. Following a consolidated approach, the study coast has been subdivided into twelve coastal segments, including the southernmost portion of the Abruzzo, the entire Molise and the northernmost part of the Apulia coast (Dilauro et al., 2025). A multi-temporal analysis based on aerial photographs, orthophotographs and satellite images dating from 1954 to 2025, showed a marked increase in hard coastal defence structures from 1989 onwards. The shoreline protection increased significantly from 1989 to 2012, from 20% to 42%, corresponding to respectively 11.6 km and 24.7 km of protected shoreline, then remained substantially unchanged during 2012-2022. Coastal armouring is highly unevenly distributed: the Abruzzo coastal sector shows 31% of protection, the Molise coast reaches 62%, whereas the Apulian sector shows only 4.8% of protection. This trend had already been observed by Di Paola et al. (2023) for the Molise coast located south of the Termoli promontory (the southern Molise coast), who documented a progressive increase in the coverage of coastal defence and harbour structures from 7.0% in 1957 to 64.2% in 2019, highlighting the most important intermediate states of protection with 32.0% and 49.9% in 1985 and 1992, respectively. In particular, the sector extending from the Termoli promontory towards Campomarino Lido represents one of the most heavily engineered stretches. Nevertheless, as documented by Dilauro et al. (2025), the southern Molise coast continued to undergo significant erosion also during the period 2012-2022, with retreat rates of −1.17 m/y for the shoreline and −0.54 m/y for the dune foot, while the remaining part of the physiographic unit showed shoreline and dune-foot trends generally more favourable. The impact of coastal defence structures on the physiographic unit was also particularly significant regarding variations in morpho-bathymetric features as documented for some key studies by Aucelli et al. (2007) and by Di Paola et al. (2023), highlighting significant morphological changes of the seabed in protected sectors. Among the several impacts of breakwaters, the failure of bar-and-trough morphologies and the deepening of breakwater gaps, as well as seabed deepening in areas directly facing the structures is observed. The effect of hard defence structures on coastal equilibrium appears therefore not unequivocally positive. Although these structures may locally promote stability or progradation, they surely alter the sediment transport towards the coast and along the shoreline, so may redistribute rather than remove, coastal vulnerability. This highlights the need for an integrated assessment of coastal armouring, sediment budget, shoreline evolution, dune-foot dynamics and submerged-beach morphology. Based on precedent and recent data collected, this contribution aims at analysing together local to regional shoreline trends, hard structure constructions and seabed morphology, in order to better highlight their relationships and to acquire particularly data on the eventual inefficiency of hard defences.

Aucelli P.P.C. et al. (2007) - Caratterizzazione morfologico-dinamica e meteomarina della costa molisana nel settore compreso tra la foce del torrente Sinarca e Campomarino Lido (Italia meridionale). Studi Costieri, 13, 75-92.

Dilauro G. et al. (2025) - Long- to short-term evolution of the beach-dune systems along the physiographic unit Punta Penna-Punta Pietre Nere (Central Adriatic coast, Italy). Catena, 256, 109102.

Di Paola G.E. et al. (2023) - Holocene to near-future evolution of the southern Molise coast (Central Adriatic, Italy) under the influence of natural and anthropogenic controls. Journal of Maps, 19(1).

Living in Campi Flegrei with bradyseism and eruptions and its anthropogenic Impact through time

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Keywords: Campi Flegrei, bradyseism.

After centuries of subsidence, documented by numerous monuments since the Roman period, the ground of the Campi Flegrei caldera has been rising again for over seventy years. This movement has been accompanied by progressively more intense seismic crises.

The fear that the uplift might precede an eruption, as occurred in 1538, has in recent decades led to drastic but ultimately inconclusive decisions, causing economic damage and significant social consequences.

In 1970, ground uplift prompted, as a precautionary measure, the evacuation of a district of Pozzuoli, the historic centre known as the Rione Terra. The decision was sudden, and the evacuation was carried out by force, plunging more than 3,000 people into deep disorientation. The choice, based on unclear assumptions and not shared by the population, gave rise to suspicions—never entirely dispelled, although ultimately unfounded—of real estate speculation. The construction of a new district, Rione Toiano, inevitably led to the uprooting of the displaced population from their distinctive urban and social fabric.

In 1983, a new uplift episode, accompanied by stronger seismic activity than the previous one, led to the voluntary evacuation of more than 40,000 people from the centre of Pozzuoli, who were temporarily relocated to tourist facilities or provisional housing. The new district of Monte Rusciello alleviated the most severe hardships but, being distant from customary living conditions and separated from workplaces, was never fully accepted by the evacuees.

During this crisis, the National Civil Protection Department was established, and monitoring institutions were strengthened.

From 1985 to 2006, the ground subsided again. Thereafter, a slow inflation resumed, which is still ongoing, although at a much lower rate than during the two previous crises.

A relative acceleration has been accompanied by several seismic crises, with shallow earthquakes beneath the city of Pozzuoli reaching magnitudes up to 4.6—values never observed during earlier crises—which have alarmed the population.

The gradual development of the current crisis, together with the constant presence of monitoring systems and Civil Protection authorities, has allowed for an orderly emergency response, supported by enhanced communication efforts and a detailed intervention plan in the event of worsening conditions. The experience of the two previous crises, and the outcomes of the measures adopted, has provided a useful basis for comparison.

However, the persistence of this situation, without clear prospects for resolution, continues to fuel a widespread sense of insecurity and growing doubts about predictive capabilities, as well as a proliferation of unclear proposals regarding the actions to be taken in the event of an unfavourable evolution.

Living with volcanoes: obsidian exploitation, mobility and cultural networks in the Aeolian Islands during the Bronze Age

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Keywords: Stromboli, obsidian technology, raw materials circulation.

The Bronze Age settlement of San Vincenzo on Stromboli represents a key case study for investigating the role of volcanic islands within Mediterranean exchange networks and human mobility systems during the 2nd millennium BCE. Located on one of the most active volcanoes in Europe, the site occupied a strategic position in the southern Tyrrhenian Sea and functioned as an important node linking insular and mainland communities. Recent investigations carried out within the Stromboli Project have highlighted the central role of obsidian exploitation and circulation in shaping the economic and cultural dynamics of the settlement.

This contribution presents the preliminary results of a technological, spatial and geochemical study of the obsidian assemblage from the Capo Graziano village of San Vincenzo. The analysis combines techno typological approaches, *chaîne opératoire* reconstruction, GIS spatial distribution and non-destructive p-XRF analyses in order to investigate raw material procurement, reduction strategies and the organization of domestic and productive activities.

The results indicate that the obsidian exploited at San Vincenzo most likely originated from Lipari and was intensively worked through highly opportunistic reduction sequences aimed at maximizing raw material use. The assemblage includes blades, bladelets, flakes and numerous exhausted cores, suggesting both domestic consumption and specialized production activities. Spatial analyses reveal significant concentrations of obsidian within dwelling contexts and productive areas, pointing to the integration of lithic production into daily life and local economic organization.

The study contributes to broader discussions concerning volcanic landscapes as active cultural and economic hubs rather than marginal environment. In the Aeolian context, obsidian circulation reflects long term maritime connectivity, technological knowledge transmission and adaptive strategies developed within a highly dynamic volcanic environment. The evidence from Stromboli highlights how volcanic resources played a major role in shaping social interaction, resilience and mobility across the prehistoric Mediterranean.

Volcanic landscapes of Latium: Resources, myths and environmental risks in a Mediterranean perspective

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Keywords: volcanic landscape, Latium, evolution of coastal environments.

Mediterranean volcanic areas have long represented strategic environments where natural resources, human mobility, and cultural elaboration converged. Far from being marginal landscapes, these territories historically functioned as dynamic nodes within broader exchange networks, providing fertile soils, abundant water resources, and mineral wealth (Dolfini et al., 2019). This contribution explores the volcanic landscape of the Latium coast between the Tiber mouth and the Alban Hills as a case study to investigate long-term interactions between geology, cultural heritage, and human settlement.

The area, shaped by the volcanic activity of the Colli Albani, was characterized in antiquity by coastal lagoons, freshwater springs, gas emissions, and highly productive agricultural land. These environmental features supported subsistence and trade and played a key role in shaping mythological narratives and ritual practices. Archaeological and geomorphological evidence indicates that inland settlements such as Lavinium and Ardea, located close to the coast, were connected to lagoon systems through river networks (the Numicus and the Fosso dell'Incastro) and to coastal access points ranging from landing places such as the sanctuary of Sol Indiges to more structured harbour sites such as Castrum Inui, thus forming part of wider Mediterranean mobility networks (Jaia, 2012).

The myth of Aeneas, as transmitted by classical sources, can be interpreted as a cultural reflection of these dynamics. The so-called "Aeneas route" mirrors ancient cabotage routes that supported the trade in metals, salt, and other commodities, linking the Latium coast with the eastern Mediterranean (Cifani, 2021). In this perspective, myth and landscape appear deeply intertwined: geomorphological features such as lagoons, rivers, and volcanic phenomena—including sulphurous emissions and gas exhalations—contributed to the construction of symbolic and religious meanings, including oracular practices and sacred geographies.

At the same time, these environments reveal a long-term vulnerability. The same geological characteristics that ensured resource abundance—such as unconsolidated volcanic deposits and dynamic coastal systems—also make these areas particularly fragile. Over time, processes such as coastline progradation, wetland reclamation, and increasing anthropogenic pressure have profoundly transformed the original landscape, often leading to the loss of both natural and cultural heritage (Madonna et al., 2022).

By integrating geological, archaeological, and literary data, this study highlights how volcanic landscapes functioned as interconnected systems in which resources, risks, and cultural identities co-evolved. Understanding this legacy is crucial not only for reconstructing past Mediterranean connectivity but also for addressing present-day challenges related to sustainability, risk mitigation, and heritage management in volcanic regions.

Cifani G. (2021) - The origins of the roman economy From the Iron Age to the Early Republic in A Mediterranean Perspective. Cambridge University Press. Printed in the United Kingdom by TJ International Ltd, Padstow Cornwall. ISBN 9781108748742.

Dolfini A. et al. (2019) - Copper to Tuscany: The dynamics of metal exchange in early Italy. PLoS ONE, 15(1), e0227259, https://doi.org/10.1371/journal.pone.0227259.

Jaia A.M. (2012) - Il Santuario di Sol Indiges e il sistema di controllo della costa laziale nel III sec. a.C. , in Lazio e Sabina. 8. Ottavo incontro di studi sul Lazio e la Sabina. Atti del Convegno, Roma 30 marzo - 1 aprile 2011, 373-383.

Madonna S. et al. (2022) - Enea e Turno: Il paesaggio del mito tra geologia ed archeologia. Mem. Descr. Carta Geol. d'It., 109, 123-136.

From Quaternary coastal evolution to present and future vulnerability to seawater intrusion: new insights from the SAL.WE. project in the Volturno coastal plain, southern Italy

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Keywords: saltwater intrusion, Quaternary coastal evolution, coastal vulnerability.

Coastal plains are sensitive to Quaternary inheritance, anthropogenic pressure and ongoing relative sea-level rise. Specifically, the Volturno coastal plain (southern Italy) provides a case study to investigate how long-term coastal evolution may influence present-day saltwater intrusion and future environmental vulnerability. This contribution presents preliminary results from the SAL.WE. project, developed within an agreement between CNR-ISMAR and the Southern Apennines River District Authority, aimed at characterizing saltwater intrusion in the Volturno coastal plain.

The study combines published geomorphological and stratigraphic reconstructions with newly acquired and processed datasets. Late Quaternary reconstructions, integrated with recently mapped fault systems, were used to define the geological background (Amorosi et al., 2012; Bruno et al., 2025) and support the interpretation of present-day saltwater intrusion patterns. GIS-based spatial analysis includes 3D subsoil stratigraphy, subsidence time series data and shoreline-change analysis.

New SAL.WE. data include both surface-water monitoring, by means of multiparametric profiles acquired along the terminal Volturno River, hydrochemical data, chloride analyses and sediment characterization, and groundwater monitoring with ERT profiles aimed at identifying low-resistivity bodies potentially related to saline waters. Preliminary results suggest that salinization is spatially heterogeneous and may preferentially affect sectors where paleovalley fills, lagoonal-palustrine deposits, low hydraulic gradients and subsidence converge. These observations suggest that the geological setting may modulate the effects of groundwater exploitation, climatic variability and relative sea-level rise.

Vegetation and salinity patterns have been analysed using Sentinel-2 imagery acquired between June and September 2025 to investigate spatial relationships between vegetation stress and salinization processes (Su et al., 2025). NDVI and Salinity Index layers have been compared with natural, anthropogenic and hydromorphological variables in a geodatabase and analysed through an R-ArcGIS multiple regression workflow to produce effect and vulnerability maps. Preliminary results suggest that vegetation stress is mainly concentrated along the Volturno fluvial axis and near productive and waste-disposal areas, while salinity appears to be a relevant driver of NDVI variability and mainly associated with natural factors.

Future vulnerability is discussed considering the combined effects of land subsidence, climatic change and sea-level rise, which may favour coastal flooding, reduce freshwater hydraulic gradients and promote inland salinity migration (Aucelli et al., 2017). Overall, the SAL.WE. project provides new multidisciplinary data to support the assessment of saltwater intrusion and coastal vulnerability in a strongly anthropized Mediterranean coastal plain.

Amorosi A. et al. (2012) - Late Quaternary incision and deposition in an active volcanic setting: The Volturno valley fill, southern Italy. Sedimentary Geology, 282, 307-320, https://doi.org/10.1016/j.sedgeo.2012.10.003.

Aucelli P.P.C. et al. (2017) - Coastal inundation risk assessment due to subsidence and sea level rise in a Mediterranean alluvial plain (Volturno coastal plain-southern Italy). Estuarine, Coastal and Shelf Science, 198, 597-609, https://doi.org/10.1016/j.ecss.2016.06.017.

Bruno P.P.G. et al. (2025) - Investigating tectonic links between the deep Volturno plain and Campanian volcanism using vintage seismic and potential field data. Scientific Reports., 15, 21602, https://doi.org/10.1038/s41598-025-03836-5.

Su Q. et al. (2025) - The growing trend of saltwater intrusion and its impact on coastal agriculture: Challenges and opportunities. Science of the Total Environment, 966, 178701, https://doi.org/10.1016/j.scitotenv.2025.178701.

GIS-based analysis of anthropogenic coastline advances and retreats of the eastern Friuli Venezia Giulia region (NE Italy) over the past 200 years

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Keywords: anthropogenic coastline changes, land reclamation, North-eastern Adriatic Sea.

Coasts are land-ocean interfaces of high environmental and economic value, providing essential ecosystem services and representing highly dynamic areas where natural processes interact with increasing anthropogenic pressure. As areas of intense urban and economic development, they have been widely modified, resulting in the loss of natural resources, habitats and biodiversity, and the transformation of coastal landscapes from natural to anthropogenic.

The Italian coastal area is highly anthropised, with 34% of the population permanently residing in coastal cities (Mirto, 2022). The Italian coastline is approximately 8,300 km long, 13% of which is occupied by artificial structures, with an increase in coastal artificialisation of over 100 km in the last 20 years.

The study area is located along the eastern coast of the Friuli Venezia Giulia (FVG) region (north-eastern Italy), facing the north-eastern Adriatic Sea, and includes the municipalities of Monfalcone, Duino-Aurisina, Trieste and Muggia. 18% of the FVG coast is considered natural, while the remainder is classified as artificial (IRDAT FVG, 2022). Anthropogenic pressures are associated with the main industrial, port and urban activities (Pagano et al., 2023).

The aim of the study is to evaluate and quantify coastline changes (advances and retreats), where the coast is predominantly rocky, caused by anthropogenic activities over the past 200 years, through the analysis of maps in a GIS environment.

To conduct the analysis, a series of charts and maps of the study area from the past 200 years were collected. After georeferencing the charts, past coastlines were digitised and compared with each other and with the 2025 coastline using a Geographic Information System (GIS).

The areas of advances and retreats were calculated, and periods of intense coastal change were identified, with each change analysed in relation to human pressure and the intended land and sea use at the time it occurred.

Between Monfalcone and Muggia, a total advance of 7.1 km² and a total retreat of 1.4 km² have been quantified.

In some areas, advances reached several hundred metres, mainly due to the construction of infrastructure, ports, and industrial settlements.

In Monfalcone, the greatest coastline changes were related to dredging activities for the construction of the port (retreat of 1.019 km²) and the construction of a dredged material disposal site (advance of 1.517 km²). In Trieste, the advance was mainly due to the construction of the Old Port and urban development during the 19th century, and the New Port and industrial area development during the 20th century (advance of 2.825 km²). The greatest retreat is observed in the Bay of Muggia, caused by the construction of the Zaule navigable channel (retreat of 0.141 km²) .

In Duino, changes are limited, with modest advances associated with tourism and urban areas.

IRDAT FVG (2022) - Tipologia di costa. https://irdat.regione.fvg.it/consultatore-dati-ambientali-territoriali/results.

Mirto A.P.M. (2022) - Attività antropiche e salute delle coste: indicatori territoriali di rischio e sostenibilità per aree costiere e insulari in Italia e nell'Unione Europea. Istituto Nazionale di Statistica (ISTAT), Roma, 134 pp.

Pagano M. et al. (2023) - Multicriteria GIS-based analysis for the evaluation of the vulnerability of the marine environment in the Gulf of Trieste (north-eastern Adriatic Sea) for sustainable blue economy and maritime spatial planning. People and Nature, 5, 2006-2025. https://doi.org/10.1002/pan3.10537.

Campanian Ignimbrite used as building stone for the 3rd century BC "Sacelli" of the Italic Sanctuary of Pietrabbondante (Isernia, Southern Italy)

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Keywords: archaeometry, volcanology, archaeology.

The Italic Sanctuary of Pietrabbondante (Isernia, Italy) represents one of the main monumental complexes of ancient Samnium. In the eastern sector of the sanctuary, downhill from the main Temple and the Theatre, near the Aerarium, a cult building is known as the "Sacelli", whose earliest architectural phase can be dated to 3rd century BCE. The preserved structure is characterised by grey volcanic stones occurring in masonry walls, foundation blocks, column drums and capitals. The building, destroyed by the Carthaginian armies (Hannibalic War, 217 BCE) was later restored and transformed in its layout, with the volcanic stone blocks being reused, also in other structures of the sanctuary (Mazzeo, 2024).

The volcanic building stones are represented by a welded grey ignimbrite consisting of a matrix-supported tuff, from noncohesive to lithified. The tuff is crystal poor and contains black juvenile pumice lapilli. The matrix is composed of light to dark-gray fine ash. In thin section the texture is vitrophyric (porphyritic index never exceeding 10 vol %) with abundant sanidine phenocrysts and rare microphenocrysts and microliths of clinopyroxene, biotite and opaques. The composition of all the investigated volcanic samples is trachytic. The above lithological and petrographic features concur in indicating the welded grey facies of the Campanian Ignimbrite (Pyroclastic Density Current, PDC) of the Phlegraean Fields as the building stone rocktype, also confirmed by preliminary X-Ray Powder Diffractometric analyses. In the stratigraphic sequence of distal outcrops (Campanian Plain) of this PDC erupted at 39.8 ka, the welded grey ignimbrite facies is by far the most voluminous unit, represented predominantly by a massive valley-pond ignimbrite, even across rough mountain terrains. It extended over an area of more than 6000 km^2 on land around the Phlegraean caldera, with a final runout of ca.75 km, and surmounted mountain ridges higher than 1000 m above sea level, even at distal reaches. In this way, the outcrops of the Campanian Ignimbrite from which the building stones at Pietrabbondante would have been taken, undoubtedly represent the more distal ones of the PDC. In particular, the provenance could be the paleovalleys of the Campanian Plain comprised between Mondragone and the W/SW to E/SE piedmont areas of the Matese Mountains, these latter areas being those with overthickened welded grey tuff with respect the average thickness (ca.26 m) throughout the whole Campanian Plain of (Silleni et al., 2024).

Strategies of supplying of the Campanian Ignimbrite to build the 3rd century BCE "Sacelli" and connections between the Italic Sanctuary and the southernmost neighbouring areas will be topics of paramount importance to be investigated.

Mazzeo R. (2024) - I Sacelli in tufo del Santuario orientale, in A. La Regina (a cura di), Archeologia a Pietrabbondante II. Ricerche e Studi 2010-2022, Roma 2024, 345-424.

Silleni A. et al (2024) - Transport and deposition of the 39.8 ka Campanian Ignimbrite large-scale pyroclastic density currents (Italy). GSA Bulletin, https://doi.org/10.1130/B37500.1.

Increasing coastal resilience through nature-based solutions: Lessons learned from a crevasse delta in the Po River Delta (Italy)

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WITHDRAWN

White marbles *spolia* on the Stromboli volcano associated to medieval occupation of the island

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Keywords: rock artifacts, archaeometry, petrography.

Archaeological evidence on Stromboli volcano attests human presence during the Late Neolithic, Chalcolithic, Bronze Age, Hellenistic, Late Roman and Late Antique. Recently, medieval occupation has been emphasized by the discover of a religious building whose roof collapsed during the Late Middle Ages due to local seismic shaking linked to repeated flank collapses of Stromboli (also triggering tsunamis; Rosi et al., 2019). The most complete archaeological dataset comes from the excavation site of San Vincenzo (investigated since 2009 and extending over 700 m^2), located near the northeastern end of the island on a large plateau, at an altitude of 40-100 m a.s.l. This location provided a remarkable visual control over the southern Tyrrhenian Sea and its entrance from the Strait of Messina.

In this work, we are going to deal with the classification of seven white worked stones found during the above excavations, including fragments of colonnettes (parts of windows or doorways), a Corinthian capital or parts of columns of Hellenistic to Roman Imperial chronology and, possible, parts of tombs. The studied artifacts, regardless to their pristine history and chronology, were recovered in: (*i*) the rubble associated with the collapse of the medieval church, (*ii*) the medieval layers above Late Antique tombs (but below the collapsed medieval church), (*iii*) post medieval colluvium channel.

Thin section mineralogy of the investigated samples lead to the classification of six marbles and one biocalcarenite. Maximum Grain Size (MGS) of the marbles shows three different ranges of values: 0.8 mm (one sample); 2.4 mm (one sample) and 3-3.6 mm (four samples). The marble with lower MGS shows a homeoblastic fabric with sutured to embayed boundaries of calcite crystals. The remnant marbles with MGS>2mm are characterised by a heteroblastic fabric with sutured to strained boundaries of calcite. Comparing MGS and carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) stable isotopes of each marble (Antonelli & Lazzarini, 2015) a geological origin from at least two marble lithotypes of the Aegean Islands can be hypothesised.

Archaeological evidence and relative chronological constraints enable us to establish that in the Late Middle Ages a significant human community was present on the island during the Crusades period likely due to the strategic position of Stromboli on the naval routes. In this way, the investigated white marble artifacts found at Stromboli could have arrived as architectural stone elements reused on the island, *i.e.spolia*.

Antonelli F. & Lazzarini L. (2015) - An updated petrographic and isotopic reference database for white marbles used in antiquity. Rend. Fis. Acc. Lincei, 26, 399-413, https://doi.org/10.1007/s12210-015-0423-4.

Rosi M. et al. (2019) - Geoarchaeological evidence of middle-age tsunamis at Stromboli and consequences for the tsunami hazard in the Southern Tyrrhenian Sea. Sci.Reports, 9(1), 677, https://doi.org/10.1038/s41598-018-37050-3.

Assessing climate change impacts on beach carrying capacity: The case of the "Dune Costiere" regional park (Apulia Region)

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Keywords: beach carrying capacity, climate change, coastal morphodynamics.

Coastal areas are highly dynamic systems vulnerable to the effects of climate change, particularly to rising average sea levels and the increased frequency and intensity of extreme marine events. These processes influence the morphodynamic balance of beaches, affecting the shoreline position, modifying sediment budgets, and progressively reducing their carrying capacity (López-Dóriga et al., 2019). In this context, it is essential to develop integrated approaches to quantitatively assess future impacts and support sustainable management strategies.

The study area is located along the Adriatic side of the Apulia region and include two coastal sites within the Apulian Regional Natural Park "Dune Costiere da Torre Canne a Torre San Leonardo", characterized by high environmental value and the presence of dune systems and sandy beaches. The area also represents a major hub for regional beach tourism and is crisscrossed by a dense network of infrastructure, creating a context of intense interaction between natural dynamics and human pressure.

This study adopts a multidisciplinary approach aimed at assessing changes in carrying capacity in relation to climate change, integrating i) analysis of shoreline variation trends using satellite data, historical maps, and in-situ surveys, ii) estimation of vertical ground movement rates from InSAR data for the determination of RSLR for the years 2050, 2100, and 2150 (Anzidei et al., 2021), iii) analysis of wave data from the RON buoy for the classification of extreme events, iv) creation of a high-resolution DTM using topographic and photogrammetric surveys, and v) application of hydrodynamic simulations to assess the impacts of sea level rise and extreme events under different climate scenarios.

The results allow to define evolutionary scenarios for coastal dynamics, quantifying the combined effects of sea-level rise and extreme events on beach morphology and, consequently, carrying capacity. The adopted approach not only provides a detailed assessment of the potential vulnerability but also serves as example of operational tool for the management of coastal areas and the development of tailored climate change adaptation strategies.

Anzidei M. et al. (2021) - Relative Sea-Level Rise Scenario for 2100 along the Coast of South Eastern Sicily (Italy) by InSAR Data, Satellite Images and High-Resolution Topography Remote Sensing, 13(6), 1108.

López-Dóriga U. et al. (2019) - Impact of sea-level rise on the tourist-carrying capacity of Catalan beaches. Ocean & Coastal Management, 170, 40-50, https://doi.org/10.1016/j.ocecoaman.2018.12.028.

The Euganean Hills' blowing caves: Proposal for a geo-site

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Keywords: hypogean meteorology, radon, dissemination.

Blowing vents are one of the known phenomena in karst environments, where they constitute an aspect of marginal speleological interest compared to the discovery of large cavities.

In the Euganean Hills, carbonate lithologies are present and only locally give rise to karst cavities.

In this note, we wish to highlight and promote as a geosite a new aspect that concerns the presence of blowing vents identified in magmatic rocks, therefore completely unrelated to karst processes.

In the Euganean Hills, magmatic lithologies represent the morphological highs that characterize this area. Along some steep slopes, in the cold season, it has been possible to detect warm, humid air escaping.

Although general indications of the presence of such phenomena are reported in the naturalistic literature of the area, a systematic survey with measurements of the chemical-physical parameters of the escaping gases has never been conducted.

In popular tradition, the release of hot air has always been associated with the volcanic context of the Euganean Hills, despite magmatic activity ceased approximately 30 million years ago (Cucato et al., 2011).

The mechanism best suited to explain this phenomenon is the same described in karst environments and attributed to the chimney effect triggered by the difference in temperature, humidity, and air density between the inside and outside the slope (Badino, 2015).

Surveys conducted in recent years have identified at least three areas where the phenomenon is clearly evident and confirmed by temperature, humidity, and flow measurements. These three areas are approximately 4 km apart along a roughly NW-SE direction.

Blowholes occur in highly fractured alkaline trachytes and alkaline rhyolites (Piccoli et al., 1980). Based on available maps, fault zones and gravitational movements correspond to two of these three sites.

The temperature of the outgoing air, recorded in the cold season, varies between 13 and 17°C, remaining well above the measured external temperature of 5-6°C. At the mouth, the air is saturated with humidity, generating visible steam and water droplets on the walls and the immediately surrounding vegetation. The flow velocity is about 1m/s and the composition of the outgoing gases is compatible with that of the air, with a certain increase in the amount of CO_2, up to 2000 ppmv.

In light of the renewed attention to the presence of radon in the Euganean Hills area (Reg. Council Res. 464/2025), in-situ measurements have been initiated at both air outlets and reference points unaffected by the phenomenon. A measurement campaign of radon concentration in air has been planned to be repeated seasonally.

The proposal to establish a geosite of the "set of elements" type is supported by the exceptional occurrence of blowing vents in igneous rocks, the plurality of sites where the phenomenon is observed, the popular memory associated to these occurrences, and the extraordinary opportunity to promote geological culture.

Badino G. (2015) - Il vento ipogeo: una storia delle prime osservazioni. Atti e Memorie della Commissione Grotte "E. Boegan", 46, 31-70.

Piccoli G. et al. (1980) - Carta geologica dei Colli Euganei (2. ed.). Memorie di Scienze Geologiche, 34(25).

Cucato M. et al. (2011) - Note Illustrative della Carta Geologica d'Italia alla scala 1:50.000, F. 147 Padova Sud. 224 pp., LTS Land Technology & Services - Padova e Treviso.

Plastic pellets preserved in the sedimentary record: Three examples from sandy beaches (western Sicily)

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Keywords: microplastic, beach pollution, coastal dune system.

Plastic waste is the most widespread pollutant in marine and terrestrial environments. Among these, microplastics, typically ranging in size from 2 to 5 mm, have become one of the most abundant pollutants in oceans and beaches in the last years. In the Mediterranean Sea plastic pollution is a severe problem that has received considerable attention, however, few studies have reported pollution by plastic pellets on the Mediterranean beaches. In this study we document the occurrence of plastic waste on three beaches located in the western Sicilian coast with the aim of assessing not only the presence of plastic waste in the surface but also at depth. A new sampling method is proposed to detect the presence of plastic particles along the beach surface and within the sedimentary column. Moreover, sedimentological analyses were applied to the plastic particles to establish the transport and sedimentation processes responsible for their introduction into the coastal system until their burial. The data obtained by sampling confirm the presence of plastic particles both on the surface (e.g. storm berms) and buried at depths up to 50 cm (dune foot) highlighting how these particles have become part of the sedimentary/lithological cycle. The study of the transport and sedimentation processes of the plastic particles can be useful to define the dispersion mechanisms of these microplastics in the environment.

Holocene cliff retreat along a soft-rocky coast of the Adriatic Sea

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Keywords: lgm, backwearing, down wearing.

Rocky coasts account for constitute approximately 80% of the world's coastline and are frequently affected by instability phenomena that lead to cliff retreat. While estimating retreat rates over recent decades has become relatively straightforward, thanks to remote sensing techniques, reconstructing long-term trends remains challenging. This in mainly due to the absence of key information, such as geochronological constraints of relevant geomorphic indicators.

In this context, a sector of the Adriatic coastline at Monte San Bartolo (Pesaro, Marche Region), located in the easternmost sector of the Apennines, represents an ideal test site for investigating this issue. The area consists of a soft rocky coast affected by intense cliff retreat driven by diffuse instability processes strictly associated with Holocene eustatic sea-level rise and current high-stand conditions.

The style and chronology of the morphoevolution including retreat rates of the coastal system has been estimate based on field surveys, integrated with sedimentological and radiocarbon dating of deposits, Geomorphometric quantitative analyses of the stream network draining the coastal area completed the analysis. Geochronological and sedimentological data indicate that alluvial deposits formed during cold phases of the Late Pleistocene, under lowstand conditions associated with the Late Glacial Maximum (LGM). Subsequent Holocene eustatic sea-level rise lead to wave-cliff interaction that induced instability phenomena characterised by two distinct styles, controlled by different litho-structural conditions: downwearing in the northern sector and backwearing in the southern part. Geomorphometric quantitative analyses, including the analyses of Slope/Area functions carried out to determine the dominant processes in 44 basins, supported the estimation of the Holocene retreat rates with values ranging from 1.0 and 2.8 cm/y for the last ~2000 and ~7000 years, respectively. In particular, the cliff retreat rates are suggested by some basin that are located near the cliff upper edge, where they are intercepted by instability phenomena.

This research contributes to understand the evolution of soft-rocky coasts under conditions of eustatic sea-level rise and highstand from the LGM to the present, combining quantitative geomorphic analysis with geochronological constraints.

Immediate and secondary consequences of volcanic activity on coastal cultural landscape. Example from the Campania Region (southern Italy)

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Keywords: volcanic hazard, cultural landscape, flash flood.

Volcanic-related hazard such as bradyseisms, earthquakes, lava flows, tephra fall and primary pyro-clastic flows are the direct and immediate consequence of volcanic activity or can be the result of geomorphological perturbation introduced by an eruption (Blong, 2000). These secondary hazards include alluvial events due to pyroclastic fall-out which can be contemporary or follow an explosive eruption.

In this paper we give examples of how primary and secondary volcanic events have affected landscape changes and human activity at the Roman settlement Baia, in the volcanic area of the Campi Flegrei, and at Amalfi Coast (Gulf of Salerno), a famous coastal area included in the UNESCO World Heritage List since 1997.

The Amalfi Coast is located about 20 km south of the Somma-Vesuvius. The physical landscape is characterized by short steep rivers with high-elevation drainage basins, which deeply dissect coastal slopes. The steep topography forced the development of human settlements at the mouth of the main streams where low topographies and water resources occur. This placed local communities at high risk during intense and prolonged rainfall able to trigger catastrophic streamflows.

Rainstorm-induced streamflows (flash flood) are the main morphogenetic phenomena responsible for natural hazards and for shaping the coastal landscape of the Amalfi Coast. Alluvial events are strictly connected to the long-range effect the explosive AD 79 eruption of Vesuvius, which deposited pyroclastic air-fall materials on the steep coastal carbonate slopes of the study area. This created favorable conditions for volcaniclastic debris to generate mass flows and flash floods in concomitance with rainy periods. Geological analysis of the submarine delta systems at mouths of the Amalfi streams indicates several alluvial cycles following the 79 AD Plinian eruption of the Somma-Vesuvius, recorded as successive phases of delta growths (Violante, 2009).

The roman site Baia is part of a large caldera, the Campi Flegrei caldera (De Natale et al., 2006), a volcanic complex located north of Naples characterized by frequent earthquakes, hydrothermal manifestations and phenomena of slow uplift and subsidence known as bradyseism. Due to this phenomena, this area has experienced gradual flooding resulting in the submersion of numerous Roman artifacts, including thermal complexes, villas, and harbor structures, off the modern settlement of Baia. This area was investigated with detailed marine geophysical surveys including ultra-high resolution bathymetry and sub-bottom profiling (Violante et al., 2025). The first results indicate that bradyseism significantly influenced the urban structure of the city and forced the Romans to adapt to the gradual rise in sea level, until the settlement was completely abandoned around the 4th century AD.

Blong, R. (2000) - Volcanic hazard and risk management. In: Sigurdsson, H., Houghton, B. F., McNutt, S. R., Rymer, H. & Stix, J. (eds), Encyclopedia of Volcanoes, Academic Press, New York, 1215-1227.

De Natale G. et al. (2006) - The Campi Flegrei Caldera: Unrest mechanisms and hazards. In: Troise C., De Natale G., Kilburn C. R. J. (Eds.), Mechanisms of Activity and Unrest at Large Calderas, Geological Society Special Publications, 269, 25-45.

Violante C. (2009) - Rocky coast: geological constraints for hazard assessment. In: Violante C. (ed), Geohazard in rocky coastal areas, Geological Society Special Publications, 322, 1-31, https://doi.org/10.1144/SP322.1.

Violante C. et al. (2025) - 3D Acoustic remote sensing mapping of the underwater cultural heritage in the marine protected area of Baia submerged park (bay of Pozzuoli, southern Italy). Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., 48(2), 303-308, https://doi.org/10.5194/isprs-archives-XLVIII-2-W10-2025-303-2025.

Volcanic activity and human occupation of Stromboli during the Roman and Medieval periods

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Keywords: volcanism, Stromboli, archaeology.

Throughout its recorded history, from around 2,500 years ago to the present, the island of Stromboli has been an active volcano. It has had continual low-level activity for many centuries, but there have also been some more dramatic episodes of volcanic activity. It has also had human occupation for much of the past 2,500 years, but with some periods of abandonment. It is tempting to assume that the periods of abandonment should be related to the periods of increased volcanic activity. However, as noted by Di Renzoni et al. (2021), there does not appear to be a strong correlation. Instead, decisions regarding volcanic risk seem to depend on many contextual factors.

A detailed comparison of evidence for human occupation and volcanic activity during the Roman and medieval periods illustrates this point. For much of the Roman period, relative political stability and peace combined with active maritime trade, and in this socioeconomic environment, coastal islands were favored locations for occupation, despite volcanic activity. Settlement was resilient, despite major eruptive episodes. In the medieval period, on the other hand, frequent warfare, pandemics, and economic dislocations created an environment with many sources of risk. Volcanic and seismic activity of Stromboli appears to have been one factor among many that may have influenced decisions about episodes of settlement occupation or abandonment.

Di Renzoni A. et al. (2021) - Should I Stay or Should I Go? 6000 Years of Human Presence and Abandonments at Stromboli Volcano and an Overview on the Whole Aeolian Archipelago (Southern Tyrrhenian Sea, Italy). Ann. Geophys., 64(5), VO545, https://doi.org/10.4401/ag-8664.

S33.

Geological knowledge as cultural heritage: Historical pathways in the Earth Sciences

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Linking geodiversity and ecosystem services to the 2030 Agenda goals in the active Campi Flegrei volcanic area (southern Italy)

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Keywords: grid-diversity-index, sustainable development, abiotic matrices.

Geodiversity, defined as the manifestation of the Earth's physical variability, represents a key component of natural capital. It plays a fundamental role in preserving the environmental integrity of territories and in sustaining essential geosystem services. In this study, geodiversity was evaluated within the active Campi Flegrei caldera (CFc), a highly complex area characterized by considerable volcanic risk and remarkable heritage significance. Geodiversity was assessed through the application of Shannon's Diversity Index (SHDI), combining four abiotic environmental matrices - geology, geomorphology, permeability, and soils - with spatially discontinuous abiotic features such as thermal springs, lakes, and fumaroles. To achieve an optimal representation of spatial patterns, a multiscale methodology was employed, allowing the spatial heterogeneity of the datasets to be effectively captured. The resulting integrated geodiversity map highlights marked spatial variability across the CFc and provides the basis for the identification of four focal zones of geodiversity (FZoGs) together with key singularities of geodiversity (SoGs). FZoGs as relatively small areas characterized by high geodiversity, often representing unique environments capable of hosting rare biota or microenvironments that enhance biodiversity (Hjort et al., 2015). SoGs are defined as sites distinguished by the presence of at least one rare or exceptional geodiversity element, which may function as interconnected nodes within geo-naturalistic and cultural pathways (Miller et al., 2024). Within these areas, several geosystem services - including cultural, provisioning, and supporting services (Brilha et al., 2018) - were identified and characterized, contributing to the development of a valuable framework for territorial resource management. By linking geodiversity assessment to geosystem services within FZoGs and SoGs, the proposed approach offers decision-makers a practical and targeted tool for incorporating geodiversity into land management strategies and policy planning processes. Moreover, the produced map can support the conservation of abiotic natural capital and contribute to the advancement of territorial sustainability objectives in line with the 2030 Agenda.

Brilha J. et al. (2018) - Geodiversity: An integrative review as a contribution to the sustainable management of the whole of nature. Environ. Sci. Policy., 86, 19-28, https://doi.org/10.1016/j.envsci.2018.05.001.

Hjort J. et al. (2015) - Why geodiversity matters in valuing nature's stage. Conserv. Biol., 29(3), 630-639, https://doi.org/10.1111/cobi.12510.

Miller W. D. et al. (2024) - The importance of geodiversity in understanding and conserving the Western Rift Valley Corridor. Ecol. Soc., 29(3), http://doi.org/10.5751/ES-15100-290307.

"Mente et Lapis": the role of Secretaries in the history of the Italian Geological Society

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Keywords: history of geology, Italian Geological Society, secretaries.

Since its foundation in Bologna in 1881, the *Società Geologica Italiana* has entrusted its Secretaries with responsibilities that extend far beyond mere administrative management. While the President represents the scientific and strategic direction for the term duration, the Secretary serves over time as the guardian of institutional continuity, ensuring transmission of knowledge and stability of the organization. During the Society's running-in phases, figures like Romolo Meli, Enrico Clerici and Antonio Neviani played a key role in joining researchers across a recently unified Italy. Their contribution was pivotal in handling the *Bollettino* - lengthily the official organ of the entire scientific community - and in organizing the annual meetings, essential for national and international scientific exchange.

A significant responsibility held by the Secretaries involved also the management of the library and the historical archives, both fundamental for tracing the evolution of Italian geological thought. Until 1946, the board of SGI included other auxiliary roles (Vice Secretary, Archivist, Bursar, Vice Treasurer), then lifted. Consequently, the work of the Secretary evolved over time from a purely administrative management to a sort of cultural and digital mediation; thus, the position of ViceSecretary, albeit interruptedly active until 1992, was finally reintroduced in 2018. Modern Secretaries, jointly with Treasurers, oversee bureaucratic workflows, but also act as a primary interface between the academic community, industry, professionals and institutional bodies.

Since 1881, 79 presidents have been succeeding one another to lead over time the Society; conversely, in the same laps of time, only 17 members have taken charge of ensuring, as Secretaries, the continuity of the system, and relationship management too (Argentieri et. al., 2018; Argentieri et. al., 2024). A difficult and long lasting task, considering that, among them, seven persons stand out, holding cumulatively the position for 116 years.

Without the dedication of these figures - often less prominent than the leading characters in research - the Geological Society could not have navigated wartime crises and the epochal shifts of modern science, while preserving intact its original mission. In this contribution, we thus pay a tribute to all our Secretaries, who kept the SGI flag flying for nearly a century and a half.

Argentieri A. et al. (2018) - Ritratto di un gentiluomo con il papillon: Achille Zuccari, Segretario Generale della Società Geologica Italiana. Rend. Online Soc. Geol. It., 44, 3-6, https://doi.org/10.3301/ROL.2018.01.

Argentieri A. et al. (2024) - Mente et Malleo. La Società Geologica Italiana e i suoi presidenti. Supplemento n. 1 all'Ital. J. Geosci., 143(2), Società Geologica Italiana, 423 pp., ISBN 9788894484472.

Natural hazard and risk mitigation before geology: Insights from the Aniene River valley (Central Italy)

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Keywords: Aniene valley, history of geology, natural hazard.

In 21th century, risk prevention culture still has difficulties in breaking through. In Italy, fatalism, superstition and religious faith in Providence still prevail in popular opinion (Argentieri et al., 2019). A long tradition of misbelief in the supernatural, dating back to classical culture and reinforced during the Middle Age, regrettably persists over centuries, and people rely more on divine protection against natural disasters rather than on science and technology.

An interesting test site in central Italy is represented by the upper Aniene River valley, on the Simbruini Mounts, belonging to the Latium-Abruzzi carbonate platform domain, formed by thick sedimentary sequences deposited on the southern passive continental margin of Tethys ocean since Triassic. As known, the present day structural and geomorphological setting of the area is the result of tectonic processes of the Apennine orogeny and of the subsequent post-collisional events. At the end of 19th century, the geographical and geological features of the area were described by Gioacchino De Angelis d'Ossat (1897). This border area between Latium and Abruzzi was a cradle of monasticism, because of St. Benedict of Nursia, founder of the monastic order. The geomorphological characteristics of the mountainous area, rich of natural caves and water resources, favored the development of hermitic settlements since the earliest period of Christianization (Branciani, 2012). Religious settlements of high historical and artistic importance are thus scattered along the Valley from Subiaco to the Simbrivio springs: Saint Scolastica Abbey; Saint Benedict or Sacro Speco monastery, nestled under the steep cliff of Mount Taleo peak; Holy Trinity Sanctuary, located under the impressive vertical southwestern crag of the Mount Autore ridge. Saint Francis visited the area in A.D. 1223, as witnessed by the extraordinary portrait of the young monk, painted on the wall of St. Gregory Chapel in the *Sacro Speco*. The overwhelming natural resources are preserved by the presence of the Simbruini Mts. Regional Park, established in 1983; with its 30,000 acres of forest land, it represents the larger protected area of Latium. In more recent times, a rediscover of this territory has been proposed (D'Orefice et al., 2014).

Among the natural resources of the park, Mesozoic calcareous cliffs embody the essence of Simbruini Mts. scenery, but at once constitute a threat for safety of people and infrastructures. Landslide hazard is in fact relevant in the whole area, due to high relief energy; rockfall represent of course the main tipology. Within this framework, a strong connection between religious faith and natural hazard characterizes the history of human settlement in the upper Aniene valley, still sparsely populated today. A fascinating path is thus proposed along the road of the monasteries, retracing the history of human living with hazards and of risk mitigation practices, before the birth of geological sciences.

Argentieri A. et al. (2019) - Replace fear of the unknown with curiosity: natural risks and culture of prevention in the metropolitan area of Rome. Rend. Online Soc. Geol. Ital., 49, 85-93.

Branciani L. (2012) - Origine e sviluppo dell'eremitismo nella Valle Sublacense. In: Ermini Pani L. (Ed.), Atti del Convegno internazionale di studio "Le valli dei monaci", Roma-Subiaco, 17-19 maggio 2010.

De Angelis d'Ossat G. (1897) - L'Alta valle dell'Aniene. Studio geologico-geografico. Mem. Soc. Geogr. Ital., 7, 191-265.

D'Orefice M. et al. (2014) - Un territorio da (ri)scoprire: l'alta Valle del fiume Aniene. Mem. Descr. Carta Geol. d'It., 102, 101-118.

The “citizen science”: Two historical antecedents in seismological field

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Keywords: citizen science, seismology.

Citizen science is an approach to scientific research in which ordinary people actively collaborate with researchers or scientific institutions. The first case is an early attempt to collect information about an earthquake that struck the Romagna hills and Imola in 1854, carried out by two “naturalists”, Giacomo Tassinari and Giuseppe Scarabelli. Both were among the founders of the Imola Civic Museum, and Scarabelli is considered one of the “fathers” of Italian geology. They drafted, printed, and sent many copies of a letter asking for detailed information about the effects of the earthquake. The correspondents were very different kinds of people: relatives, friends, technicians, and some civil servants distributed across a large geographical area. The answers form a corpus that represents a rich source for understanding the event.

The second case is represented by early 20th-century Austrian newspapers, which offer a kind of spyhole through which to observe a double aspect of the relationship between science and civil society. When an earthquake struck an Austrian region and was at least noticeable to the population, it was possible to find many reports in which newspaper readers described their own experiences and observations of the event. Each report included the precise address: the street name and number and, very importantly, the floor on which the reader was at the moment of the earthquake. When the earthquake was strong enough, the news reports ended with a request issued by the Geophysical Office of Vienna asking newspaper readers for further information about the event. At the same time, the Italian Seismic Service requested information only from selected people, although they were not necessarily trained.

Similarities and differences between these cases provide useful hints for reflecting on the social, cultural, and political features that shape the relationship between civil society and science.

Ulisse Aldrovandi and the *Musaeum Metallicum*. A reconstruction of a 16th-century collection based on objects, written sources and images

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Keywords: museum collections, Renaissance, Ulisse Aldrovandi.

The campaign to catalogue the collections and the National Edition of the works of Ulisse Aldrovandi, undertaken to mark the 400th anniversary of Ulisse Aldrovandi's birth (2022), and the recent reorganisation of the collections at the Palazzo Poggi Museum (2026) have revived the attempt, if not at an unlikely reconstruction, at least a mapping of the surviving materials of the Aldrovandian Museum, through the research and identification of objects distributed amongst Bologna's university museums and their comparison with printed texts, manuscripts and the rich iconography comprising the illustrations in the volumes, the related woodcut plates (including unpublished ones) and the watercolour plates (Ceregato, 2007).

The word Geology (in the form 'Giologia'), which had already appeared almost a century earlier with a different meaning, was used to denote the study of minerals and fossils (the 'fossilia') in Aldrovandi's will of 1603 (Vai & Cavazza, 2003), but the contribution of the Bolognese naturalist to Earth sciences and palaeontology is not entirely correctly attributed to the *Musaeum Metallicum*, published posthumously in 1648 by Bartolomeo Ambrosini.

The complex reconstruction of the collection relating to these disciplines, which were still in their infancy in the sixteenth century and which, like the rest of his "*Theatro di Natura*", underwent numerous relocations and dispersals, and the identification of connections with other contemporary scholars, from Conrad Gessner to Francesco Calzolari and on to Fabio Colonna, opens up new perspectives on the early phase of the development of the Earth Sciences, the interpretation of fossils, the transition from Aristotelian orthodoxy to modern science, and the influence of Aldrovandi's work on scientists of subsequent generations.

Ceregato A. (2007) - I Fossili nell'armadio. In: Alessandrini A., Ceregato A. (Eds), Natura Picta. Ulisse Aldrovandi, Editrice Compositori, Bologna, 107-109.

Vai G.B. & Cavazza W. (2003) - Four Centuries of the word Geology. Ulisse Aldrovandi 1603 in Bologna. Minerva Ed., Bologna, 326 pp.

The mineralogical collection and the crocodilian mummy: Trendy science and education

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Keywords: practical museum, history of teaching, mineralogy.

Luigi Bombicci Porta (1833-1903), mineralogist and Italian academic, in 1860 became the first professor of mineralogy in the University of Bologna and, since 1861, he was also given the direction of the Mineralogy Museum (now Bombicci Museum of Mineralogy) and its historical collections. Bombicci inherited the 9.000 specimens of the old XVI century mineralogical collection from the Academy of Science and during his life he dedicated himself to the classification and implementation of the collections. At the end of his directorship the Museum housed more than 44.000 specimens.

Bombicci is also well known in Bologna for his dedication to teaching: he was particularly involved in reforming natural history teaching in primary schools. Bombicci had a very modern vision of education, believing that pupils should learn from experience. He planned and realized a series of practical museums for schools, where samples from the mineral and animal world were chosen in relation to their use in XIX century everyday life (D'Ascenzo & Vignoli, 2008). Similarly, he organized the Museum of Mineralogy of the University of Bologna following an up-to-date classification method bearing in mind the educational purposes of the museum. Here in particular we concentrate on a display which was intended to explain the transformation of organic material into fossil oils. Bombicci introduced in the center of the cabinet an Egyptian mummy of a crocodile, as he believed it was an example of organic material soaked in tar. At the time of its acquisition (around 1880) there was a big rush on archeological items from Egypt, and the public demonstrated a keen interest in the subject. Bombicci then exploited a new trend in archeology to transmit a different message related to chemistry, geology and natural resources, following a multidisciplinary approach very similar to the modern idea of education and science.

Recently, a similar multidisciplinary approach has been adopted to rediscover the crocodile mummy. The aim is to reconstruct the history of the specimen and re-collocate as an educational resource for the museum. So far, CT scan and Raman microscopy have been performed, providing valuable insights into the mummification and preservation processes, as well as the age and anatomy of the specimen and revealing a different story from what Bombicci had expected.

D'Ascenzo M. & Vignoli R. (2008) - Scuola, didattica e musei tra Otto e Novecento. Il Museo didattico 'Luigi Bombicci' di Bologna. CLUEB, Bologna, 245 pp.

The colonial question and a four-year journey around the world: Felice Giordano's letters to Isaac Artom (2/3/1872 - 25/9/1874)

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Keywords: historical journey, Felice Giordano, Isaac Artom.

Felice Giordano is generally known as Sella's fellow student in Turin and dear friend, and later effective performer of his projects for the Matterhorn and the Geological Map of Italy. Although hidden in the shadow of his powerful friend, Giordano was a very special character, who deserves to be better known and popular, as his life has been very intense, varied and adventurous. Giordano was an expert and appreciated hydraulic and mining engineer, field geologist, faithful civil servant as regent, inspector and director of R. Corpo delle Miniere, head of the project for the Geological Map, despite the hostility of academy and the bureaucracy of ministry. He was also a brave mountaineer, ascending Mont Blanc and Matterhorn, and protagonist of an adventurous four-years journey around the world. Giordano had been confidentially instructed by the government to find a suitable site for an Italian penal colony in Borneo. In March 1872, he left Italy for his trip to the far east, and once in 1873 the mission was finished, he continued privately to gain personal knowledge of the New World. Many details of Giordano's life are provided by the 230 letters that he wrote to Quintino Sella for over 37 years, from 1847 to 1884, and which we published in the *Rivista di Storia dell'Università di Torino* (2020-24), but only four concern the mission in Borneo. However, this adventure is extensively described in Giordano's memoir and reports (his geographic and ethnologic accounts on northern Borneo and far seas were used by Salgari for his novels). Further details are reported in diaries of the captain and ship's personnel of Governolo, the paddle steam corvette with which Giordano completed the cruise from India to Borneo and then to Japan. Born in Asti in 1829, Isaac Artom studied law in Pisa and during the first War of Independence he fought at Curtatone and Montanara in the ranks of the famous Tuscan university battalion. He later moved to Turin where he graduated, befriended Sella and Giordano, and soon became one of Cavour's closest collaborators. He then held diplomatic posts in Paris and Copenhagen and in 1870 became secretary general of the Foreign Ministry and then been appointed senator in 1876, the first Italian Jew to hold this office. The 19 letters Giordano sent between March 2, 1872, and September 25, 1874, to Isaac Artom, then Secretary General of the Ministry of Foreign Affairs, constitute an unpublished documentary source, essential for reconstructing in detail the very little-known events and stages of the second part of the journey that took Felice Giordano, after Asia, through Oceania to the Americas. After leaving Japan, Giordano went to Australia, Tasmania and New Zealand, crossed the Pacific with stops in Fiji and Sandwich (Hawaii) islands, landed in San Francisco, went to Canada, Salt-Lake-City and New York, then moved to Mexico, Central America and Lima, and finally returned to Italy in 1876, via Chile, the Strait of Magellan and Argentina.

1926-2026: Haughton's Nyasaland vertebrates and the birth of Gondwanan palaeobiogeography

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Keywords: Permian, Gondwana, geoheritage.

In 1926, Dr. Sidney Henry Haughton published "On Karoo vertebrates from Nyasaland*",* a contribution that became a landmark in the early study of Permian continental vertebrates in Gondwana. Although often overshadowed by the classic works of Robert Broom and later syntheses on therapsid evolution, Haughton's contribution represented a decisive shift from a regional understanding of the South African Karoo fauna toward a broader palaeobiogeographic perspective encompassing substantial portions of southern Africa. Based on Late Permian vertebrate remains recovered from the Chiweta Beds, in present-day northern Malawi, Haughton recognised strong affinities between the Nyasaland assemblages and the therapsid faunas of the Beaufort Beds in the Karoo supergroup. His study provided some of the earliest evidence that Permian tetrapod communities were distributed across extensive Gondwanan continental environments rather than being confined to isolated basins. The paper also contributed to the development of vertebrate-based continental biostratigraphy, a methodological approach that would become fundamental for correlating Permian and Triassic terrestrial successions worldwide. This contribution examines the scientific and historical significance of Haughton's 1926 work within the broader context of interwar vertebrate palaeontology, imperial geological exploration, and the emergence of Gondwanan paleobiogeography before the widespread acceptance of continental drift. One century later, Haughton's study can be recognised as a foundational step in transforming the Karoo fauna assemblage from a regional palaeontological affair into a key framework for understanding late Palaeozoic terrestrial ecosystems on a continental scale.

The scientific journey of Paolo Spadoni and the geological resources of the Ernici Mountains (Latium, Italy)

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Keywords: cultural heritage, bitumen, speleology.

In the summer of 1796, Paolo Spadoni (1764-1826), a little-known Marchean naturalist and geologist, and professor of Zoology and Mineralogy at the University of Macerata, undertook a two-month scientific journey through the mountains of the Frosinone area to assess the mineral exploitation potential of the region. The mission followed the discovery of iron mineralizations in the Ernici Mountains near the village of Guarcino. The results of his investigations were eventually published in 1802 in the volume *Osservazioni mineralovulcaniche fatte in un viaggio per l'antico Lazio* (Spadoni, 1802), one of the most remarkable geological and naturalistic accounts of pre-unification Italy. Far from being a simple mining report, the work developed into a broad scientific description of the landscape of Latium, based on direct observations of landforms, rocks, karst caves, mineral springs, and fossil-bearing deposits. Particular importance is given to the explorations of the Collepardo Cave and the Pozzo d'Antullo, which represent some of the earliest modern descriptions of karst phenomena in Latium. Spadoni's descent into the sinkhole, carried out with rudimentary equipment and assisted by local guides, assumed the character of a pioneering expedition, poised between the Enlightenment scientific curiosity and the Romantic fascination with the "wonders of nature". His observations reveal a remarkable ability to correlate landscape analysis, lithology, and geomorphological processes, anticipating themes that would later become central to nineteenth-century geology and speleology. Alongside his geological observations, Spadoni (a largely overlooked figure who deserves a re-evaluation) also documented traditional extractive activities, including the collection of pitch and bitumen in the Frosinone area. His work preserves a rare testimony of local mining culture prior to nineteenth-century industrial development, as well as of the medicinal practices and popular superstitions associated with bitumen, toward which he expressed clear skepticism. Spadoni's journey therefore represents not only a scientific expedition, but also an integrated interpretation of the Apennine landscape, in which nature, history, and human activity are understood as interconnected elements of a single territorial system.

Spadoni P. (1802) - Osservazioni mineralovulcaniche fatte in un viaggio per l'antico Lazio. Tip. B. Capitani, Macerata, 165 pp.

Geoheritage and geosites in the Calabrian National Parks: The cases of Pollino, Aspromonte and Sila

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Keywords: geodiversity, geosites, geotourism.

In this study, the geoheritage of the Calabrian National Parks (Pollino, Aspromonte and Sila) is analysed from the perspective of the history of Earth Sciences, considering geosites as fundamental territorial units for the assessment of geodiversity, conservation and geotourism development. Geoheritage is interpreted as the outcome of a historical process of knowledge production, protection and enhancement, shaped by the evolution of geosciences and by institutional recognition frameworks. In this perspective, Calabria's geodiversity is read in line with Gray's (2013) conceptual framework as both a structural component of the landscape and a scientific and cultural heritage. The study builds on the growing attention to geoheritage and geodiversity, and on the need to strengthen the operational role of geosites as tools for knowledge, communication and management in protected areas. It considers geosites included in national and institutional inventories, with particular reference to the ISPRA National Inventory of Geosites, established in 2002 as a national knowledge base for the conservation and enhancement of geological heritage. The research adopts a historical-interpretative and comparative approach, based on scientific literature, institutional and regulatory documents, geosite inventories and materials related to UNESCO recognitions in the three areas. Particular attention is given to key stages in the construction of Calabrian geoheritage: the CARG Project, as a milestone in the systematisation of national geological cartography (Servizio geologico d'Italia, 2011); the IUGS Global Geosites Project for the recognition of the intrinsic value of geological sites (Wimbledon, 1996); and Law 394/1991, as the reference framework for protected areas in Italy. The results highlight the specific features of the three contexts. In Pollino, a UNESCO Global Geopark since 2015, geosites represent key elements for interpreting the geomorphological and landscape complexity of the massif. In Aspromonte, a UNESCO Global Geopark since 2021, geoheritage emerges from a process in which geology, landscape and cultural identity contribute to the construction of an integrated territorial narrative, with geosites playing a central role in the representation of local geodiversity. In Sila, recognised as a UNESCO MaB Biosphere Reserve, geological heritage contributes to landscape interpretation and to the definition of strategies oriented towards conservation and sustainable development. The study shows that geosites act as scientific and territorial tools capable of connecting geodiversity, geoheritage and geotourism (Reynard & Brilha, 2018). They enable the translation of geological knowledge into practices of conservation, communication and public use, demonstrating how geosciences can support both the enhancement of geological heritage and public engagement with landscape dynamics.

Gray M. (2013) - Geodiversity: valuing and conserving abiotic nature. John Wiley & Sons, 512 pp.
Reynard E. & Brilha J. (2018) - Geoheritage: assessment, protection, and management. Elsevier, Amsterdam, 482 pp.
Servizio geologico d'Italia (2011) - Carta geologica d'Italia alla scala 1:50.000. ISPRA, Roma.
Wimbledon W.A. (1996) - Geosites-a new conservation initiative. Episodes J. Int. Geosci., 19(3), 87-88, https://doi.org/10.18814/epiiugs/1996/v19i3/009.

Scientific vision and gender inclusion: Henry De la Beche, an innovator

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Keywords: inclusion, De la Beche, Science barrier free.

Henry de la Beche (1796-1855) was a central and profoundly outstanding and in the meanwhile unconventional figure in the scientific geological community of nineteenth century in Britain. This research aims to analyse his pioneering and innovative approach, capable of ground-breaking the rigid conventions of the time and transforming the geology from an elite pastime for wealthy gentlemen into a visual, socially inclusive scientific discipline and, above all, an institutionalised profession of public benefit.

In terms of gender inclusion, while the Geological Society of London formally at the time excluded women, de la Beche forged a deep collaboration and friendship with self-taught paleontologist Mary Anning, fighting for her financial and academic recognition. To support her financially, in 1830 de la Beche created Duria Antiquior (A More Ancient Dorset), considered the first true work of paleoart in history. This lithograph, based on fossils discovered by Anning, inaugurated a revolutionary visual trend, reconstructing for the first time an entire prehistoric ecosystem in action for educational purposes.

Alongside this communicative sensibility, de la Beche was the most extraordinary “institution builder” in modern geology. Aware of the strategic value of Earth sciences in the era of the Industrial Revolution, in 1835 he founded and directed the Geological Survey of Great Britain, the world’s first national geological mapping organization, transforming field surveying into a systematic, state-funded activity. His vision also led to the creation of the Museum of Economic Geology (1835), the Mining Record Office (1839) for mine safety, and the Government School of Mines (1851), culminating in his election as President of the Geological Society itself (1847-1849).

This study highlights how de la Beche’s legacy lies precisely in this unique synthesis: having demonstrated that the study of the Earth’s deep past required both an open mind and socially barrier-free science and a solid professional and institutional structure at the service of the progress of the Community.

A treatise on salt production in Volterra by Rocco Romegialli (1636)

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Keywords: Saline di Volterra, solution mining, mining history.

On the western slopes of Volterra, salt springs were probably exploited as early as Etruscan times, particularly in the present-day localities of Buriano, Montegemoli, Saline, and Querceto, along the Cecina River. The salt deposits in this area consist of halite layers included within the Messinian *gessoso-solfifera* formation, locally made up of irregularly interbedded sand, marl, and clay, with minor gypsum and anhydrite. The depth of the salt layers, still exploited today by solution mining, varies from 100 to 200 m (Mazzanti et al., 1963).

Salt production and trade were major sources of wealth for medieval Volterra. The earliest historical record dates to 962, when Emperor Otto I decreed that jurisdiction over, and revenues from, the saltworks should be equally divided between the Bishop and the Commune of Volterra. A legal document issued by the bishop in 974 refers to the saltworks as *moja regis*, from the Late Latin *muria*, "brine", and *regis*, "royal", i.e., king's property. A manuscript preserved in the archives of Volterra recounts two journeys undertaken by Volterra salt workers to Halle, in Saxony, who were invited in 981 by Emperor Otto II to teach German laborers the techniques of salt production and the construction of brine boilers (Borelli, 2000).

Between the 12th and 14th centuries, political, economic, and military conflicts arose between the Bishop and the Commune of Volterra over control of the saltworks. The struggle ultimately resulted in the consolidation of power by the municipal government, which slowly stripped the bishop of jurisdiction over the *moje*. Between 1240 and 1250, Emperor Frederick II also contested these privileges and briefly confiscated the ancient rights to the *moje* in favor of the Holy Roman Empire. Siena and Florence also took an interest in Volterra's wealth, and the city lost its autonomy in 1472, following its military conquest by Lorenzo de' Medici *il Magnifico*, when ownership of the saltworks passed to Florence.

Salt production in Volterra is based on the evaporation of brine extracted from wells. Until the late 19th century, wells of square or rectangular cross-section were dug by hand, often lined with bricks and mortar, and then reinforced with oak timber casings. The brine was withdrawn from the wells by means of buckets and a manual winch, known as *burbera*, then poured into open lead boilers, which were heated by wood-fired furnaces. The work was demanding, because the furnaces had to be kept continuously alight (Martelli, 1843). Salt production was never interrupted from the Medici era through the Grand Duchy of Tuscany, and it continues to this day. The 17th-century manuscript by Rocco Romegialli describes the organization of the entire cycle of salt production, from authorization procedures to the management of storage and distribution by the *Dogana del sale* (salt administration) and provides detailed accounts of production techniques, including several original illustrations (Romegialli, 1636).

Borelli F. (2000) - Le Saline di Volterra nel Granducato di Toscana. Olschki, Firenze.
Martelli C. (1843) - L'agricoltura, l'industria e le saline volterrane. Tip. Giusti, Lucca.
Mazzanti R. et al. (1963) - Geologia della zona di Montecatini Val di Cecina. Boll. Soc. Geol. Ital., 82(2), 2-65.
Romegialli R. (1636) - Delle Saline, e del Sale della città di Volterra (manuscript in Italian). Guarnacci Library, Volterra, Ms. 5903. Additional copy: Guarnacci Library, Fondo Funaioli Ms. 921.

Strategic minerals history: The "copper rush" in 19th century Tuscany

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Keywords: copper mining, VMS deposits, mining history.

Global demand for metals increased in the second half of the 18th century, driven by the Industrial Revolution, which introduced the extensive use of hard coal in metallurgy, and by the steam engine, which shaped the 19th-century economy. The production of non-ferrous metals benefited from the new models of production, and copper was crucial for the optimization of the steam engine itself, not to mention later developments in electrical engineering and telegraphic applications: "no copper, no industrial revolution" (Cunha, 2020).

This study examines the historical and the technical development of the 19th-century "copper rush" (Dini & Boschi, 2017) associated with ophiolite-hosted volcanogenic massive sulfide (VMS) ore deposits in Tuscany and the surrounding regions of Emilia and Liguria. These copper deposits are remarkable from a technical standpoint because they proved to be highly profitable during the early stages of production. However, it is now known that these deposits did not contain sufficient reserves to sustain mining operations over long periods, a crucial factor that led to overambitious investments and subsequent financial and employment crises (Dini et al., 2024).

As early as the beginning of the 19th century, the copper ore produced at the Montecatini Val di Cecina mine was exported to smelters in Liverpool (Schneider, 1890). The mine, reactivated in 1827, soon became well known both in Italy and abroad, and its success was reflected in the geological literature of the time, owing both to the high copper content of its commercial products and to the initial abundance of its resources. The mine's success soon attracted the attention of many investors, especially from France and England, who sought to explore the potential deposits associated with the Jurassic ophiolitic sequences of Tuscany, Liguria, and Emilia. Numerous mining companies, often undercapitalized, were formed to carry out intensive exploration campaigns.

The Montecatini copper mine is particularly significant from the standpoint of mining history, as its commercial success paved the way for the development of Italy's largest chemical and mining company of the 20th century, the Montecatini Company. By the end of the century, the mine was considered nearly depleted, and mining operations ceased, owing both to a crisis in the copper market and to the aging of the technical infrastructure. However, in the late 19th century, an ever-increasing share of copper production came from the Massa Marittima area (Boccheggiano-Merse and Fenice-Capanne mines). Unlike the mines mentioned above, which exploited ophiolite-hosted VMS deposits, the Massa Marittima mines were developed on quartz veins associated with hydrothermal mineralization (pyrite with Pb, Zn, and Cu) related to Plio-Quaternary magmatism. The Massa Marittima mines soon became the leading copper producers in Tuscany and were intensively exploited until the end of the 20th century, mainly for pyrite production.

Cunha D. (2020) - Coppering the industrial revolution. History, materiality and culture in the making of an ecological regime. J. World-Syst. Res., 26(1), 40-69, https://doi.org/10.5195/jwsr.2020.917.

Dini A. & Boschi C. (2017) - I giacimenti cupriferi delle ofioliti toscane. Riv. Mineral. Ital., 42, 84-101.

Dini A. et al. (2024) - The Ophiolite-Hosted Cu-Zn VMS Deposits of Tuscany (Italy). Minerals, 14(3), 273, https://doi.org/10.3390/min14030273.

Schneider A. (1890) - La miniera cuprifera di Montecatini in Val di Cecina. Ministero di Agricoltura, industria e Commercio, Appendice alla Rivista Mineraria del 1889, G. Barbera, Firenze, 86 pp.

Periadriatic landslide style: Too long return periods or poor memory? Highlight on the Monteodorisio landslide (Adriatic Abruzzi, Italy)

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Keywords: history of geology, Monteodorisio, periadriatic landslides.

In January 2026, the wake-up of the Niscemi landslide (SE Sicily) largely aroused the interest of mass media in such phenomena, often disregarded by public opinion. The reactivation in April of the Petacciato landslide, along the small coastline of Molise, brought also the issue of Periadriatic mass movements to the fore anew. But, as renown, the attention physiologically declines over time, and each disaster quickly becomes an out-of-date news, despite representing a persistent hazard. As a general rule, the more a landslide is large and deep, and the more meteorological conditions able to reactivate it (continuous rainfall distributed in a lenghty period) have long return times (up to 100 years). This often induces inhabitants and administrators to dismiss the past or to consider the issue closed. Historical geomorphological reconstructions may thus help to highlight these 'cold cases', in order to support urban planning, promote monitoring system and prevent disasters.

We propose here the story-telling of a currently silent geomorphological feature of the Periadriatic Abruzzi: the Monteodorisio landslide, occurred during the mid-20th century, on the hinterland of the southern "Trabocchi Coast". This event is roughly contemporary of the great one that affected the nearby town of Vasto in 1956, destroying an entire block of the historic center (see Argentieri et. al, 2020, and reference therein).

The Monteodorisio village (province of Chieti) stands on a ridge formed by a Pleistocene regressive marine to circalittoral sedimentary sequence; a clayey unit passes upwards to golden-yellow sands, and then on top to a conglomerate, formed by well-rounded heterometric clasts, which represents the foundation soil of the village, dominated by the XI century castle. The mass movement activated on the western hillside probably around 1940, and then again in 1947 and 1954. Given the scarcity of bibliographical sources (Buccolini, 1990; Catenacci, 1992), we performed an archival research, in order to reconstruct the history of the Monteodorisio landslide, consulting official documents conserved in the *Archivio Centrale dello Stato* and the ISPRA Library in Rome. An unpublished "geotechnical report" of 1955 by Amedeo Balboni, engineer of the Italian Geological Survey describes a body of considerable size (200 m wide and 800 m long, with a maximum height of the scarp of about 40 m). The landslide reached the Sinello valley floor, where the river erosion induced instability of the lower clayey slope of the Monteodorisio hill.

Relying on the precious information found in the "grey literature", we integrated the historical study with a geomorphological survey of the slope, in order to reconstruct its evolution and present state. The proposed approach could help to increase the level of awareness of local community about long-term active natural hazard.

Argentieri A. et al. (2020) - La frana di Vasto del 1956 (Abruzzo adriatico) - The 1956 Vasto landslide (Adriatic Abruzzi). Acque Sotter. - Ital. J. Groundw., AS33-469, 73-79.

Balboni A. (1955) - La frana di Monteodorisio (Chieti). Relazione geotecnica. Unpublished report, Servizio Geologico d'Italia, ISPRA Library, Rome, 6 pp.

Buccolini M. (1990) - Le caratteristiche geologiche e geomorfologiche. In: Robotti C. (Ed), Monteodorisio. Ambiente, immagini, documenti, Capone editore, 125-127.

Catenacci V. (1992) - Il dissesto geologico e geoambientale in Italia. 1.13 Cronistorie abruzzesi. Mem. Descr. Carta Geol. Ital., 47, 156-166.

The Gola del Bottaccione (Gubbio - Umbria): A geological heritage site that contributed to the historical development of the geological sciences

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Keywords: Gola del Bottaccione Gubbio, heritage, ethical code.

The Bottaccione Gorge has always been known to anyone interested in Earth sciences and has been visited and studied by generations of geologists from around the world. The International Union of Geological Sciences (IUGS) has included this place among the top 100 geosites worldwide. In this location, situated just north of Gubbio in the Umbrian Pre-Apennines, a section of pelagic sedimentary rocks from the Umbria-Marche Meso-Cenozoic stratigraphic succession crops out continuously over a time interval extending from 160 to 10 Ma.

The Gorge is not simply a passage between two mountains; it has always represented a transit point and, above all, a convergence of nature and humanity. Here, we can observe how the history of the Earth—geology, indeed—and the history of humanity merge. Driven by evolution, each operating on different timescales and in different ways, they allow for the development of life and the progress of civilizations.

Within the Gorge, the Cretaceous-Paleogene (K-Pg) stratigraphic boundary crops out where the "iridium anomaly" was detected for the first time, leading to the hypothesis of a mass extinction—including that of non-avian dinosaurs—caused by an asteroid impact 66 million years ago. This site is located along the SR 298 road, in a freely accessible turnout that is frequently visited by both geotourists and geologists. However, the significance of the location contrasts sharply with its poor state of maintenance. Two issues are immediately noticeable: the first is a general degradation linked to heavy road traffic and occasional littering. Because the site is owned by the road management authority, maintenance is limited strictly to what falls within their immediate purview.

The second concern involves the evident oversampling of the site by geologists for scientific purposes. This includes sampling via core drills for paleomagnetism or rock geochemistry research, and even the removal of entire blocks of rock. Furthermore, the near-total removal of the centimeter-thick clay layer at the K-Pg boundary is glaringly obvious, making future sampling highly difficult. The rocky outcrop also suffers from natural structural instability, which is partly triggered by traffic vibrations.

We wish to draw the attention of the scientific community to the conservation issues facing this geosite, as we believe an in-depth discussion on how to proceed is vital. First and foremost, it may be necessary to protect the site from redundant excavations and sampling. Equally important is the establishment of an ethical code for sampling, especially in locations of exceptional scientific relevance that have contributed the most to the historical development of the geological sciences.

Twentieth-century hypotheses on the formation of Volcanic Caves on Mount Etna

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Keywords: history of volcanology, history of geology, history of science.

Speleology in volcanic areas, also known as volcanospeleology, is one of the many significant aspects of Mount Etna (Sicily, Italy). Although local populations have known and used Etnean caves since time immemorial for various purposes, such as habitation or snow storage, their scientific study began only in the modern age. Following nineteenth-century explorations, such as those carried out by M. Gemmellaro (1773-1839), and the reports published by Sartorius von Waltershausen (1809-1876), the systematic mapping of caves began in the twentieth century thanks to the work of the Etnean Section of the Italian Alpine Club (Miceli, 1933).

A major step forward in understanding their genesis came after the 1971 eruption: for the first time, several international research groups were present to observe all phases of the eruption. The studies conducted in the following years proved highly productive and, from a volcanospeleological perspective, led to the development of new hypotheses. In particular, Rittmann (1893-1980) emphasized the interpretation of rheological and fluid-dynamic processes to explain the formation of lava tubes within an aa lava field (Rittmann, 1977). As recently noted (Puglisi, 2023), this theory had already begun to emerge in the Etnean area in the late 1950s (Poli Marchese, 1959). This circumstance also gave rise to another important point of reflection concerning the dissemination of scientific knowledge on these topics. Subsequent models, following Rittmann's work, do not cite his theoretical framework, perhaps because his ideas were disseminated mainly in Italian and German, while English was beginning to establish itself as the primary language of science in the Western world. The models most widely accepted today are often based primarily on studies of Hawaiian volcanoes, which host some of the largest and best-studied volcanic caves on Earth, whereas the scientific tradition concerning Mount Etna appears to have engaged with other models only relatively recently, showing limited permeability to the reception of external ideas.

Miceli F. (1933) - Le grotte dell'Etna. Sezione Etnea, Club Alpino Italiano.

Puglisi G. (2023) - Le bocche di Serracozzo del 1971 e la vulcanospeleologia all'Etna. Un binomio inscindibile. In: Branca S., Musumeci D. (Eds), Etna 1971 tra storia e vulcanologia. Edizioni INGV, Roma, 66-83.

Poli Marchese E. (1959) - Genesi e morfologia di alcune grotte dell'Etna. Boll. Soc. Geogr. Ital., 30, 452-462.

Rittmann A. (1977) - La formazione delle grotte vulcaniche. In: Licitra G.M. (Ed.), Settimana Speleologica Catanese e Seminario delle Grotte Laviche. Gruppo Grotte Catania della Sezione Etna del C.A.I., 87-100.

From karst to volcanic terrains: Historical development and modern expansion of the sinkhole concept

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Keywords: historical development, sinkhole concept, geohazard.

The concept of sinkhole has undergone a significant transformation in Earth Sciences, reflecting broader shifts in geomorphology, karst research, and geohazard studies. Initially rooted in the analysis of karst landscapes, the term has evolved from a narrowly defined geomorphological feature into a flexible, multidisciplinary concept encompassing a wide spectrum of subsidence phenomena, including those in non-carbonate and volcanic environments.

In late nineteenth-century European literature, closed depressions in soluble rocks were primarily described as dolines, a term introduced by Cvijić (1893) within a descriptive, morphographic framework. In contrast, sinkhole, widely adopted in North American scientific literature during the mid-twentieth century, progressively acquired a genetic connotation, referring to depressions formed by carbonate dissolution and subsequent collapse. This karst-centered interpretation was supported by classifications based on formation mechanisms, including solution, collapse, and cover-subsidence processes (Ford & Williams, 2007).

Since the late twentieth century, the term has undergone a marked semantic expansion, extending to non-karstic settings such as evaporites, unconsolidated sediments, and anthropogenically modified environments (Nisio et al., 2007; Gutiérrez et al., 2014). Particularly significant is its application to volcanic terrains, where sinkhole-like features develop through processes unrelated to dissolution. In these contexts, piping sinkholes result from subsurface erosion driven by concentrated water flow, removing fine-grained materials within pyroclastic and volcaniclastic deposits. These processes can produce rapid collapses and morphologies closely resembling karst sinkholes despite fundamentally different genetic controls.

This conceptual broadening reflects a shift from a strictly genetic definition to a morphology-based, hazard-oriented framework, widely applied in susceptibility assessment and risk management. While this transition enhances interdisciplinary communication, it also introduces ambiguities, as similar landforms may derive from distinct processes. Consequently, recent studies emphasize the need for precise genetic classification within the expanded use of the term. The evolution of the sinkhole concept thus exemplifies a broader trend in Earth Sciences, from descriptive terminology to integrative frameworks addressing complex environmental phenomena within heterogeneous geological settings.

Cvijić J. (1893) - Das Karstphänomen. Geogr. Abh., 5(3), 217-329.

Ford D.C. & Williams P.W. (2007) - Karst hydrogeology and geomorphology. Wiley.

Gutiérrez F. et al. (2014) - A review on natural and human-induced geohazards and impacts in karst. Earth Sci. Rev., 138, 61-88.

Nisio S. et al. (2007) - Sinkholes in Italy: First results on the inventory and analysis. In: Parise M., Gunn J. (Eds.), Natural and anthropogenic hazards in karst areas: Recognition, analysis and mitigation. Geological Society, London, Special Publications, 279, 23-45, https://doi.org/10.1144/SP279.4.

Making deep time habitable: Scientific thought and narrative in "*le Cosmicomiche*"

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Keywords: Italo Calvino, deep time, paradigm shifts.

In the context of the major scientific revolutions that developed between the second half of the nineteenth century and the first half of the twentieth century, from Charles Darwin's theory of evolution to the redefinition of Earth's age in terms of billions of years through the isotopic studies of Clair Patterson, and the gradual affirmation of the Big Bang theory a profound shift emerged in the perception of time, the history of life and humanity's position within the universe. Concepts such as deep time, extinction and the mutability of species progressively moved beyond the academic sphere and entered popular culture. In the wake of these paradigm shifts, Italo Calvino (1923-1985), through "*le Cosmicomiche*" (1965), offers significant testimony to the cultural reception of these ideas during the 1960s. The collection, structured around short stories introduced by a scientific statement followed by a fantastical narrative development, addresses central themes of geology, paleontology and cosmology. In "The aquatic uncle" the transition of the first vertebrates onto land is explored, while "The dinosaurs" presents reflections on extinction through the hypothesis of biological replacement of dinosaurs by emerging animal groups. In "A sign in space" the overcoming of fixism appears through the idea of the transience of living forms. These stories, although seemingly imaginative exercises, may instead reflect the need to make scientific concepts that exceed the scale of ordinary human experience inhabitable. Significantly, the protagonist directly inhabits the epochs and environments described, becoming at times a dinosaur, a marine organism, or a cosmic presence. Calvino's work therefore represents a form of cultural mediation through which the decentering of humanity within the history of the Earth and life itself becomes imaginable, accessible, and emotionally assimilable.

GeoEsplora Calabria: Reconstructing and communicating geological knowledge in Calabria

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Keywords: geosites, Calabria.

Geological knowledge is not only a scientific asset but also a fundamental component of cultural Heritage. In Calabria, intensive mining activities developed from the early 19th to the mid-20th century generated a significant body of geological, mineralogical, and territorial data that is now largely fragmented and underexploited. Furthermore, nature, through various geological processes, has shaped places of enchanting beauty in this region that are often little or not at all known except at a local level. This contribution presents the GeoEsplora Calabria project as a case study to demonstrate how historical geological knowledge can be recovered, systematized, and reinterpreted within a contemporary geo-heritage framework.

A key methodological feature is the application of a multi-criteria assessment approach (La Russa et al., 2024). By combining scientific value, educational potential, touristic relevance, and degradation risk (Brilha, 2016), following established geoheritage evaluation frameworks, the project enables a structured reinterpretation of geological knowledge, bridging historical data with present-day conservation and valorization strategies.

Furthermore, the project emphasizes the role of digital technologies in enhancing geo-heritage communication. Digital tools, including algorithms for personalized itinerary planning, are integrated into a mobile application designed to have interactive and accessible experiences. In this context, geological knowledge is not merely preserved but actively re-mediated, fostering new forms of public engagement and learning.

By linking historical geoscientific practices with contemporary digital approaches, this work highlights how geological knowledge can be reframed as a dynamic cultural resource.

Brilha J. (2016) - Inventory and quantitative assessment of geosites and geodiversity sites: a review. Geoheritage, 8(2), 119-134.

La Russa M.F. et al. (2024) - Quantitative Assessment of Geosites and Mine Heritage as a Resource: The Case Study of Lungro Salt Mine (Calabria, Italy). Geoheritage, 16(3), 1-11.

The ReMi-ISPRA Network of Mining Museums and Parks

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Keywords: mining tourism, cultural heritage, resources and sustainability.

When the process of decommissioning industrial mining activities began in the 1980s, Italy's decommissioned mining heritage remained largely abandoned to itself for a few decades, with no prospect of its future. Some regulations aimed at reconversion and environmental recovery in the 90s and 2000s favored the first recovery and enhancement actions on the territory in Sardinia, Tuscany, Piedmont but overall, there was no national strategy capable of dealing with the management of disused mining realities in a unified manner. Today, mines are once again a topical issue due to the international economic policy that is pushing for the relaunch of the mining sector for the extraction of strategic critical minerals, related to historical mining deposits. Since 2009, ISPRA has been coordinating the National Day of Mines in collaboration with AIPAI (Italian Association of Industrial Archaeology) and since 2015 the ReMi Network of Museums and Mining Parks, in collaboration with the Lombardy Region, MASE, ANIM, AIPAI, CNG, ASSORISORSE, with the priority objective of promoting the conservation, protection and enhancement of disused mining heritage throughout the country. The enhanced mining realities have adopted different management models, but all suffer from the same problems that are the absence of a unified regulatory framework and the chronic lack of economic resources. The ReMi network has 77 upgraded mining sites, including the four national mining parks established by Ministerial Decree in the 2000s, in Sardinia, Tuscany, Marche and Emilia-Romagna (Patanè et al., 2023). The archives of data and information related to past mining activities, preserved at the mining parks and museums participating in the network, constitute one of the essential sources for identifying the study areas of the National Mineral Exploration Program managed by ISPRA, in collaboration with MASE and MIMIT. ReMi-ISPRA has put forward draft law 1274/2018 "Provisions for the protection and enhancement of disused mining sites and their geological, historical, archaeological, landscape and environmental heritage", which is the expression of an elaborate summary of the various entities that daily manage the mining heritage with difficulty in the country that has represented a reference text for the launch of some regional laws on the subject. Always for the purpose of knowledge of mining sites, ReMi-ISPRA, in collaboration with the Department of Earth Sciences at the University of Florence and AIPAI, published a cataloguing sheet dedicated to cultural mining sites and industrial sites and structures, in agreement with the Central Institute for Cataloging and Documentation. The cataloguing sheet "SPD Decommissioned production sites" is applicable to all industrial archaeology sites and can be downloaded from the ICCD website of the Ministry of Culture.

Patanè A. et al. (2023) - National's Network of Parks of Mining Museums (OTT), Viaggio nell'Italia Mineraria - Edizione 2023. ISPRA, 157 pp.

The Renaissance mining activity in the Apuan Alps (Tuscany): A case study of the Bottino mining complex

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Keywords: renaissance silver mines, topographic survey, Apuan Alps.

The Apuan Alps (northern Tuscany) are characterized by extraordinary geodiversity, supporting their candidacy for inclusion in the UNESCO Global Geoparks Network. The mining geosites are among those of greatest scientific and cultural significance. However, many of these sites remain largely unknown and are rarely integrated into educational or tourist itineraries.

Beyond their scientific relevance, these mining sites played a crucial historical role in shaping both local communities and the transformation of the landscape. With the end of mining activities in the 80s, these sites gradually fell into oblivion, except for limited scientific interest. This study aims to promote the historical, cultural, and scientific valorisation of these mining heritages, focusing on one of the most significant examples: the Bottino mining district (Stazzema municipality). The research documents and reconstructs the underground mining complex to support conservation strategies, cultural dissemination, and provides a cartographic basis for future geological surveys of the Apuan Alps ores.

At Bottino mine, the ore assemblage consists of galena (PbS) and sphalerite (ZnS), associated with Ag-rich tetrahedrite, hosted within the tourmaline-bearing Filladi Inferiori Fm, derived from a Cambrian-Lower Ordovician sedimentary protolith. Some authors have suggested that mining activities may date back to the Etruscan or Roman periods; however, this hypothesis remains unconfirmed. The earliest documented evidence dates back to the 13th century, when the area was controlled by the local nobles of Corvaia and Vallecchia, although mining activities were limited due to an unfavourable political context. Significant exploration began in the 16th century, following the annexation of the "*Capitanato di Pietrasanta*", the present-day Versilia, to the Florentine Republic through Pope Leo X's decree (Lodo) in 1513. Under the Medici control, the Pb-Zn-Ag ore bodies were exploited for nearly a century. These ancient excavations were only marginally affected by subsequent mining activities during the 19th and 20th centuries. As a result, the Renaissance underground mining complex is exceptionally well preserved, as testified by the tunnels and extraction voids displaying characteristic tool marks and "coffin-shaped" tunnel sections. Recent exploration, integrated with a new topographic survey of the Bottino underground mining complex and comparison with historical cartography, has enabled the delineation of the preserved Renaissance heritage. The underground complex consists of six main mines and eight minor excavations, with a total spatial development of approximately 1.5 km. Notably, nearly 45% of the mapped tunnels consist of ancient works attributable to Renaissance mining activities.

Between observation and misinterpretation: Francesco Stelluti, fossil wood, and the epistemological tensions of early Seventeenth-century geology

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Keywords: history of palaeontology, Accademia dei Lincei, CARG project.

Francesco Stelluti's *Trattato del legno fossile* (1637), produced within the intellectual framework of the *Accademia dei Lincei*, represents a remarkable yet paradoxical document in the early history of geology and palaeontology. Although Stelluti adopted highly innovative observational practices, including systematic field observations, detailed illustrations, and comparisons between different states of preservation, he ultimately rejected the organic nature of fossil wood from the Todi area of Umbria (Romano, 2025). Instead, he interpreted these remains as products generated directly within the Earth through the action of mineral waters, subterranean heat, and transformative "virtues" of clay-rich sediments. This contribution reassesses Stelluti's treatise not simply as an example of scientific error but as evidence of the coexistence of competing explanatory frameworks during the early seventeenth century. The work illustrates how empirical accuracy did not necessarily lead to correct theoretical conclusions in a period when traditional mineralogical concepts, Renaissance natural philosophy, and emerging observational methodologies overlapped. Stelluti's interpretations are particularly significant because they emerged within one of Europe's most progressive scientific circles, the *Accademia dei Lincei*, which strongly promoted direct observation and visual documentation of nature. Special attention is devoted to the role of illustrations in the treatise, which constitutes one of the earliest systematic iconographic representations of fossil wood in European scientific literature. Rather than representing a marginal episode, Stelluti's work offers a valuable case study for understanding the complex and non-linear emergence of modern geological thought.

Romano M. (2025) - Between empiricism and tradition: reassessing Francesco Stelluti's Trattato del legno fossile (1637). J. Mediterr. Earth Sci., 17, 55-69.

Atlantis as environmental memory: Geological catastrophes and the Platonic tradition

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Keywords: Minoan eruption, Plato, geomythology.

The myth of Atlantis, introduced by Plato in the Timaeus and Critias, represents one of the most influential intersections between mythological narrative, environmental memory, and geological speculation in Western intellectual history. Far from being merely a fictional allegory, the Atlantis tradition profoundly influenced early modern debates concerning catastrophic events, continental instability, and the evolution of Earth's surface. From Renaissance interpretations to nineteenth-century theories of submerged continents, Atlantis played a significant role in shaping geological imagination before the establishment of plate tectonics. This contribution examines the historical evolution of geological interpretations of Atlantis and evaluates the main geomythological models proposed to explain the Platonic narrative. Particular attention is devoted to two hypotheses that appear most coherent with the environmental and catastrophic framework described by Plato: (1) post-glacial sea-level rise following the Younger Dryas climatic event, which may have preserved collective memories of rapidly submerged coastal landscapes during the early Holocene; and (2) the Minoan hypothesis, linking Atlantis to the Bronze Age eruption of Thera (Santorini) and the subsequent collapse of the eastern Mediterranean world. Through an interdisciplinary approach integrating the history of geology, palaeoclimatology, geomorphology, archaeology, and geomythology, Atlantis is interpreted not as the memory of a lost continent but as a cultural and philosophical construct that encodes real environmental crises within a symbolic narrative framework. In this perspective, the Atlantis myth emerges as a remarkable example of long-term cultural resilience and environmental memory.

Abandoned mine lands in the Calabria Region (Italy): A review of geological features, conservation status, and reclamation potential

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Keywords: abandoned mine lands, geoheritage, geosites.

Abandoned mining lands (AMLs) are quite common in the Calabria region, as in much of the Italian territory. This abundance is mainly due to the complex geological evolution, which led to a wide diffusion of the different types of mineral resources that were extracted in the past. The present research aims to systematically group and describe those different AMLs through a comprehensive literature review combined with targeted field activities. This approach allows AMLs to be ranked, from pre-protohistoric pigment mines to recent industrial-scale sulphur and barite operations, to evaluate their current conservation status and residual potential. This study also relies on a rigorous assessment methodology defined by Brilha (2016) and already applied in La Russa et al. (2024) on a historical salt extraction site. In detail, this method utilises weighted macro-indexes, defined as Scientific Value (SV), Tourism Potential (PTU), Educational Potential (PEU) and Degradation Risk (DR), to reduce subjectivity in evaluation processes, which allows a direct comparative evaluation between considered AMLs. The early findings suggest which AMLs are in such a critical condition that needs urgent attention and reclamation/geoconservation efforts, at least to reduce their mineralogic, archaeological, and industrial heritage loss. From this evaluation, it also turns out which sites also have the highest potential to become a point of reference in the local/national earth sciences education circuit or even a geo-tourism site of interest (geosites). Only integrated approaches, combining scientific and historical characterisation, rigorous assessment method, reclamation action, may ensure AMLs sustainable management and trigger local economic growth.

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Brilha J. (2016) - Inventory and quantitative assessment of geosites and geodiversity sites: a review. Geoheritage, 8, 119-134, https://doi.org/10.1007/s12371-014-0139-3.

La Russa M.F. et al. (2024) - Quantitative assessment of geosites and mine heritage as a resource: the case study of Lungro Salt Mine (Calabria, Italy). Geoheritage, 16(3), 77, https://doi.org/10.1007/s12371-024-00978-2.

The Copais basin in Mycenaean times: Some preliminary thoughts for an integrated archaeological and geological approach

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Keywords: karstic hydraulic engineering, Mycenaean land reclamation.

The Copais basin is a karstic polje located in north-western Boeotia (central Greece). In antiquity, it was partly occupied by a shallow and marshy lake, whose fluctuations were unpredictable and dictated by a range of natural phenomena. Despite these conditions, the region attracted settlers since prehistoric times, owing to the resources it offered. In addition to freshwater and aquatic fauna, the sediments forming the belt around the lake were exceptionally fertile. It is within this framework that, during the Bronze Age, more precisely roughly from the 18th century BC onwards, the basin witnessed the development of increasingly complex hydraulic works (Hope Simpson & Hagel, 2006; Lane, 2023). These aimed at reclaiming as large portions of the Copais as possible, through a series of polders and earthen dams. At the same time, the lake's waters were channelled for irrigation purposes. Although these early reclamation efforts began slightly before the onset of the so-called Mycenaean period (c. 1700-1100 BC), it was during its apogee, in the 13th century BC, that a new and larger system was devised (Kountouri et al., 2013). This system included a channel approximately 20-25 km in length, running along the northern rim of the basin. By partially collecting the waters of the two principal tributaries of the Copais, the Kephisos and the Melas, the channel accelerated their flow towards the karst located along the north-western and western margins of the basin. This operation made it possible to reclaim a significant amount of arable land, showing how Bronze Age engineers had already understood the functioning of karstic landscapes from a geological perspective.

Kountouri E. et al. (2013) - Mycenaean Drainage Works of North Copais, Greece: A New Project Incorporating Surface Surveys, Geophysical Research and Excavation. Water Sci. Technol.: Water Supply., 13(3), 710-718, https://doi.org/10.2166/ws.2013.110.

Lane M.F. (2023) - The Mycenaean Northeast Kopaïs Project: A Report from Ayia Marina Pyrgos. Hesperia, 92(4), 587-643, https://doi.org/10.2972/hes.2023.a914393.

Simpson H.R. & Hagel D.K. (2006) - Mycenaean Fortifications, Highways, Dams and Canals. Dept. of Classics Queen's University at Kingston, 254 pp.

The Praborna manganese mine: From Alpine ore to Renaissance Venetian cristallo

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Keywords: history of geology, geoheritage, subduction.

The ancient manganese mine of Praborna, located in the upper Saint-Marcel valley in the Aosta Valley, offers a remarkable example of how a small Alpine deposit became entangled with the history of glassmaking, mineral trade, scientific collecting and modern petrology. Documented at least since 1402, Praborna supplied a manganese-rich ore that was used for centuries by Venetian glassmakers to produce the highly prized *cristallo veneziano*. Known historically as "Piedmont manganese", this material was added in small amounts to glass melts to remove the greenish tint caused by ferrous iron, allowing the production of transparent glassware, mirrors and optical lenses.

Our forthcoming monograph, "The manganese mine of Praborna (Aosta Valley, Italy). An open-air mineralogy museum at the origin of Renaissance Venetian cristallo", will appear in the *Quaderni* series of the *Accademia delle Scienze di Torino* and reconstructs this long history by combining archival research, historical sources, mineralogical literature and geological observations. The first part follows the mining history of Praborna and the commercial routes that carried its ore from the Aosta Valley to Venice and, later, towards France and Saint-Gobain. The second part examines the scientific importance of the deposit, which has attracted mineralogists, crystallographers, geologists and collectors from the eighteenth century to the present day.

Beyond its historical role, Praborna is a highly unusual petrological object. The manganese-rich ores are now interpreted as part of an oceanic hydrothermal system developed in the Jurassic Tethys and later incorporated into the Alpine orogenic belt. During subduction, these oceanic sediments and associated rocks were transformed under high-pressure, eclogite-facies conditions, producing mineral assemblages that preserve the memory of both seafloor hydrothermal processes and Alpine metamorphism, with peak conditions inferred from nearby metaophiolites at about 2.1 GPa and 550°C.

This high-pressure overprint is also expressed by one of the most emblematic minerals of Praborna: violan, a violet-blue Mn-bearing variety of omphacite, historically appreciated as a semiprecious stone but scientifically important as a pyroxene recording the unusual chemistry and pressure conditions of the deposit. Praborna is also the type locality of several mineral species, including piemontite, braunite, strontiomelane and manganiandrosite-(Ce), and contains rare assemblages enriched in Sb, Cr, As, V, Ba, Sr, Au and rare earth elements.

The history of Praborna therefore connects mountain mining, Renaissance craftsmanship, ocean-floor mineralisation, Alpine subduction and the development of mineralogical and petrological science. A material extracted from a remote Alpine valley contributed to some of the most refined products of Venetian technology, while the same rocks now provide a unique record of how a Tethyan hydrothermal deposit was transformed at depth and returned to the surface during Alpine orogenesis.

S34.

Scientific museums and contemporary museology: Research, education, and heritage mediation

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Fabrizio Nestola (Università di Padova)

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STORIES, TALES, EXPLORATIONS at the Museum of Mineralogy, Petrography and Volcanology and the City of Science of the University of Catania

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Keywords: edutainment, participatory methodology, social engagement.

Edutainment and Participatory Methodology are the key work of this experience, a project designed in two different phases, where geological samples were used as tools for teaching geology to students of different levels of education. During the first phase university students are involved to plan and implement the tools action necessary to develop the second one. Specifically, an heterogenous group of students, composed by geologist and humanists, created educational books for children to teaching and communicating geology in a not conventional way. Stories and graphic design were designed both manually and using AI, combining their different scientific and humanistic skills. After the narratives about the geological nature of the samples and their use in antiquity for the construction of prestigious structures and goods; the book ends with some dedicated play activities.

The second part of the project has foreseen educational-museum activity dedicated to children of primary schools. Learning was achieved through linked activities that helped to understand the basic aspects of geology with a first direct contact with rock samples. Starting from geological samples, the operators spoked about different rocks using the books as guide; then, the children acquired insights into the rocks thanks to a guided tour visiting the Museum of Mineralogy, Petrography and Volcanology and City of Science, belonging to the University of Catania. The experience was enriched by sensorial activities, in fact the students were guided in the tactile recognition of geological and paleontological objects, and they observed a reproduction of the Catania Cathedral exploring some examples of the materials used for its construction (Barone et al., 2024).

The positive feedback gathered from questionnaires distributed to all participants (teachers, students, and operators) highlights the significant social impact of this project. Indeed, it proved highly beneficial in introducing elementary school children to STEM subjects through an interactive and multidisciplinary approach (Barone et al., 2023)**.** Furthermore, the project successfully bridges thecollaborative, multidisciplinary expertise of the university with lower levels of education and active societal engagement (Cioppi, 2014).

Barone G. et al. (2023) - Un approccio sperimentale multisensoriale per le Scienze della Terra. Museologia Scientifica, nuova serie*,* 17, 73-83, https://doi.org/10.53246/ANMS0037.

Barone G. et al. (2024) - "Il Museo per tutti i Sensi": nuovo progetto inclusivo per il Museo delle Mirabilia dell'Università di Catania. Museologia Scientifica, nuova serie, 18, 114-127, https://doi.org/10.53246/anMs0049.

Cioppi E. (2014) - Aspetti di educazione nel museo. In: Pratesi G., Vannozzi F. (Eds), I valori del museo. Politiche di indirizzo e strategie di gestione, FrancoAngeli, Milano, 2014, pp.135-145, ISBN 978-88-917-1095-6.

Cultural heritage and social justice: Experiences of inclusion and cultural mediation between the Museo dei Saperi e delle Mirabilia Siciliane and the District Office for External Penal Enforcement of Catania

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Keywords: cultural heritage, social inclusion, cultural mediation.

This contribution presents an interdisciplinary and interinstitutional project developed through a protocol agreement between the Museo dei Saperi e delle Mirabilia Siciliane of the University of Catania and the District Office for External Penal Enforcement (UDEPE) of Catania, in collaboration with associations. The initiative aims to experiment with practices of social inclusion, cultural mediation, and active participation involving offenders subject to community sanctions and alternative measures.

The project is based on the recognition of cultural heritage and local identity as tools capable of fostering responsibility, personal growth, and social reintegration. Within the distinctive geological and cultural context of eastern Sicily, marked by the presence of Mount Etna, participants engage in heritage education activities, guided tours, museum mediation programs, and dialogue-based experiences. In this framework, the university museum, with its naturalistic, archaeological, and historical collections, is reinterpreted as a relational space and civic hub, open to interaction among institutions, communities, and individuals.

A central role is played by the UDEPE of Catania, which promotes educational and restorative approaches to punishment. Through cultural participation, individuals are encouraged to develop self-awareness, a sense of belonging, and prosocial attitudes. The collaboration between museum and community justice services demonstrates the potential of cultural heritage in welfare processes, active citizenship, and restorative practices, helping to counteract marginalization and the social stigma often associated with criminal behavior (Bouchard & Mierolo, 2005; Eusebi, 2015).

This experience also aligns with recent national reflections on the relationship between culture, health, and well-being, particularly following the Memorandum of Understanding signed by the Italian Ministry of Culture and the Ministry of Health for the promotion of social and cultural prescribing. The agreement recognizes the contribution of cultural institutions to social cohesion and highlights museums as environments capable of positively influencing quality of life and addressing contemporary vulnerabilities.

Within this perspective, the Museo Mirabilia functions as a laboratory for research and experimentation in innovative rehabilitative practices. The voluntary contribution of academics, professionals, and experts involved in the training activities, together with the participants ability to return acquired knowledge to the community, generates virtuous processes of trust, reciprocity, and social responsibility. Such dynamics contribute to overcoming stereotypes, repairing social fractures caused by crime, and rebuilding relationships between individuals and society (Mannozzi & Lodigiani, 2015; Tramonte, 2023).

The project demonstrates how museums can extend their mission beyond conservation and education, becoming active agents of inclusion and social cohesion.

Bouchard M. & Mierolo G. (2005) - Offesa e riparazione. Giuffrè, Milano, 238 pp.

Eusebi L. (2015) - Una giustizia diversa. Il modello riparativo e la questione penale. Vita e Pensiero, Milano, 92 pp.

Mannozzi G. & Lodigiani G.A. (2015) - Giustizia riparativa. Ricostruire legami, ricostruire persone. Il Mulino, Bologna, 156 pp.

Tramonte V. (2023) - Giustizia riparativa. Pratiche, effetti, potenzialità. Erickson, Trento, 24 pp.

The New Natural History Museum Abu Dhabi: A 13.8-billion-year journey

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Keywords: dinosaurs, meteorites, mammals.

The Natural History Museum Abu Dhabi (NHMAD) opened to the public on 22 November 2025 and offers visitors an extraordinary journey through 13.8 billion years of natural history. The NHMAD galleries showcase specimens of exceptional scientific value.

Upon entry, visitors are greeted by five giant Jurassic aged sauropod dinosaurs from the Morrison Formation (USA), representing some of the largest land animals ever to have lived. The first gallery introduces the formation of the Universe, alongside an animation highlighting the Murchison meteorite—a 1.3 kg specimen containing 7-billion-year-old presolar grains. The story of the Sun, Earth, and the formation of the Solar System is presented with high-end animations and a display of 136 meteorite specimens, such as the 651 kg Brenham pallasite (touchable by visitors), the 45.7 kg Ash Shaqqah 002 lunar meteorite (the world's largest touchable Moon rock), and the 7.8 kg Sayh al Uhaymir 008 Martian meteorite. Fossil highlights include a near-complete skull of the placoderm fish *Dunkleosteus* sp. from Morocco but also displays specimens from the NHMAD collections of invertebrates and vertebrates that chart the evolution of Palaeozoic life.

The Mesozoic gallery showcases fossils from Lagerstätten in the UK and Germany but also displays Argentinian cast skeletons from the dawn of the dinosaurs. Notable exhibits include two battling *T. rex*, featuring two of the most complete skeletons ever found, alongside beautiful ammonites and marine reptiles displayed within floor fissure showcases reminiscent of the UK Jurassic Coast. Marine fossils from the UAE, including rudists, highlight the region's evolutionary history during the Late Cretaceous.

A dedicated gallery presents Late Miocene vertebrate fossils from the Baynunah Formation (Abu Dhabi), revealing a time when the region consisted of large rivers, savannah, and forests teeming with life. Iconic species such as the four-tusked *Stegotetrabelodon emiratus*, saber-toothed cats, hyaenids, hippos, and the three-toed equid *Hipparion abudhabiense* are brought to life through detailed, scientifically accurate reconstructions.

The human story is also represented, with displays of replica hominin skulls and animations tracing early human dispersals. The NMHAD proudly hosts a loan of "Lucy," the famous *Australopithecus afarensis* fossil, courtesy of the Ethiopian Heritage Authority.

The NHMAD offers the public interactive engagement through sub-galleries, including PalaeoLab, where visitors can handle fossils and participate in a reconstructed dinosaur excavation. The Arabia's Climate gallery immerses visitors in a projection that illustrates environmental changes in the UAE from the Late Cretaceous to the present day. Finally, the NHMAD brings visitors to the UAE's rich natural heritage and the evolution of life on Earth in the present day, but with a clear focus on how we look towards a more sustainable future for all life on Earth.

From past to future: The type-mineral collection of the Regional Museum of Natural Sciences of Turin

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Keywords: mineralogical collections, type-mineral, museum curation.

Within the geosciences, and particularly in mineralogical research, type-mineral collections are an indispensable reference framework for both primary investigations and subsequent comparative studies aimed at the identification and characterization of mineral species.

It constitutes a fundamental reference database for research in mineralogy, crystallography, and geology, comprising specimens of mineral species used as standards for the definition and characterization of geomaterials.

Their central role implies that they must be preserved in museums and academic institutions that ensure their long-term preservation, conservation, and scientific valorization.

In this context, a comprehensive reorganization and revision of the type-mineral collection housed at the Regional Museum of Natural Sciences of Turin (MRSN) has been undertaken. A preliminary assessment has enabled the evaluation of the collection's composition, historical development, and geographical-temporal distribution.

This study highlights the scientific and museological significance of the collection, retraces its historical development and assesses its current status.

The recent reopening of the museum, following a decade of closure, offers a unique opportunity to strengthen dialogue and collaboration among institutions, researchers, and enthusiasts, thereby revitalizing the scientific and cultural mission of the MRSN.

Enhancing this network of collaboration will not only contribute to the growth of the collection but also to its scientific, educational, and cultural valorization. In this perspective, the Section of Mineralogy, Petrography, and Geology aims to re-establish sustained and productive interactions with both the academic community and the amateur mineralogical sector.

The revision of the type-mineral collection represents a tangible first step in this direction. As a comprehensive reference database for the scientific community, it embodies not only significant scientific value but also reflects the historical legacy of the museum and its future aspirations.

Digital platforms and cocreative solutions in cultural heritage enhancement through heritage communities engagement

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Keywords: digital storytelling, virtual exhibition, participatory storytelling.

Digital platforms and tools like izi.TRAVEL, ArtSteps, and Loquis are useful for new forms of art presentation, visualization, and narration, in a participatory, collaborative, and sustainable manner. Three projects will be presented, in which these platforms have been used, in University courses between 2024 and 2026: the VR exhibition "*Michelangelo antifascista a Bari 1964-2024*" on Artsteps and the digital storytelling projects connected on izi.TRAVEL, by readapting in a transmedial way an analogical exhibition in 1964 (Bonacini, 2024; Leonardi & Bonacini, 2024); the VR exhibition "Sarajevo from war to peace, thirty years later" on Artsteps, in which students and institutions have been involved between Bari and Sarajevo (Bonacini & Ibrišimbegović, 2026); and six storytelling and geopodcasting projects through the profile "Digital Heritage & Heritage Communities" on Loquis, and the use of AI to create podcast covers. In all projects, students have been involved in cocreating stories and digital contents. These projects were highly inclusive, both in terms of the age groups involved (from elementary school children to master's students) and the participation of individuals with special needs and various learning (Asperger's Syndrome) and sensory (deafness) disabilities.

Bonacini E. (2024) - Michelangelo (1964) e intorno a Michelangelo 2024. Dall'effimero analogico al transmediale digitale. In: Leonardi A. (Ed), Michelangelo antifascista a Bari (1964-1965) Il 'non finito' di Adriano Prandi e il critofilm di Carlo Ludovico Ragghianti nel IV centenario della scomparsa del Buonarroti, Bari: Edipuglia, 197-224, https://dx.doi.org/10.4475/0932_8.

Bonacini E. & Ibrišimbegović S. (2026) - Sarajevo, dalla guerra alla pace trent'anni dopo. Un progetto virtuale partecipativo per preservare memoria della solidarietà e della resilienza dell'arte. In: Volpe G. (Ed), Paesaggi storici, Tradizioni e Identità culturali, Bari: Edipuglia, 1-13, http://dx.doi.org/10.4475/1724.

Leonardi A. & Bonacini E. (2024) - Michelangelo su ArtSteps. L'esperienza VR di 'Michelangelo antifascista a Bari. In: Leonardi A. (Ed), Michelangelo antifascista a Bari (1964-1965). Il 'non finito' di Adriano Prandi e il critofilm di Carlo Ludovico Ragghianti nel IV centenario della scomparsa del Buonarroti, Bari: Edipuglia, 225-240, https://dx.doi.org/10.4475/0932_9.

The GeMM | Geo-Mineralogical Museum of the Politecnico di Torino: Research, heritage, and knowledge enhancement

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Keywords: geoheritage, science communication, sustainability.

GeMM, the Geo-Mineralogical Museum of the Politecnico di Torino, was inaugurated in June 2024. This is the first permanent exhibition established within the University, and it is hosted by the Department of Environment, Land and Infrastructure Engineering (DIATI).

The project intends to reveal and showcase the University's mineralogical and mining collections. These include mineral samples, educational models, instruments, and mining machinery of great historical and scientific value. At the same time, the museum aims to focus on the current challenges of research in these domains, in line with the University's mission of knowledge valorization and transfer, by sharing research findings with society and contributing to local social and cultural development.

The main focus of the exhibition is the role of research itself. Just as scholars in the 19th Century grappled with new discoveries, today's researchers face challenges that open up to horizons that are still unexplored. The project achieved to make collections more accessible, with the aim of making a broad and diverse audience familiar with a historical, documentary and scientific heritage of great value. GeMM also aims to stimulate interest in the history of science and technology, conveying to new generations the importance of understanding our roots in order to better understand the present time and to imagine more sustainable futures.

The exhibits on display are highly heterogeneous and include collections spanning several domains of Earth Science, including Mineralogy, Geology, Lithology, Paleontology and Mining techniques. Most of the materials constitute an historical heritage: except for a limited number of recent donations and teaching instruments acquired in recent decades, nearly all the objects come from collections that have been assembled between the mid-nineteenth Century and the 1970s.

GeMM has also been conceived as a tool for science communication and public engagement. The final section of the exhibition integrates multimedia installations addressing current issues related to the extraction, processing, and recycling of raw materials, as well as their social and economic implications. The goal is to raise public awareness on the relevance of raw materials for our daily life and to produce essential technologies for energy and digital transition.

Public access is primarily provided through guided tours, which can be tailored to different audiences. Since its inauguration, the museum has welcomed more than one thousand visitors. Interactive educational activities are also regularly organized for schools and younger audiences.

Authentication of museum diamonds through the use of spectroscopic analysis

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Keywords: diamonds, authentication, spectroscopic techniques.

Being able to discern whether a diamond is natural or synthetic is one of the most difficult challenges in modern gemology. This happens because synthetic diamonds have the same identic aspect, optical properties and mineralogical structure of natural ones so traditional methods of gemological analysis can't distinguish between them. Synthetic diamonds are produced in laboratory with two methods: the High Pressure High Temperature method, that simulate the forming environment of diamonds, and the Chemical Vapor Deposition method that allows diamonds growth around a nucleus. Obviously synthetic diamonds have less value than natural ones, so it is crucial to authenticate them. For this reason, the aim of this research was analysing a set of eleven diamonds by using spectroscopic analysis to study them at molecular bonds level and to find characteristic spectral parameters for both natural and synthetic diamonds.

The analysed diamonds were borrowed from the Museum of Mineralogy, Petrography and Volcanology of the University of Catania, from local jewelers and from the Italian Gemological Institute (I.G.I.), part of which will be exhibited in a museum. The methods chosen for the analysis are the Raman spectroscopy, the infrared spectroscopy both in diffuse reflectance (DRIFT) and transmission configuration. After these analyses, a DiamondView analysis was conducted exclusively on diamonds coming from the I.G.I. in order to study growth structures. These analyses were proven to be valid means of characterization of materials in a non-destructive and non-invasive manner from previous studies (Barone et al., 2015; Martynova et al., 2021) and that is why they were chosen for this research.

Raman spectroscopy allowed us to tell if simulants were present in our samples, so we had the certainty that they were diamonds, but it was impossible to distinguish natural and synthetic ones. IR spectroscopy provided us more information about diamonds, DRIFT and transmission configurations gave comparable results, but DRIFT has proven to be the most suitable method and allowed us to find spectral parameters typical for natural and synthetic diamonds and to classify them (Breeding & Shigley, 2009).

Another kind of analysis was conducted using the DiamondView on the 5 diamonds borrowed from the I.G.I in order to study photoluminescence and observe growth structures: thanks to this analysis it was possible to establish if these diamonds were synthetized using the HPHT or CVD method.

In conclusion we can state that this research proved that spectroscopic analyses are very efficient and reliable to identify synthetic diamonds in modern gemology in order to certify gems and avoid fraud. This study also allowed us to correctly label the gems during their museum display.

Barone G. et al. (2015) - Nondestructive investigation on the 17-18th centuries Sicilian jewelry collection at the Messina regional museum using mobile Raman equipment. J. Raman Spectrosc., 46(10), 989-995, https://doi.org/10.1002/jrs.4649.

Breeding C.M. & Shigley J.E. (2009) - The "Type" Classification System of Diamonds and Its Importance in Gemology. Gems Gemol., 45(2), 96-111, https://doi.org/10.5741/GEMS.45.2.96.

Martynova T.V. et al. (2021) - Fourier-transform infrared spectroscopy for analysis of diamond materials of different origin. IOP Conf. Ser.: Mater. Sci. Eng., 1047(1), 012187, https://doi.org/10.1088/1757-899X/1047/1/012187.

A catalogue of data from the MAR98 and TIR2000 oceanographic campaigns (ISMAR-CNR): The "Marsili" section of the "Tyrrhenian Rocks" website

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Keywords: Marsili, website, catalogue.

Seafloor exploration of the Tyrrhenian Sea was carried out in the late 90s by the Istituto di Geologia Marina of Bologna (now ISMAR-CNR), during oceanographic campaigns. During two of these campaigns, i.e., the MAR98 and TIR2000 ISMAR-CNR cruises, several submarine volcanic edifices and structures of the Tyrrhenian Sea were mapped and sampled. The "Tyrrhenian Rocks" website (https://tyrrhenianrocks. ismar.cnr.it/) aims to offer a catalogue of the data (bathymetric maps, metadata, and visual documentation of the rock samples) retrieved by the two campaigns and archived at ISMAR-CNR. The website was created by a team of researchers from ISMAR-CNR (M. Marani, F. Gamberi, V. Ferrante) and the University of Parma (C. Cavozzi, T. Trua), and is organized into the following sections: Home; Oceanographic surveys and maps; Samples; Bibliography; Collaboration network; Team. It reports published or public data that may be freely downloaded. The "Samples" sub-sections of the website refer to the samples collected in the following areas of the Tyrrhenian Sea: the Marsili, Vavilov, Palinuro, Eolo, Enarete, Sisifo, and Glabro volcanoes; the Prometeo lava field; the Basiluzzo area; and the southern margin of the Marsili Basin. Currently, only the Marsili sub-section is complete thanks to a cataloguing work carried out within the framework of the PRIN2022-AWARE project. The Marsili seamount is the largest volcano in the Tyrrhenian Sea, formed over the last 0.7 million years along the active back-arc spreading center of the Tyrrhenian Sea. During the MAR98 and TIR2000 campaigns, a large set of volcanic and sedimentary samples was recovered from different parts of the volcanic edifice. The "Marsili" sub-section of the "Tyrrhenian Rocks" website provides a virtual view of a comprehensive inventory of volcanic and sedimentary rock samples collected from the volcano, including images, 360 degree photography, and thin-section photomicrographs. All the samples are georeferenced, but only a few of them have been studied in detail so far. An overview of the references referred to the results obtained from these studies, carried out within the framework of a scientific collaboration network, is reported in the "Bibliography" section of the "Tyrrhenian Rocks" website. The "Bibliography" section will be updated with the results obtained from the units involved in the PRIN2022- AWARE project. The "Marsili" sub-section is a pilot section. It will guide the creation of sample sub-sections for the other Tyrrhenian Sea submarine areas sampled during the MAR98 and TIR2000 campaigns. The "Tyrrhenian Rocks" website will serve a wide community, including researchers, students, and amateur users. It provides closer contact with the collected rocks from the Tyrrhenian Sea and highlights the limitations of the current sample studies. The site may also suggest future directions for new research collaborations and multidisciplinary investigations. It helps advance the comprehensive understanding of geodynamics, georesources, and natural hazards in the Tyrrhenian Sea region.

A new discovery in the storege room of the Museum of Nature and Humankind (MNU): A giant sloth

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Keywords: fossil, sloth, Perù.

Over the past year, we have had the opportunity to study fossil bones originally attributed to a proboscidean. These fossil remains were collected in Peru between 1976 and 1978 by Prof. Andrea Drusini (1947-2019). After being stored in the Museum for many years and largely forgotten, the fossils were brought back into focus when E. Centomo chose to examine them for her graduation thesis last year. The study activities were: cleaning of the remains, consolidation, pre-cataloging, and identification of the bone remains. The fossil remains consist of 18 pieces: 4 vertebrae, 7 rib fragments, 1 molar tooth, 1 fifth metacarpal, and 1 fragment of the ungueal phalanx of the hand. Among these, only the molar, the fifth metacarpal and the phalanx have diagnostic value. Based on the specific characteristics of these fossil remains, we concluded that they belonged to a ground sloth, specifically a Megatheriidae, rather than a proboscidean.

This hypothesis has been confirmed by Dr. François Pujos, an expert of Peruvian giant sloths and senior researcher at the National Scientific and Technical Research Council, Argentina, who co-authored a review of Peruvian giant sloths (Pujos &Salas, 2004).

Unfortunately, the incompleteness of the remains prevents the identification at the species level, allowing the determination only at the family level, also due to the unknown age of the fossiliferous site of provenance.

The study of ground sloths is crucial because it provides valuable information on the evolution of life, interactions with the environment, and the causes of megafaunal mass extinction at the end of the Pleistocene (Stuart, 2015; Varela et al., 2019). Indeed, the evolution of sloths is an important case study in the adaptation and resilience of species to environmental change (Boscaini et al., 2025). Furthermore, giant sloth fossils provide clues to the ecosystems and biodiversity of North and South America, helping to reconstruct Neogene and Pleistocene ecosystems (Pujos & Salas, 2004). Finally, given their abundance, they are also useful for the biochronological dating in continental environments of certain intervals of the Geological Time Scale. For example, in some regions, such as the Argentine pampas, the presence of a specific species of giant sloth (*M.americanum*) is so common that it defines an entire "biozone". Therefore, these remains deserve to be highlighted because their uniqueness enriches the heritage that the Museum is committed to preserving and protecting.

Boscaini A. et al. (2025) - The emergence and demise of giant sloths. Science, 388, 864-868, https://doi.org/10.1126/science.adu0704.

Pujos F. & Salas R. (2004) - A systematic reassessment and paleogeographic review of fossil Xenarthra from Peru. BIFEA, 33(2), 331-377, https://doi.org/10.4000/bifea.5746.

Stuart A.J. (2015) - Late Quaternary megafaunal extinctions on the continents: a short review. Geol. J., 50, 338-363, https://doi.org/10.1002/gj.2633.

Varela L. et al. (2019) - Phylogeny, macroevolutionary trends and historical biogeography of sloths: Insights from a Bayesianmorphological clock analysis. Syst. Biol, 68, I2, 204-218, https://doi.org/10.1093/sysbio/syy058.

An integrated study of raw materials for early Ginori ceramic production: From archival research to the Targioni Tozzetti Naturalistic Collection

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Keywords: Ginori porcelain, raw materials, Targioni Tozzetti.

The collaboration between the Florentine naturalist Giovanni Targioni Tozzetti and Marquis Carlo Ginori, founder of the pioneering porcelain manufacture of Doccia, is well-known but debated (Biancalana, 2009). The opportunity to examine this relationship during the early stages of the Doccia manufactory (1737-1757) has opened a new perspective on some of the earliest raw materials used by the manufactory, for both porcelain and majolica artefacts.

Through an integrated approach, the study combines archival research on original documents with analytical investigations on selected samples from the Targioni Tozzetti litho-mineralogical collection (Cipriani & Scarpellini, 2007) variously linked to Marquis Ginori, now preserved at the Museum La Specola, part of the University Museum System of Florence. The main sources analyzed include documentation in the Ginori Lisci family Archive, the catalogue of the Targioni Tozzetti Collection, and *Relazioni di alcuni viaggi fatti in diverse parti della Toscana*, the major work of the naturalist.

The revision of Targioni Tozzetti's catalogue enabled the identification of 33 inventory entries attributable to the manufacture, e.g. clays, artifacts, and other minerals. Most of the descriptions associated with each sample include information about the supplier, source location, or material use. Only 11 samples are currently preserved within the collection, due to processes of dispersion and reorganization over time. Among these, five samples were selected for their representativeness of Doccia's ceramic production and subjected to X-ray powder diffraction (XRPD) and X-ray fluorescence (XRF) for the samples of clay-based materials, and to optical microscopy (OM) and SEM-EDS analyses for the metallic minerals.

The analytical framework highlights an extensive search directly linked to the Marquis's own activities. Four main source locations for the clayey material used in porcelain production have been confirmed: Tretto area (Vicenza) (Dondi et al., 2000), compatible with sample T0382; Montecarlo (Lucca), compatible with sample T0384; Elba Island (same locality as sample T0383); and fluvial deposits near Vienna (Austria). More common materials, such as clay for majolica and quartz, were collected close to the manufactory. Finally, the supply of metallic minerals, consisting mainly of cobalt and bismuth mineralization came from the mining districts of the Saxon-Bohemian area (Coelli, 2026).

Biancalana A. (2009) - Porcellane e maioliche a Doccia. La fabbrica dei Marchesi Ginori: i primi cento anni. Polistampa, Firenze, 304 pp.

Cipriani C. & Scarpellini A. (2007) - Un contributo alla mineralogia settecentesca. La collezione di Giovanni Targioni Tozzetti. Leo S. Olschki Editore, Firenze, 202 pp.

Coelli C. (2026) - Le materie prime della porcellana Ginori a Doccia (Toscana): indagine archivistica e studio della Collezione Naturalistica Targioni Tozzetti per la ricostruzione delle prime produzioni. Tesi di laurea magistrale, Università degli Studi di Firenze.

Dondi M. et al. (2000) - Le "argille bianche" del Tretto e della Val Leogra (Vicenza): giacimenti, composizione, proprietà tecnologiche ed impieghi industriali. In: L'argento e le "terre bianche" del Tretto e della Val Leogra. Atti della giornata di studio, Schio, 125-143.

The Rocca di Papa Geoscience Museum of INGV: A place where scientific heritage, research, dissemination and education play an important role in increasing public awareness of natural phenomena and risks related to territory

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Keywords: geoscience, education, dissemination.

The Geoscience Museum of Rocca di Papa (MuGeos) promotes scientific dissemination and education as part of the Third Mission of the National Institute of Geophysics and Volcanology (INGV), aimed at spreading scientific knowledge. Founded in 1886 as a Geodynamic Observatory as a consequence of 1883 devastating Casamicciola earthquake, the MuGeos is located 30 km south of Rome, in the center of the Colli Albani volcanic district, a quiescent volcanic complex whose last eruptive activity dates back to about 20.000 years ago. Since 2022, MuGeos has carried out activities for both students and generic public. Visiting schools have been involved into a structured educational program, welcoming thousands of students from all school levels, from Primary to Upper Secondary School. The activities with students are organized into a guided, interactive, and engaging journey through the discovery of the Earth system, with particular focus on INGV mission and the study of phenomena such as earthquakes, volcanoes, geomagnetism, and climate change. Students are also introduced to seismic and volcanic monitoring procedures in Italy. Part of the visit is focused on Alban Hills volcanic complex and its associated risks represented mainly by endogenous gas emissions. Audiovisual materials and a rock library illustrate its genesis and evolution and a touchscreen table offers a three-dimensional view of its morphology. For the final years of Upper Secondary Schools, expert researchers provide lectures on specific topics aiming to encourage students toward scientific university paths. Moreover, the Museum has been involved in the Science Together Net project cofunded by the EU through the organization of the European Researcher Night. In this context a great number of activities have involved kids, children and adults such as geotrekking on Alban Hills volcano, scientific seminars, labs of explosive and effusive volcanoes, paper volcanoes (origami) and fairy tales on geological myths, guided tours of the Museum, sky observation through a telescope. Such activities have been proposed also during the Museum opening during the second Sunday each month. Further several activities dedicated to generic public have been promoted together with Rocca di Papa municipality in occasion of local events such as the October Chestnut Festival, the World Moon Day, the World Horse Festival, the Marconian Day Recurrence etc. During these popular events the MuGeos has been a fundamental actor promoting the knowledge of Geosciences and increasing the awareness of citizens towards natural hazard and risks related to the territory. The feedback collected from all MuGeos activities highlights high satisfaction of the public and continuous participation from local schools. Located within the Castelli Romani context, MuGeos represents a benchmark cultural and scientific hub for the Roman area, fostering the connection between local geological heritage, research and citizens.

University scientific heritage and contemporary museology: The Case of A.R.C.A. Lab

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Keywords: university scientific heritage, museum storehouse, public engagement.

As part of the long-standing collaboration between the *Cassa di Risparmio* di Padova e Rovigo Foundation and the University of Padova, "A.R.C.A. Lab" will be established by 2027 as an innovative project aimed at enhancing and promoting the university's scientific heritage within the municipality of Rovigo. The new facility will host approximately 300,000 objects from the University of Padua's collections — including fossils, minerals, scientific instruments, models, archaeological and ethnographic artefacts — fostering new forms of cultural mediation and public engagement grounded in the integration of research, conservation, education, and public participation.

The project is conceived as a permanent laboratory for contemporary museology, capable of overcoming the traditional distinction between storage facility, museum, and educational space. Planned activities include multidisciplinary temporary exhibitions, historical reconstructions dedicated to the machines of Giovanni Poleni, public access to conservation areas, and participatory workshops involving conservators and scholars. A central aspect of the project is the enhancement of the museum "behind the scenes" and of collections that are normally inaccessible, through immersive and relational experiences designed for diverse audiences.

Particular attention will be devoted to schools through interdisciplinary educational programmes, PCTO pathways (school-work transition programmes), and summer activities, with the aim of building a territorial network capable of involving a wide interprovincial audience. At the same time, the project will develop inclusive strategies for audiences with special needs — including people with sensory or cognitive disabilities and socially marginalised groups — by adopting co-creation methodologies already tested by the Centro di Ateneo per i Musei Universitari of University of Padova.

A.R.C.A. Lab therefore presents itself as a case study in participatory museology, in which university scientific heritage becomes a tool for inclusion, education, and the construction of new relationships between university, territory, and community.

Interventions for improving accessibility at the Museum of Geology and Paleontology University of Florence Museum System

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Keywords: museums, accessibility, NRRP project.

The University Museum System (*Sistema Museale di Ateneo*) is a permanent, non-profit institution dedicated to serving society. It ensures the conservation, enhancement, promotion, and public accessibility of the scientific, historical-scientific, and art-historical collections of the University of Florence.

The Museum of Geology and Paleontology houses the largest fossil collection in Italy and one of the most significant worldwide. The collection comprises approximately 425,000 specimens—about 7,700 of which are on display—including numerous holotypes upon which new species of Plio-Pleistocene mammals were established. The core of the exhibition is the gallery of mammals that inhabited Tuscany over the last few million years, a collection of international historical and scientific relevance. Given the nature of its holdings, the museum's mission is focused on the enhancement and dissemination of knowledge regarding the geological history of the region. Consequently, the museum serves as a primary vehicle for raising awareness of biological evolution and planetary transformations, providing visitors with the tools to discern parallels and contrasts between the past and present, particularly within the context of climate change.

The exhibition space attracts diverse audiences, primarily school groups from Florence and the broader Tuscan region. The Museum System is member of the "MUSEI WELCOME FIRENZE" network, a consortium of diverse institutions. This network aims to present the museum as a welcoming, participatory, and relational space for all types of audiences, with initiatives specifically designed for people with disabilities.

The project's objective is to promote and ensure full, safe accessibility to the museum by dismantling the physical, sensory, and cognitive barriers that still hinder many potential visitors.

Recent interventions include a new entrance that provides the museum with greater visibility through an independent architectural identity, and an extensive redevelopment of internal spaces and facilities.

The planned interventions contribute to the following strategic goals:

- PEBA (Plan for the Elimination of Architectural Barriers): Implementation in accordance with Law no. 41 of February 28, 1986, and subsequent amendments.
- Barrier Removal: Eliminating remaining architectural obstacles at the entrance and in common areas.
- Facility Redevelopment: Upgrading the reception area, ticket office, bookshop, and restrooms.
- Lighting Efficiency: Enhancing and optimizing the lighting systems within the exhibition halls.
- Expanded Accessibility: Increasing access to the museum's world-class collections through high-quality cultural engagement, utilizing innovative digital tools and methodologies.
- Inclusive Services: Expanding the range of services and events specifically designed to meet the needs of visitors with motor, sensory, or cognitive impairments.

The Cultural Heritage of Italian Universities: A widespread asset for the country

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Keywords: Cultural Heritage, CRUI, Museum

Italian universities preserve a cultural heritage of extraordinary breadth and diversity, encompassing museums, collections, archives, botanical gardens, historic buildings, and scientific and artistic assets that bear witness to centuries of knowledge production and transmission. This widespread heritage is deeply intertwined with the history of universities and their local communities. Universities safeguard, study, and make these resources available to society as part of their institutional mission. Within this framework, the Italian Rectors' Conference (CRUI), through its Commission on University Museums, has launched an initiative aimed at enhancing the value of university cultural heritage, beginning with the development of a national survey designed to identify the scale, diversity, and significance of a heritage that remains largely underrecognized in its overall dimension. This initiative stems from the need to provide a comprehensive representation of this wealth and to increase awareness among institutions and the general public of the heritage that universities care for on a daily basis, as well as of their role in preserving and transmitting the nation's cultural memory. At the same time, since 2021 CRUI has promoted a support program for the accreditation of university museums within the National Museum System, assisting universities in meeting the required quality standards and fostering the gradual integration of university museums into national policies for the protection and enhancement of cultural heritage. Through these two complementary lines of action, CRUI seeks to strengthen knowledge, appreciation, and recognition of university cultural heritage, while promoting greater awareness of the contribution that universities make to the preservation and transmission of the country's cultural memory.

Space in museum drawers: The Italian National Cataloging Campaign for extraterrestrial materials

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Keywords: cataloging, meteorite, collections.

Meteorites are archives for the investigation of the early Solar System, providing unique insights into planetary bodies that are otherwise hardly accessible to direct exploration and analysis. Most of the meteorites currently known are preserved in natural history and scientific museums, which therefore serve as key infrastructures for their safeguarding and documentation.

Cataloging represents a foundational practice in the management of meteorite collections, as its standardized procedures enhance accessibility for the research community, facilitate comparative studies across institutions, and ensure long-term conservation of physical specimens and their informational records. In this sense, cataloging is not merely an administrative activity, but a core scientific and curatorial function underpinning the sustainable use and preservation of meteorites.

This presentation aims to illustrate the national campaign for the cataloging of extraterrestrial materials (CAMEX) developed within "Space It Up!" (SIU!), a large-scale initiative promoting interdisciplinary research and infrastructure development in the field of space sciences.

CAMEX adopts methodologies grounded in the models and praxes established by the Central Institute for the Catalog and Documentation (ICCD), which is part of the Italian Ministry of Culture. The project employs the ministerial standard BN-PL (*Beni Naturalistici-Planetologia*) for the documentation of extraterrestrial materials, with the resulting records made openly accessible through the General Catalogue of Cultural Heritage ministerial database.

CAMEX, coordinated by the University of Firenze, is currently focused on the meteorite collections held by institutions participating in SIU!, and will subsequently be extended to additional museums, universities, and research institutes across the country to achieve comprehensive national coverage.

Following an overview of the current state of BN-PL implementation in Italy, this presentation examines the operational framework of the cataloging campaign and critically discusses the results derived from the pilot case study.

CAMEX represents a structured effort to advance the national cataloging of extraterrestrial materials through the systematic adoption of the BN-PL standard. By integrating standardized methodologies within a coordinated institutional framework, the project contributes to the harmonization, accessibility, and sustainability of meteorite documentation in Italy, strengthening both the scientific and cultural value of national extraterrestrial heritage.

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Engaging with geo-biodiversity around the Gulf of Naples through the Biodiversity Gateway (NBFC) - Regional Hub Naples

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Keywords: biodiversity, geodiversity, science communication.

What stories lie beneath the waters and around the coasts of the Gulf of Naples (GoN)? Beyond its iconic landscapes, this region hosts an extraordinary and often invisible layer of natural heritage: its geodiversity. Volcanoes, submarine canyons, coastal morphologies, and dynamic sedimentary systems continuously shape the environments that sustain life and interweaves with millennia of Anthropocene transformations. The strong relationship between geodiversity and biodiversity is well established, as abiotic heterogeneity directly influences habitat distribution and ecosystem functioning (Casaburi et al., 2024; Alberico & Petrosino, 2026).

Within the Biodiversity Gateway (www.biodiversitygateway.it) - Regional Hub Naples (BG-RHN), the CNR-ISMAR team has transformed this hidden dimension into a living narrative, where geodiversity becomes a key to understanding biodiversity and our relationship with the natural world. Rooted in a place-based approach, the initiative draws on the unique geodynamic setting of the Gulf of Naples where the terrestrial and submerged volcanic systems of Somma-Vesuvius, Ischia and Campi Flegrei-Procida island interact with complex coastal and marine environments creating an exceptional diversity of habitats. In this area, geomorphological variability and seabed complexity play a fundamental role in shaping coastal and marine ecosystems (Di Giovanna et al., 2026).

Through multimedia storytelling videos, visual narratives, and interactive tools, complex geological and marine processes are translated into engaging experiences. Visitors are guided through the evolution of underwater landscapes, coastal cliffs and volcanic systems, the dynamics of the water column, the formation of habitats and their resilience to anthropic impact, discovering how geodiversity underpins biodiversity patterns. The narrative also offers insight into the behind-the-scenes of scientific research, presenting the methodologies employed by the scientific community to investigate bio-geodiversity. The GoN itself becomes both subject and medium of communication, anchoring scientific knowledge in a familiar yet newly revealed environment.

At the core of this approach is the recognition that effective science communication is not only about transferring knowledge, but also about fostering awareness, curiosity, and emotional engagement. In this perspective, the BG-RHN provides an immersive and interdisciplinary space to engage with science through direct experience and intuitive learning pathways, ensuring a balance between scientific rigor and narrative effectiveness. This approach supports the development of innovative and transferable models for science communication, capable of bridging the gap between research and society.

By revealing the fundamental role of geodiversity in sustaining biodiversity, this experience contributes to reshaping the perception of geological sciences to a dynamic and essential component of sustainability and environmental awareness.

Alberico I. & Petrosino P. (2026) - A pathway to achieving the 2030 Agenda goals through ecosystem services provided by geodiversity in Campi Flegrei active volcanic area (southern Italy). Environ. Dev. Sustain., https://doi.org/10.1007/s10668-026-07644-3.

Casaburi A. et al. (2024) - Geodiversity of Italy. J. Maps, 20(1), 2340988, https://doi.org/10.1080/17445647.2024.2340988.

Di Giovanna F. et al. (2026) - Habitat suitability model for predicting the occurrence of cold-water corals in the Gulf of Naples (Tyrrhenian Sea). Mar. Environ. Res., 216, 107879, https://doi.org/10.1016/j.marenvres.2026.107879.

The Royal Mineralogical Museum at Federico II University (Naples): Memory, cultural mediation, and education—contemporary interpretations of the mineralogical collections

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Keywords: mineralogy, vesuvio, Napoli.

Housed in the 16th-century *Palazzo del Salvatore*, the Royal Mineralogical Museum, the first of the five museums comprising the "*Centro Musei delle Scienze Naturali e Fisiche*" of the Federico II University (Naples, Italy) represents, with its 225-year history, one of the oldest scientific institutions in Naples. The Museum houses a rich collection of minerals from around the world, alongside important and unique regional collections where each specimen, with its intrinsic historical and scientific value, tells the story of the relationship between humans and nature. The museum is therefore not only a place of conservation but also a space for interpretation, mediation, and production of knowledge. From this perspective, cultural communication plays a central role, especially in historical museums, where the collections, originally created, as in the case of Neapolitan Museum, for educational and scientific purposes, can now be reinterpreted and valued as educational tools capable of engaging with the present. Museum collections, in fact, do not merely document the natural world but offer insights useful for understanding historical, social, economic, and cultural processes. According to Pomian (1989), the collections or individual objects that museums preserve are symbols endowed with the capacity to connect the real world—which has its own space and time—with the world from which they originate or which they represent, which has a different space and time, and is therefore invisible in the real world. Although this concept may sometimes seem abstract, it finds a particularly clear expression in mineralogical collections: the mineral world, only seemingly distant, enters direct dialogue with the urgent issues of the present, revealing its full relevance.

It is within this perspective that the educational program dedicated to the role of minerals as strategic resources in the contemporary world is situated, exploring how and to what extent many of them now occupy a central position in processes related to the energy transition, technological development, and global geopolitical balances. With the support of specialized staff, who not only explain and narrate but also guide students to reflect on issues that affect everyone and to understand the connection between geological resources, environmental sustainability, the distribution of wealth, and social and economic-political dynamics, thereby developing tools for a critical analysis of the present.

The achievement of this objective is supported by a particular focus on diversifying audiences using inclusive language and interactive devices. In this way, the reinterpretation of historical mineralogical collections, complemented by hands-on activities, allows museums to strengthen their educational, social, and cultural roles, positioning themselves as spaces for mediation capable of connecting scientific heritage with societal transformations.

Pomian K. (1989) - Collezionisti, amatori e curiosi. Parigi-Venezia XVI-XVIII secolo. Il Saggiatore, Milano, 367 pp.

Museum valorization and analytical characterization of demantoid and other mineral specimens from the historic Magistretti Collection, Earth Sciences Museum, University of Milan

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Keywords: mineral collections, valorization, characterization.

The Earth Sciences Museum of the University of Milan preserves important historical mineral collections (Bianchi Potenza, 2000). Among these, Luigi Magistretti's collection represent one of the most significant and includes some of the finest pieces housed at the museum. Luigi Magistretti was an engineer, mineral collector and a long-standing collaborator of the Institute of Mineralogy. Over decades of filed activity and through exchanges with other collectors, he has assembled an exceptional collection of Alpine minerals, particularly from Val Malenco and other classic localities of the Western Alps. Subsequebtly, part of this collection was donated by the heirs to the Institute and is today preserved within the historic "*Sala dei Minerali delle Alpi - Luigi Magistretti*".

Among the most remarkable specimens, demantoid crystals from Val Malenco are particularly noteworthy, together with large and aesthetically relevant samples such as the giant rhombohedral dolomite from Traversella and several historical specimens of perovskite, artinite, ilmenite and Alpine quartz. As part of ongoing efforts to inventory update, conservation and museum valorization, a comprehensive analysis of the Magistretti samples held in the collections was conducted. Several samples were analytically characterized by X-ray diffraction methods, while selected specimens were restored and enhanced for museum exhibition.

Particular attention was devoted to two demantoid-bearing specimens. One specimen, of exceptional museum quality, was simply carefully cleaned and left intact. A second specimen underwent a meticulous and accurate preparation process carried out by MCP to enhance its visual appeal and exhibition value. Small detached fragments and the removed serpentinite matrix were recovered and used for mineralogical, petrographic and geochemical investigations, including preparation of thin sections, single-crystal X-ray diffraction, electron microprobe analyses and LA-ICP-MS analyses.

The investigated demantoids correspond to nearly pure andradite garnet, with very limited substitution by minor elements such as Cr and Al. Structural refinements confirm cubic symmetry with unit-cell parameters consistent with end-member andradite. Trace-element concentrations are generally low, with limited enrichment in REEs and the absence of significant U-Th contents, wich precludes meaningful geochronological investigations. Petrographic observations of the associated serpentinite reveal the typical mineral assemblage of Val Malenco ultramafic rocks, consisting -mainly of serpentine, olivine, pyroxene and magnetite.

The study highlights how historical mineral collections may represent not only an important cultural and museum heritage, but also a valuable source of scientific information, where modern analytical approaches can be integrated with conservation, restoration and exhibition activities.

Bianchi Potenza B. (2000) - Le collezioni mineralogiche del Dipartimento di Scienze della Terra, Università di Milano (Italia). Atti Soc. It. Sci. Nat. Museo civ. Stor. Nat. Milano, 141, 119-123

VISION3D: Connecting crystals and real life through augmented and virtual reality

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Keywords: augmented reality, mineralogical and crystallochemical collections, public engagement.

Scientific museums play an increasingly role in connecting research, education and public engagement, especially when they can explain scientific concepts that are not immediately visible or intuitively accessible. This is particularly relevant for crystallography, mineralogy and structural sciences, where the understanding of geological materials requires a constant transition between macroscopic objects, microscopic structures and abstract models.

Within this context, the project "*VISION3D: creazione di ambienti in realtà aumentata e realtà virtuale per la divulgazione delle scienze cristallografiche*" aims to develop immersive and interactive tools for selected collections of MuDeS, the *Museo Diffuso delle Scienze* of the University of Parma. The project, funded by FAPE (*Fondi di Ateneo per il Public Engagement*) involves both the Crystallochemical and the Mineralogical Collection, with the broader objective of making structural sciences more accessible to different audiences, including the general public, schools and university students. Through augmented and virtual reality, VISION3D will allow visitors to explore molecular, crystalline and mineral structures extracted from international scientific databases and transformed into interactive educational resources (Glasby et al., 2023). The project also includes thematic narratives related to major contemporary issues. These include the supply of Rare Earth Elements, antibiotic resistance, drug design through the exploration of metalloprotein active sites, the role of silicon in artificial intelligence technologies, and the relationship between crystals and territory, with a focus on minerals from the Parma area.

Within this latter theme, the visitor experience is enriched by combining augmented reality models with contextual information on the history, geology and mineralogical heritage of the Parma area. Models of selected mineral structures, such as datolite and baryte, accessible through smartphones by scanning a QR code, connect the physical specimen with its invisible crystallographic structure and show how macroscopic mineral properties relate to atomic-scale organization. Informative notes on finding sites, former mining areas and local collecting practices further highlight the close relationship between geology, history and the exploitation of natural resources, contributing to the valorisation of the local territory.

Overall, VISION3D shows how augmented and virtual reality can renew the role of university scientific collections, transforming them into accessible and engaging spaces where research, education, territorial heritage and public engagement are brought into dialogue.

Glasby L. et al. (2023) - Augmented reality for enhanced visualization of MOF adsorbents. J. Chem. Inf. Model., 63(19), 5950-5955, https://doi.org/10.1021/acs.jcim.3c01190.

Garnet-group minerals from Tuscany (Italy) in the mineral collections of the Natural History Museum of the Pisa University

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Keywords: garnet-group minerals, mineralogical museum, historical specimens.

Garnet-group minerals occur in Tuscany (Italy) in a wide range of geological settings, from rodingites embedded in serpentinites to skarn bodies, pegmatite dykes, and volcanic ejecta (Biagioni et al., 2026). These different environments make possible to study the control of P-T-X conditions on garnet chemistry and its hydration state. In order to accomplish this study, the mineral collection of the Natural History Museum of the Pisa University has been useful, containing 194 specimens, along with additional dozens of specimens still uncatalogued and belonging to the recently acquired collection of Roberto Nannoni (1943-2022). This study allowed a better comprehension of the specimens of garnet-group minerals currently kept in the mineral collections.

An important fraction of the studied specimens (151 out of 194, neglecting the recently acquisition of the Nannoni collection) is catalogued as belonging to the "Museum collections", indicating that were present within the collection before the 1970s. Among them, 98 are from the Elba Island, with 21 specimens from the pegmatite dykes of San Piero in Campo, 10 from the Eastern Elba (in particular from the Fe ore deposits), and 67 from the thermal aureole of the Monte Capanne. Most of the latter are from the Affaccata locality, known for the occurrence of octahedral crystals of grossular studied by several authors (e.g., D'Achiardi, 1896).

Several of these specimens were studied by Antonio D'Achiardi at the beginning of the 1870s and described in his paper on garnets from Tuscany (D'Achiardi, 1871). Indeed, mineral specimens are accompanied by hand-written labels indicating that they were used for both morphological and chemical studies. It is worth noting that among them there are some specimens from the Pitigliano area that were described by Giorgio Santi (1746-1822) at the end of the 18th century.

Since the 1970s, additional specimens have been added to the collection, mainly through the activity of Prof. Paolo Orlandi who collaborated with several mineral amateur who provided self-collected specimens from classic or new mineral localities.

Thus, the examination of the garnet specimens of the Natural History Museum of the Pisa University is a window opened not only on the crystal chemistry of garnet-group minerals but also on the evolution of the school of Mineralogy of Pisa, that has grown around its museum, in particular between the second half of the 19th century and the first decades of the 20th century.

Biagioni C. et al. (2026) - Granato. Tesori mineralogici della Toscana. Pixarprintin S.p.A., Lavis (TN), 128 pp., ISBN 9788894443066.

D'Achiardi A. (1871) - Sui Granati della Toscana. Boll. R. Comit. Geol. It., 2, 166-181.

D'Achiardi G. (1896) - Il granato dell'Affaccata nell'isola d'Elba. Ann. Univers. Tosc., 20, 1-26.

The Roberto Nannoni mineral collection: A new acquisition of the Natural History Museum of the University di Pisa

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Keywords: Roberto Nannoni collection, mineralogical museum.

The Natural History Museum of the Pisa University keeps more than 25,000 mineral specimens. Most of them were sampled in Tuscany and were studied by the scholars of Mineralogy of the Pisa University since the second half of the 19th century. Currently, one of the main goals of the mineralogical section of the Natural History Museum is to improve and valorise the mineralogy of Tuscany, through the collection of further specimens, both of aesthetic and scientific significance. Indeed, during the last 25 years, several important acquisitions were performed, e.g., the sulfides and sulfosalts from the Bottino mine of the Cerpelli collection (in 1999), the minerals of the cavities of the marbles from the Apuan Alps of the Del Taglia collection (in 2015), or, more recently, a selection of aesthetic specimens belonging to the Da Costa collection (in 2022) (Mauro et al., 2024).

In 2024, the mineral collection of Roberto Nannoni (1943-2022) was acquired by the Natural History Museum of the Pisa University. Roberto Nannoni was a geologist and high-school teacher who devoted his life to the collection of mineral specimens and to the study of Tuscan mineralogy, as testified by several books and papers dealing with the description of selected mineral localities.

The Nannoni collection is formed by more than 3500 specimens that can be divided into two sub-collections. The first one has a systematic interest and was mainly formed by thumbnail to cabinet size specimens, whose acquisition was done during the main mineral shows attended by Roberto Nannoni. The second one has an outstanding scientific value, representing the result of the field-activity of Roberto Nannoni during his entire lifetime. It consists of specimens that are representative of a lot of different Tuscan localities, with specimens ranging from micromount to cabinet size. Some of them were illustrated on his books, as an outstanding specimen of native copper from the Montecatini Val di Cecina mine or stibnite from the Sb occurrence of Micciano (Pomarance, Pisa Province). Among specimens from Tuscany, several were from poorly studied localities and their examination and further investigations will represent an important source of future research.

Though the acquisition of the mineral collection of Roberto Nannoni, the Natural History Museum of the Pisa University has improved its collection of Tuscan minerals, adding aesthetic and unusual specimens as well as a large number of scientifically significant samples. In this way, the lifelong mineralogical activity of Roberto Nannoni will continue through his specimens, preserved, studied, and valorised by the scholars of the Pisa University.

Mauro D. et al. (2024) - The Angelo Da Costa mineral collection: a new acquisition of the Natural History Museum of the University of Pisa. In: Geology for a sustainable management of our Planet. Abstract Volume, Joint Congress of Società Geologica Italiana (SGI) and Società Italiana di Mineralogia e Petrologia (SIMP), 3-5 settembre 2024, Bari.

Neumann collection at MNU of the University of Padova: Provenance and identification

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Keywords: Neumann, collections, minerals.

On the centenary of the University of Padua's acquisition of the Neumann collection, a targeted reassessment of the Mineralogy Section of the Museum of Nature and Humankind (MNU) has enabled the discovery and re-identification of specimens that illuminate uncommon mineralizations and local georesource histories. The Neumann mineralogical assemblage, purchased from Trieste collector Eugenio Neumann (1847-1928) in 1925 through the intervention of Professors Enrico Tedeschi, Giorgio Dal Piaz and Angelo Bianchi, originally comprised a small but significant nucleus of specimens within a much larger multi-disciplinary collection. Archival documentation, notably a 1925 inventory and a letter by Prof. Angelo Bianchi, indicates the mineralogical subset includes 13 pieces from two central Austro-Hungarian era mining districts: the Idrija mercury mine (now Slovenia) and the Kapnik/Cavnic gold-base metal district (now Romania). Reconstructions of Neumann's mineralogical core faced substantial curatorial challenges: museum labels and accession tags often lack any explicit Neumann reference and many specimens carry overlapping tags from successive historical periods. To overcome these obstacles, we used diagnostic reference specimens that are unicum within the MNU holdings. In the Idrija group, an assemblage including metacinnabarite and native mercury — unique to the museum — served as primary anchors for label analysis and enabled the recognition of four additional cinnabar specimens originally recorded by Bianchi. In the Cavnic/Kapnik group, an equally distinctive bournonite specimen functioned as a guide: through label and typological correlation we identified a chalcopyrite sample and a pyrite pseudomorph after barite that had previously been catalogued as originating from "Hungary" (reflecting historical political boundaries prior to post-World War I territorial changes). The study demonstrates how combined archival methods can restore provenance and curatorial attribution for dispersed historical collections. The reintegration of Neumann's mineralogical nucleus contributes both to local geological heritage narratives and to larger historiographies of collecting, museum formation, and disciplinary development in northern Italy between the late nineteenth and early twentieth centuries.

The evolution of geo-scientific education: The success of "hands-on" learning models within the geo-paleontological heritage of the University of Pisa Natural History Museum

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Keywords: geo-education, hands-on learning, scientific museology.

The educational activities of the University of Pisa Natural History Museum represent an emblematic case study for analyzing the role of university museums as dynamic cultural infrastructures active in the production and dissemination of knowledge. The educational programs, ranging from guided tours to experimental geology-themed workshops, aim to achieve an effective didactic transposition: transforming complex disciplinary content into experiences accessible to a different audience, while simultaneously stimulating scientific curiosity and the development of interpretive skills.

The methodological strategies adopted enrich the Museum's social function, placing particular emphasis on the simplification of language—without ever sacrificing scientific rigor—and the diversification of communication channels. This approach ensures an inclusive and conscious engagement with geo-paleontological heritage, actively involving schools of all levels, families, and audiences with disabilities (Dini et al., 2012).

The effectiveness of these models is confirmed by participation data: between the 2022/2023 and 2025/2026, geology-themed programs recorded more than a twofold increase in attendance, rising from 132 to 285 classes (from 2555 students to 5807 students). A decisive boost to this growth followed the inauguration of the temporary exhibition "Dinosauri", which acted as a catalyst for the entire sector.

Among the most successful proposals is the laboratory on volcanoes (designed in collaboration with INGV, Sezione di Pisa), particularly appreciated by primary schools for its "hands-on" approach, which allows for the direct manipulation of volcanic products.

Similarly, the growing interest in the "Fossils in Form" laboratory highlights how tactile and analog experiences remain a specific need in contemporary schooling and can be complemented, but not replaced, by digital devices.

In conclusion, the constant growth trend consolidates the Museum as a leading institution in the local area, capable of offering an educational model based on co-design and scientific solidity, acting as an effective mediator between the world of university research, schools, and civil society.

Dini A. et al. (2012) - L'azione educativa del Museo di Storia Naturale di Pisa. Nuova Museol., 27, 33-37.

Valorising Calabria's mineral heritage: A scientific and museological proposal for the UNICAL Museum of Mineralogy and Petrography

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Keywords: mineralogy, geoheritage, museum education.

Calabria Region represents one of the most geologically complex areas in the central Mediterranean and boasts one of the most fascinating mineralogical diversities of the territory (Dattola & Barone, 2024). However, lacks a systematic and comprehensive representation of its mineral heritage in regional museum collections. The historically significant specimens have been either lost or transferred to institutions outside the region. Furthermore, existing local collections offer no organic account of the full mineralogical diversity of the territory. The recently inaugurated Museo di Mineralogia e Petrografia of the Università della Calabria (UNICAL) represents a concrete opportunity to address this gap, provided that collection development of its collection and educational mediation are grounded in a rigorous scientific framework.

Historical and recent sources on Calabrian mineralogy were systematically reviewed and critically assessed, distinguishing analytically confirmed identifications from macroscopic observations and unverified historical records. This review constitutes the scientific foundation for a museological proposal centered on six representative Calabrian mineral species: barite and gypsum (Acquappesa, CS), fluorite and manganese oxides (Mormanno, CS), muscovite (Fosso d'Acri, Luzzi, CS), and pyrite (Verzino, KR). Species and localities were selected based on bibliographic evidence and preliminary field assessment. The minerals were sampled and subjected to a variety of analytical methods, including optical, chemical, and structural characterization (SEM, TEM, DSC/TG, XRPD).

Each specimen will be accompanied by a dedicated didactic card, structured around five thematic sections and an interactive 3D model, designed for use on a touch-enabled OLED display housed in the museum. The physical specimen is positioned behind the screen, thereby establishing a direct connection between the real object and its digital interpretation. The device functions as a cultural mediation tool, designed to be accessible and meaningful for audiences of all levels (from primary school students to specialist visitors and the general public), in accordance with the ICOM definition of the museum as an institution that researches, conserves, and exhibits heritage in the service of society (https://icom.museum/en/). The initiative aims to illustrate how the convergence of scientific research, museum and digital education, and heritage valorization within a university museum can promote the recognition, protection, and broader public understanding of the mineralogical richness and diversity of the regional territory.

Dattola L. & Barone G. (2024) - Minerali della Calabria. Gruppo Mineralogico Lombardo - Associazione Italiana di Mineralogia, 256 pp.

Visit the Museum of Mineralogy and Petrography to discover minerals and rocks

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Keywords: science museums, minerals and rocks, social commitment and third mission.

The Museum of Mineralogy and Petrography of the University of Trieste was established in 1949 by Professor Sergio Morgante as an integral part of the Institute of Mineralogy and Petrography, just a few years after the establishment (in 1946) of the Faculty of Mathematical, Physical, and Natural Sciences of the University of Trieste. The Museum is a member of the National Association of Scientific Museums (ANMS). Since 1996, with the creation of the Department of Earth Sciences, now the Department of Mathematics, Informatics, and Geosciences (MIGe), the Museum has been located in a building on the San Giovanni University Campus at Via E. Weiss 6. It occupies three rooms of approximately 350 square meters, which include a classroom for teaching and a study for cataloguing minerals and rocks.

The initial collection of approximately a thousand minerals and rocks was subsequently expanded with the donation of various mineralogical samples, as well as samples collected during various survey campaigns. Furthermore, in 2022, it acquired 406 mineral samples from a collector. All the displayed minerals and rocks have been catalogued using the cataloguing system of the Central Institute for Cataloguing and Documentation of the Ministry of Culture. The catalog has been uploaded to the University Museum Network (SMATs) and the Regional Catalogue of Cultural Heritage (Friuli-Venezia Giulia - FVG) and is freely accessible.

The Museum is an important teaching tool for students in Geological and Natural Sciences and Engineering. It organizes guided tours for school groups with several educational itineraries themed around “A Journey to Discover Minerals and Rocks” (Princivalle, 2017). The visits conclude with a questionnaire administered to students and teachers to assess their satisfaction with the visit and to gather suggestions for better enjoyment of the experience.

The Museum also carries out activities in the field of “Public and Social Engagement - Third Mission” and has organized several exhibitions over the years, participating in Open Museums during the spring events in the San Giovanni Park where it is located.

Princivalle F. (2017) - Il Museo di Mineralogia e Petrografia del Dipartimento di Matematica e Geoscienze dell’Università degli Studi di Trieste. Dalla conservazione alla diffusione della cultura scientifica. Quaderni CIRD, 14, 164-179, https://doi.org/10.13137/2039-8646/13940.

Research, accessibility, and digital storytelling in contemporary museology: The case of Dirk Hendricksz's *Madonna della Purità* in Bisignano (CS)

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Keywords: accessibility, digital museology, heritage education.

This paper presents an integrated research and valorization project focused on the "*Madonna della Purità*", attributed to Dirk Hendricksz (1542-1618), preserved at the Sanctuary of Fra Umile in Bisignano, Calabria (South Italy).

The case study is framed within contemporary scientific museology, understood as a field at the intersection of academic research, digital technologies, scientific communication, public engagement, and cultural mediation. A museological project is currently underway to make the artwork accessible to the public within a dedicated exhibition space inside the religious complex.

The methodology combines art-historical research with non-invasive diagnostic analyses (FORS, XRF, multispectral imaging, radiography, SEM-EDS), conducted within the Master's program "The Digital Chain of Cultural Heritage: From Knowledge to Valorization" (University of Calabria), highlighting interdisciplinary training and research-based education (the training program is developed within the framework of the "*Patti Territoriali dell'Alta Formazione per le Imprese*" initiative, funded by the Ministry of University and Research (MUR) through the DPCM of 30/07/2025, CUP H22C2400012000 (art. 14 bis del D.L. 152/2021 e ss.mm.ii.).

The analyses enabled the study of materials, techniques, stratigraphy, and pentimenti, contributing to a deeper understanding of the artist's process and the relationships between the work and its variants (catalogo.beniculturali.it/detail/HistoricOrArtisticProperty/1500410063).

Scientific investigations provide not only technical data but also a documentary basis for conservation, interpretation, and exhibition design. In this perspective, scientific analysis becomes both a research tool and a narrative resource within museum communication. A key aspect of the project is the translation of scientific data into accessible museum communication through digital tools: digital catalogue, virtual restoration, web access to data, multimedia content, and immersive VR experiences designed to support experiential learning and public engagement with scientific and material aspects of the artwork. Within the exhibition design, these technologies function as interpretive, educational, and science communication devices aimed at fostering audience engagement, participatory learning, and public understanding of complex heritage research processes. In this way, these tools make otherwise invisible processes -such as chemical analyses and material stratigraphy- accessible to a wider and more diverse audience.

Accessibility, together with scientific rigor and clarity, ensures multi-layered interpretive pathways for diverse audiences, including students, researchers, and the public.

This case study demonstrates how archaeometric research, art history, and digital museology generate innovative models for heritage communication, transforming the museum into an infrastructure for knowledge, education, and cultural inclusion.

The nineteenth-century collection of "marbles and breccias" from the Gulf of La Spezia: History, cataloging, and museum enhancement

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Keywords: petrographyc collection, cultural heritage, ornamental stones.

A petrographic collection from the Gulf of La Spezia was recently rediscovered in the storage rooms of the Regional Museum of Natural Sciences of Turin (MRSN). The collection, currently consisting of 107 specimens, was donated in 1857 by Cavaliere Francesco Bernardi to the Mineralogical Museum of the University of Turin as part of a survey of active quarries in the La Spezia region. An historical and documentary contextualization of the collection is provided, followed by the presentation of the updated catalog of specimens, included petrographic, commercial classifications and macroscopic descriptions, designed to enhance the collection's museum value.

The historical context, provenance, Bernardi's role within the scientific, academic and museum community, together with the analysis of the accompanying historical and cartographic documentation, suggest that the collection is related to the evaluation of dimension-stone quarries promoted by the Savoy State during the mid-nineteenth century. Bernardi visited the principal quarries of the Gulf, selecting and collecting representative samples, considering lithologies from exhausted quarries formerly exploited in the past, as well as potential new extraction sites.

The integration of historical documentation with geological characterization makes it possible to restore scientific and cultural value to this forgotten collection. Indeed, the collection represents an emblematic case of how "hidden" scientific heritage can be recovered, studied, and recontextualized within a contemporary framework. The interdisciplinary approach combining petrography, history of science and museology has made it possible to restore both visibility and significance to an important piece of Italy's geological heritage.

New integrated museological enhancement model using archaeometric data: A journey through the Tree of Life of the Otranto Cathedral floor mosaic

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WITHDRAWN

Telling the 60-year history of the "Piero Leonardi" Museum of Palaeontology and Prehistory through digital and inclusive communication strategies

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Keywords: Museum, Ferrara, 3D

The Museum of Palaeontology and Prehistory "Piero Leonardi" of the University of Ferrara celebrates its 60th anniversary through the exhibition The Legacy of Piero Leonardi. The Museum Tells Its Story, inaugurated in 2025 at Palazzo Turchi di Bagno (Ferrara, Italy). The exhibition retraces the life, scientific activities, and intellectual legacy of Piero Leonardi, a multidisciplinary scholar whose vision and research contributed to the establishment of the museum and the development of important palaeontological, anthropological, and archaeological collections. The exhibition represents the latest outcome of a long-term digitisation strategy launched in 2013 following the earthquake that forced the closure of the museum. Initially conceived as a means of safeguarding and documenting collections that had become inaccessible to the public, the project progressively evolved into a broader effort aimed at enhancing accessibility and creating new forms of interaction with museum heritage. This process has recently been strengthened through the CHAMELEON project, funded by the Italian National Recovery and Resilience Plan (PNRR) within the CHANGES programme, Spoke 4 "Virtual Technologies for Museums and Art Collections". Within this framework, more than thirty museum objects have been digitised using structured-light scanning and digital photogrammetry. The resulting 3D models have been optimised and semantically enriched through the integration of morphological and metrical data with both tangible and intangible information. The methodology adopts ontological standards, Open Data principles, and direct interoperability with existing cataloguing systems. A key outcome of the project is the development of a "chameleonic" repository designed for the online management of multimedia content and for the integration of different modes of access and interpretation. The repository supports interactive applications based on Virtual Reality (VR), Augmented Reality (AR), and conversational Artificial Intelligence through digital avatars (Maietti et al., 2025). These tools allow visitors to explore museum collections through customizable, multi-layered narratives. By extending access beyond the physical museum and fostering participation, emotional engagement, and knowledge sharing, the project demonstrates how digital technologies can transform the communication of palaeontological and prehistoric heritage, making it more accessible, inclusive, and meaningful for diverse audiences.

Maietti F. et al. (2025) - Flexible, Integrable and Accessible Digital Tools for a Dynamic and Adaptive Experience of Museum Environments. The CHAMELEON Project. In: Digital Heritage, 8-13 September 2025, Siena, Italy, https://doi.org/:10.2312/dh.20253117.

A multi-scale spectroscopic approach unveiling hidden manipulation in mineralogical specimens

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Keywords: museum specimen manipulation, hyperspectral imaging, vbrational spectroscopies.

Geological objects constitute fundamental archives for the study and communication of geological processes and are therefore preserved in natural history museums. Among these specimens, minerals are particularly appreciated for their remarkable optical and physical properties, which have made them highly sought-after collectibles in both museums and private collections. However, their value has also encouraged legitimate restoration treatments as well as fraudulent practices, aimed at enhancing their appearance and consequently increasing their market value. As a result, manipulated specimens have flooded into the market and have eventually entered museum collections, potentially generating misconceptions about natural mineral associations and mineral-forming processes.

Given the educational and scientific mission of natural history museums, the recognition and disclosure of restoration and enhancing treatments are essential for accurate heritage interpretation and the dissemination of scientifically validated knowledge (Artioli, 2022). In order to achieve these goals, this study presents a novel multi-scale spectroscopic method to detect exogenous materials within manipulated mineralogical specimens. The proposed top-down workflow relies on a first macroscopic and non-invasive hyperspectral imaging, based on short-wave infrared reflectance response (HSI-SWIR), that allows to identify and map spatial distributions of both inorganic and organic compounds. To improve the spatial distribution estimation of restored portions of the object, a novel ORganic Index (ORI), based on diagnostic CH absorptions in the SWIR region, is introduced. Compared with UV-induced fluorescence imaging, ORI maps enhance the detection of organic materials and support the accurate identification of regions of interest for subsequent analyses. Indeed, when hyperspectral signatures alone are insufficient for material identification, complementary micro-invasive vibrational spectroscopic techniques, namely Raman and Fourier-transform infrared (FTIR) spectroscopy, are applied to these selected regions, enabling unambiguous molecular-level identification of restoration materials.

To assess the efficiency of the proposed protocol, this study examines samples from both contemporary and historical mineralogical collections that are suspected of having undergone various forms of manipulation. These include the remounting of euhedral crystals onto geological matrices, artificial color enhancement, impregnation with organic substances and the use of synthetic analogues, practices commonly observed across a wide range of mineralogical samples (Nassau, 1984; Calik et al., 2019; Artioli, 2022). The results highlight a preferential use of specific exogenous materials for particular mineralogical phases, as well as their evolution over time in relation to the historical context of the interventions.

Artioli G. (2022) - Authentication and the Perception of Fakes. Forgeries of Natural Specimens. In: Salvadori M., Bernard E., Zamparo L., Baggio M. (Eds), Beyond Forgery: collecting, authentication and protection of cultural heritage, Padova, Padova University Press, Antenor Quaderni, 52, 67-77.

Calik A. et al. (2019) - Fake and Synthetic Minerals; A Way to Sustain the Gem Supply. In: Agnihotri A.K., Reddy K.R., Bansal A. (Eds), Environmental Geotechnology, Singapore, Springer Singapore, Lecture Notes in Civil Engineering, 31, 319-328, https://doi.org/10.1007/978-981-13-7010-6_30.

Nassau K. (1984) - The Early History of Gemstone Treatments. Gems Gemol., 20, 22-33, https://doi.org/10.5741/GEMS.20.1.22.

S35.

Geoscience Outreach within the Piano Lauree Scientifiche

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Paola Donato (Università della Calabria)

Manuel Rigo (Università di Padova)

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UniMissions: A card-based escape room for geoscience outreach and education

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Keywords: geoscience outreach, game-based learning, science communication.

Gamification is emerging as a powerful approach to enhance engagement and learning in geoscience outreach. This contribution presents *UniMissions*, a card-based escape room designed as an innovative tool for geoscience communication and education.

The game is structured as a narrative-driven journey from the Earth's core to the surface, where players take on the role of a geologist attempting to escape from the planet's interior. Progression is organized into sequential *missions* corresponding to major Earth layers (inner core, outer core, mantle, and crust). At each stage, players answer geoscience-related questions and receive immediate feedback, enabling advancement, retry, or revision of previous steps. Correct answers allow players to acquire *geologist's tools*, which act as both rewards and carriers of hidden clues. By combining multiple clues, players reconstruct the final objective: identifying precise geographic coordinates corresponding to a hidden treasure.

The gameplay integrates problem solving, sequential reasoning, and iterative learning processes, reinforcing the use of scientific language and conceptual connections across geoscience domains. The design explicitly incorporates gamification elements, including progression systems, reward mechanisms, and feedback loops, to support engagement and retention. Its modular card-based structure makes it adaptable to different audiences and outreach contexts.

The game has been fully developed and is currently being tested in outreach and educational settings. Preliminary observations indicate high levels of engagement, collaboration, and persistence in problem solving. Future developments will focus on systematic assessment of learning outcomes and evaluation of its effectiveness as a geoscience communication tool. Overall, this approach highlights the potential of gamification, combined with narrative design and disciplinary rigor, as an effective and transferable strategy for geoscience communication and public engagement.

Narrating the Earth: Integrating geoscience and creative writing for scientific communication and outreach

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Keywords: geoscience outreach, creative writing, science communication.

Effective geoscience outreach remains a major challenge, particularly in fostering both conceptual understanding and emotional engagement with complex topics such as deep time, Earth system processes, and environmental change. This contribution presents "I racconti della Terra" (raccontidellaterra.unimi.it), a public engagement project developed within the Third Mission activities of the Department of Earth Sciences "A. Desio" - University of Milan, aimed at integrating scientific knowledge with creative writing practices.

The project was first implemented in 2022 through a series of workshops involving participants with heterogeneous backgrounds and was subsequently adapted to secondary education PCTO programs. The proposed framework combines geoscience content, laboratory activities, and structured creative writing exercises, and is organized into four phases: (i) observation and naming, to develop scientific attention and terminology; (ii) language activation, through constrained writing practices (e.g., haiku, acrostics), fostering synthesis and precision; (iii) stylistic transformation, where scientific texts are re-elaborated using narrative and rhetorical devices inspired by constrained writing techniques (Queneau, 1981); and (iv) autonomous production of original texts grounded in scientific accuracy.

The approach is designed to be replicable and adaptable across different outreach and educational contexts. Results highlight increased engagement, improved understanding of geoscientific concepts, and enhanced communication skills, supported by participant feedback and final evaluation activities. Outputs include a collective volume and a public student presentation of the project's trajectory and outcomes within the framework of *BookCity Milano*.

By explicitly addressing the narrative dimension inherent in geological reasoning, this project contributes to reshaping the perception of geosciences as a culturally relevant and socially impactful discipline, offering an innovative and transferable model for geoscience communication and public engagement.

Queneau R. (1981) - Exercises in Style. New Directions, New York, 128 pp.

Browsing the history of your city through stones - our PLS experience with ornamental and building stones of Padova

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Keywords: dimension stones, Progetto Lauree Scientifiche, rocks.

Differently from physics or chemistry, which are taught in the classroom and in the lab, many of the key concepts of geoscience are only visible out in the field. This includes processes and ultra-meter-scale geological features (such as faults, folds, bedding...), but also involves rock, fossil and mineral collections, which are hardly complete enough to compete to what could be seen in outcrop - or on a river bed. Yet, high school classes seldom can afford field work, either because suitable field localities are too far, or too expensive to reach, or both.

The use of dimension and ornamental stones in cities has been recently suggested as an alternative to rock collections stored in labs or field trips: stone buildings may be seen as equivalent to rich collections of huge and well prepared rock samples (Brocx & Semeniuk, 2017; Gambino et al., 2017). We therefore suggest that rock classification, and perhaps other parts of Earth Science teaching in high schools, may fruitfully take advantage from building stones exposed in the city.

In Padova, we have been proposing tours of the building stones in the city center since 2022. These tours have been offered to high school classes in the framework of the PLS program, but where also occasionally offered to younger students, as well as to university students of Geoheritage courses. Our standard itinerary follows the chronology of buildings, from Roman (or low Middle Age) buildings, through renaissance and the times of the Venetian Republic, the fascist era and finally modern prestigious buildings of the 1960s.

By coupling geology and history, we attract the attention of a large variety of students and teachers, including those more leaning towards architecture and the arts, and we can provide basic notions of how history and the evolution of technology shaped the urban landscape, similarly to what has been also observed in other European cities (e.g., Woodcock & Furness, 2021; Wolniewicz, 2024).

We are aware that our experience in Padova has been developed in parallel in other cities of Italy, first of all, Turin; we exported it in the surroundings (e.g., Vicenza). We are therefore confident that this approach to the teaching Earth Sciences may become a nationwide model, at least for those high schools that are based in historical city centers. We also suggest that its natural evolution could be the development of citizen science projects, therefore involving further disciplines as technical survey and drawing, architecture, history of arts, and informatics.

Brocx M. & Semeniuk V. (2017) - Building Stones Can Be of Geoheritage Significance. Geoheritage, 11, 133-149, https://doi.org/10.1007/s12371-017-0274-8.

Gambino et al. (2017) - TOURinSTONES: a Free Mobile Application for Promoting Geological Heritage in the City of Torino (NW Italy). Geoheritage, 11, 3-17, https://doi.org/10.1007/s12371-017-0277-5.

Wolniewicz P. (2024) - Where Geoheritage Meets Cultural Heritage: Historical Stone Use in the City of Poznań, Poland, and Its Economic and Political Background. Geoheritage, 16, 11, https://doi.org/10.1007/s12371-024-00913-5.

Woodcock NH. & Furness EN. (2021) - Quantifying the History of Building Stone Use in a Heritage City: Cambridge, UK, 1040-2020. Geoheritage, 13, 12, https://doi.org/10.1007/s12371-021-00536-0.

PLS Field Trips over time: Fighting student dropout rates according to UniPi's DST

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Keywords: piano lauree scientifiche, dropout rate, field trip.

Starting in 2016, the Department of Earth Sciences at the University of Pisa has organized an annual spring field trip to sites of geological and environmental interest, exclusively for first-year students. These field trips, funded by the PLS national projects, are designed to spark young people's interest in the various disciplines of Earth sciences and to engage them more deeply through participation in field activities—a distinctive feature of the degree program. The success of these initiatives is also linked to the fact that they are organized and managed entirely by young members of our department—postdoctoral researchers or doctoral students—who are closer in age to the students and with whom it is easier, even unconsciously, to break down barriers than it is when dealing solely with faculty members. Generally, four individuals are involved, often experts in different disciplines, so that they can address diverse topics and help students appreciate how closely related these fields can be when studying the local area and the environment.

Since the first experiences in 2016-2017, the field trips have involved increasing numbers of students and have explored several areas of southern Tuscany characterized by exceptional geological diversity. After a temporary interruption in 2020 due to the COVID-19 pandemic, the initiative resumed regularly from 2021 onward, becoming a recurring and highly appreciated event among students. The activities carried out during previous editions included field observations of sedimentary successions, tectonic structures, hydrothermal and geothermal systems, mineral deposits, and mining environments. Over time, the field trips have also increasingly incorporated interdisciplinary approaches and interactive activities aimed at improving student engagement and participation. The 2026 edition will focus on the geological evolution of the Northern Apennines through a two-day field experience in the Campiglia Marittima and Larderello areas. Students will observe sedimentary successions of the Tuscan Nappe, mineralisations and skarn systems related to the Tuscan Magmatic Province, and active geothermal manifestations within the Larderello geothermal field. In addition, this year's program will conclude with laboratory activities at the Department of Earth Sciences, where volcanic analog models and 3D/virtual reality tools will be used to help students visualize volcanic and geological processes in an immersive and interactive way.

Students appreciate the PLS spring field trip and participate enthusiastically. The plan is to continue with this initiative, which has now become a tradition, while also improving the tracking of future dropout rates among those who did not participate.

From misconceptions to engagement: A palaeontology outreach project for secondary school education

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Keywords: palaeontology misconceptions, geoscience education, student engagement.

Although geosciences are included in the national curriculum of Italian upper secondary schools, they are generally underrepresented in formal education due to limited teaching time, non-specialist teacher training, and a growing decline in students' interest in science (Barone et al., 2023). Within this context, palaeontology is an even more marginal field, and its key elements, fossils, are only briefly addressed in the recent draft of the Italian national guidelines; however, compared to other geoscience disciplines, it often shows a higher potential for student engagement (Fermeli et al., 2015). Combined with its nature as a historical science with strong educational significance, capable of fostering deductive reasoning and inquiry skills, palaeontology can be seen as a "charismatic" discipline, able to promote scientific competences and act as a bridge between geosciences and other school subjects (Estrup & Achiam, 2019).

This contribution presents a study developed within the framework of the Piano Lauree Scientifiche, aimed at strengthening the role of palaeontology in secondary education through the analysis of students' misconceptions and interest, followed by the design of targeted teaching materials and activities. The project, entitled "Enhancing interest in Earth sciences in upper secondary schools", was structured in three main phases. The first one involved 33 experts in collecting perspectives on palaeontology communication and education in Italy, alongside a literature review on the main misconceptions, leading to the construction of a dataset of 80 alternative conceptions. The second phase focused on the development of PaleoConcept, a questionnaire designed to assess student interest and the occurrence of misconceptions, supporting the evaluation of prior knowledge for targeted instructional design. The results show a generally good level of interest, but also the persistence of key misconceptions, such as confusion with archaeology and a limited understanding of deep time. The third phase involved the development of targeted teaching materials, organised into thematic modules that can be integrated across school subjects.

The questionnaire and the developed materials can support teachers in science education contexts; students can also use the questionnaire as a tool to monitor their understanding of topics related to palaeontology, such as evolutionary theory or climate change over time. The questionnaire can also be used in non-formal contexts to engage audiences and contribute to the development of constructive discussions on specific themes.

Barone A. et al. (2023) - Teachers' perceptions of the effectiveness of teaching Geosciences in Italian upper secondary school. Geogr. Fis. Din. Quat., 46(1-2), 257-274, https://doi.org/10.4454/98fghr54.

Estrup E.J. & Achiam M. (2019) - The potential of palaeontology for science education. Nord. Stud. Sci. Educ., 15(1), 97-108, https://doi.org/10.5617/nordina.5253.

Fermeli G. et al. (2015) - Geoscience teaching and student interest in secondary schools: preliminary results from an interest research in Greece, Spain and Italy. Geoheritage, 7(1), 13-24, https://doi.org/10.1007/s12371-013-0094-4.

Possible strategies to mitigate the vocational crisis in geology: Examples from the University of Roma Tre

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Keywords: enrollment decline, student engagement, teaching strategies.

The number of students enrolling in Bachelor's programs in Geology has declined worldwide in recent years. The question of why Earth Sciences are becoming less attractive to younger generations is complex and does not have a single answer. Students' choices are influenced by multiple factors, including local and regional economic and social trends, family background, school curricula, and the ability of teachers to effectively communicate Earth Science concepts.

Although working with school teachers likely represents the most effective long-term strategy, in the last two years the "Geology Team" of the Department of Science at the University of Roma Tre has adopted several shorter-term initiatives designed for students. Within the framework of "*Formazione Scuola Lavoro*" program (formerly "*Percorsi per le Competenze Trasversali e per l'Orientamento*"), we developed a series of projects adopting the following strategies aimed at increasing students' engagement with Earth Sciences:

Establish sustained interaction between students and university teachers/tutors through activities lasting 15-25 hours, since isolated seminars have proven ineffective in increasing student engagement.

Target students from the third year of high school, as students in the final year have often already chosen their future academic path.

Combine classroom lectures with laboratory activities, such as the interpretation of simplified local geological maps and fieldtrips within the city, to increase awareness of the local territory and of human impact on the environment, since lectures alone may reinforce the perception of geology as an outdated discipline.

Highlight the broader relevance of geology by integrating economic, social, and sustainability-related topics, thereby demonstrating its practical applications and societal importance and hence enhancing the visibility of geology.

Integrate cinema and science to increase students' engagement and learning outcomes, as visual storytelling allows complex scientific concepts to be communicated in a more accessible, stimulating, and emotionally engaging way, helping students to connect theoretical knowledge with real-world scenarios.

Although the effectiveness of these strategies will only be appreciated over the next one to three years, the questionnaires completed by students participating in these projects provide a valuable monitoring tool for evaluating and refining the adopted approaches. Furthermore, they offer useful insights into the factors contributing to the declining attractiveness of Earth Science among younger generations.

Practical experiences for teaching geological sciences for high school students: The example of PLS-Geologia project at the University of Pavia

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Keywords: piano lauree scientifiche, high school students.

This work summarizes the activities carried out by the Degree Program in Geological Sciences at the University of Pavia within the framework of the national PLS-Geologia project. This degree program has been engaged in orientation and outreach activities for high school students for over a decade. The involvement of an increasing number of professors and members affiliated with this degree program has made it possible to develop a structured set of orientation activities, particularly based on laboratory and field works, aimed at introducing the various aspects of geological sciences through hands-on experience. These activities involve hundreds of high school students each year, allowing them to become familiar with geological sciences and the role they play in our society and everyday life. Furthermore, the implementation of practical activities, using easily accessible materials and repeatable experiments, gives the teachers the opportunity to replicate them in the classroom, thereby also serving as a form of professional development for educators who teach this discipline in schools.

The National Geology Project of the Piano Lauree Scientifiche 2026-2028

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Keywords: piano lauree scientifiche, geoscience education, outreach activities.

The *Piano Lauree Scientifiche* (PLS) funds three-year national projects in nine STEM disciplines: Science, Technology, Engineering and Mathematics. Its overarching goals are to encourage upper secondary students to pursue tertiary education and to counter the decline in interest in scientific careers. Each project involves a network of universities and secondary schools and is associated with quantitative targets to be achieved by the end of the three-year period. The main intervention areas of the *Piano Lauree Scientifiche* include support for students during the school-to-university transition, tutor training, innovation in laboratory practices, self-assessment for university entry, and professional development for secondary school teachers.

Within this framework, the National Geology Project of the *Piano Lauree Scientifiche* has been active in Italian geosciences departments for more than ten years. The project brings together 28 Italian universities offering first-cycle degrees in Geological Sciences. For the 2026-2028 period, the main objectives are:

- strengthening orientation activities to counter the decline in enrolment in geological sciences degree programs;
- supporting degree programs in increasing the percentage of students who enter the second year of geological science degrees having acquired at least 40 credits. Statistical analyses at the national level show that students reaching this threshold are more likely to complete their degree within the expected timeframe;
- reducing the gender gap in new enrolments through a renewed narrative of the geologist profession, which today offers inclusive and non-discriminatory career opportunities; and
- enhancing the training of secondary school teachers, which is considered a key objective for counteracting the decline in enrolments in the medium to long term. To this end, an increase in training opportunities for secondary school teachers is planned.

In the presentation, we emphasize that the National Geology Project is not simply a provider of outreach activities, but rather a component of a broader geoscience education system involving universities, scientific societies, and secondary school teachers.

One year of multidisciplinary geological activities within the *Piano Lauree Scientifiche* at the University of Bologna

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Keywords: piano lauree scientifiche, geoscience education, outreach activities.

We present the activities of the *Piano Lauree Scientifiche* (PLS) developed by a group of PhD students, postdoctoral researchers, and professors in Geological Sciences at the University of Bologna.

During the 2025-2026 school year, 13 activities involved, in total, more than 450 upper secondary school students from the Bologna and the Ravenna areas. The students, aged 16-18, were introduced to several geological disciplines including applied geology, field and structural geology, hydrology and hydrogeology, mineralogy, paleontology, petrography, stratigraphy, and volcanology. The topics reflected those typically covered in a Geological Sciences degree programme, including orogenetic processes, groundwater systems, fossils, rocks and their use in the built environment, flood-city interactions, and volcanic hazards. The aim of these activities was to inform students about geology and its relevance to society. This integrated effort of the Bologna PLS group addresses three intervention areas of the *Piano Lauree Scientifiche*: (1) orientation activities supporting the transition from secondary school to university, (2) tutoring activities and (3) laboratory practices.

All projects shared a common format, consisting of lectures followed by hands-on activities and/or field trips. The lectures introduced the main concepts and terminology related to each topic. The hands-on activities and field trips provided students with direct exposure to geological methods and professional practices. In addition, field trips aligned well with the participants' preference for outdoor activities.

At the end of each activity, students were invited to complete an evaluation form containing Likert-scale questions, multiple-choice items, and short-text responses. The questionnaire investigated whether participation in the activities produced a positive shift in students' interest in geology. Preliminary results suggest that the outreach activities of the *Piano Lauree Scientifiche* created opportunities to increase students' interest in Geological Sciences. However, two issues also emerged: interest in geology tended to increase mainly among students who were already interested before participating, and students in the final year of upper secondary school had often already decided which university degree program to pursue. These findings indicate the need to reach students earlier in their educational pathway.

Building geoscience competencies in schools: insights from the "Advanced Training School for Science Teachers" within the PLS-Geologia project

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Keywords: piano lauree scientifiche, advanced training school, science teachers.

The "Advanced Training School for Science Teachers" in Geological and Environmental Sciences is an initiative developed within the *Piano Lauree Scientifiche - Geologia*, specifically under the teacher-training action, aimed at strengthening geoscience education and supporting teacher professional development. The programme was established to address a persistent gap in Earth Sciences preparation among science teachers, most of whom hold a biology background, resulting in limited classroom coverage of geological topics and, consequently, a poor understanding among students of geoscience university pathways and of the professional role of geologists.

Organised by the University of Cagliari (Department of Chemical and Geological Sciences), the School offers a structured training pathway that integrates hands-on and minds-on approaches through seminars, field studies, monitoring techniques, guided excursions, and experimental laboratory sessions using analogue and augmented-reality tools such as the Sandbox, Em-River and drone-based photogrammetry. The programme provides teachers with accessible yet innovative tools to incorporate geoscience topics into their teaching practice, promoting inquiry-based learning and fostering the ability to interpret the geological features of the Sardinian landscape. All teaching materials are made available to support classroom transferability.

Since 2018, the School has been held in multiple locations across Sardinia to ensure broad regional participation, adopting a multi-site model that facilitates access for teachers from different areas. Over the years, the initiative has been organised with the patronage and collaboration of the *Associazione Nazionale Insegnanti di Scienze Naturali* (ANISN), the *Associazione Italiana Insegnanti di Geografia* (AIIG), and the Sardinian Order of Geologists and, depending on the hosting area, in partnership with local institutions, such as CNR and regional parks. The programme is officially recognised as accredited teacher training through the MIUR SOFIA platform and involves approximately 25 teachers each year. Traditionally offered as an intensive 40-hour summer programme, the 2026 edition adopted a winter format with weekly afternoon sessions, maintaining continuity with previous PLS actions while expanding participation and outreach.

This contribution presents the structure, rationale, and educational impact of the School, highlighting its role as an effective and replicable model within the PLS network and promoting dialogue with similar initiatives across Italy.

Exploring geosciences through the Piano Lauree Scientifiche: The University of Catania experience

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Keywords: PLS Scienze Geologiche UniCT, geodiversity, secondary school.

Within the framework of the Piano Lauree Scientifiche, the University of Catania has carried out over the years a series of initiatives aimed at fulfilling its main objectives. These activities have been strongly supported by the favorable geological setting of Sicily. The island, including its smaller surrounding islands, is located at the center of the Mediterranean and is characterized by remarkable geodiversity, ranging from active and extinct volcanoes to crystalline basements, Messinian evaporitic sediments, a segment of the Apennine-Maghrebian chain with its sedimentary sequences, and the geodiversity of its coastlines. In addition, Sicily is exposed to significant seismic risk. Over the centuries, these factors have deeply influenced the development of local civilizations, which have maintained a strong connection with the geological contexts that shaped their evolution. For this reason, Sicily hosts several UNESCO sites, including tangible and intangible heritage sites as well as geoparks, such as the Madonie UNESCO Global Geopark and the Rocca di Cerere UNESCO Global Geopark. Furthermore, the island includes several mining sites, some of which are still active and related to the extraction of evaporitic salts.

Within this context, the activities of the Piano Lauree SCientificheprogram have been designed to promote knowledge of the local geology, green innovations, and topics related to climate change through laboratories offered to schools at the beginning of each academic year and subsequently developed along a coherent cultural and educational pathway. The proposed activities also include field experiences, such as geophysics laboratories, thematic field trips, and urban trekking activities in the city of Catania. In addition, the PLS program has supported the initiative entitled “Seismic Observatory,” conducted by the INGV - Etnean Observatory, with the contribution of University of Catania staff members.

Moreover, the Earth Sciences Section hosts the Museum of Mineralogy, Petrography and Volcanology, the Museum of Paleontology, and the Collection of Mineral-Petrographic, Geophysical, and Geochemical Measuring Instruments.

Some activities are also specifically addressed to secondary school teachers through several initiatives carried out in collaboration with Piano Lauree Scientifiche in Natural Sciences. Furthermore, scientific conferences often include dedicated training and professional development sessions for teachers.

In addition, the Piano Lauree Scientifichesupports several initiatives and seminars aimed at promoting knowledge and awareness of the geosciences.

Young women and geosciences: Perspectives and engagement within the PLS program

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Keywords: STEM, gender equality, soil erosion.

One of the main goals of the PLS program is to promote the gender balance in STEM (Science, Technology, Engineering and Mathematics) disciplines. In this context, since 2023, the Women's Studies Center "Milly Villa" of the University of Calabria promoted a FSL (*Formazione Scuola Lavoro*) project on "Environmental Sustainability", aimed at female high school students. The project included a seminar on "Science and Gender Issues", followed by scientific activities with female researchers across different disciplines, and a final meeting where the girls presented their results. Within the framework of the PLS in Geological Sciences, the project was successfully replicated this year, offering students an immersive and hands-on scientific experience. This contribution highlights the point of view of the girls, who designed and conducted experiments, analyzed data, and communicated their findings independently.

Guided by the teachers, the girls employed digital tools, including GIS and satellite imagery, to investigate soil erosion, developing both practical and analytical skills. The students demonstrated increasing autonomy throughout the program, gradually shifting from guided activities to self-directed investigation. They were encouraged to propose experiments and protocols and collaborate within their team to solve real-world problems. The process emphasized creativity, critical thinking, and scientific reasoning, positioning the young women as researchers rather than mere observers.

Feedback collected through surveys revealed high levels of motivation, engagement, and satisfaction. Many girls reported that the experience enhanced their understanding of geosciences and inspired them to consider future scientific pathways. A large majority of participants stated that the experience significantly improved their scientific and digital skills, particularly in data analysis and the use of GIS tools. Notably, the young women appreciated thatthey were not only passive learners, but active contributors, taking part in the design of experiments, data collection, and the interpretation of results, in a collaborative way.

Overall, the findings highlight the effectiveness of a student-centered, hands-on approach in fostering both scientific skills and motivation. These results confirm the potential of the FSL framework as a powerful tool for orientation of young women towards STEM education.

Orientation, formation and consolidation: The activities of University of Calabria in the framework of the PLS program

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Keywords: FSL projects, lab-work, field excursions.

During the last years, the PLS group of University of Calabria has carried out a number of activities, mainly dedicated to the high-grade school students and University students of the first year of the course of Geological Sciences. In particular, the activities were aimed at three main actions:

Orientation: this activity is necessary to contrast the decrease of students who enrol in the Geological Sciences courses at the University. It was carried out during the several initiatives promoted by the University or by our Department, but also through dedicated seminars in the schools, during which the main characteristics of the course and the job opportunities were presented. In this category of actions, we have also organized the "Young Geologist Prize", a contest that rewards the best multimedia products geologically themed, now at its sixth edition.

Formation: as the geological sciences occupy a very limited place in the science teaching in the high schools, it is necessary to improve it with dedicated actions. These mainly consisted of "*Formazione Scuola Lavoro*" (FSL) projects on specific geological themes, always including lectures and hands-on activities and/or fieldtrips, so that students can experiment the scientific methods used in the geological research and professional practice. Particular attention was given to promote gender equality in the geology courses, with projects exclusively dedicated to young women.

Consolidation: a problem our course deals with is the relatively high number of students who choose not to continue after the end of the first year. In order to contrast this loss of students and to support them in the difficulties with the basic courses of the first year, we have implemented several tutoring activities. The same tutors were of great help in supporting the other two actions. Moreover, with the purpose to increase the interest of students during the first year, we have organized several field trips in geologically significant areas (e.g. Etna, Calabria coastal chain etc.).

In the period 2023-26, the activities of the first two actions involved 18 schools, for a total of more than 1600 students and 10 FSL projects. These numbers do not include the other several activities organized by the University, such as "The Night of the Research" or "Orientation days" and activities targeted not only to schools, such as the FAI days, the Week of Planet Earth etc. Six tutors were formed in the framework of the third action and five field trips were organized. The high number of activities was possible only thanks to the involvement of all the researchers and professors of the geology course, together with PhD students, master students and lab technicians. Our goal for the next PLS program is to involve a higher number of schools, including those from peripheral areas and professional/technical high schools. Moreover, we plan to increase the activities related to the formation of science teachers.

An integrated effort for geoscience engagement at the University of Milan within the Piano Lauree Scientifiche framework

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Keywords: geoscience outreach, science communication, public engagement.

For more than a decade, geosciences have remained underrepresented in Italian secondary education curricula, limiting students' awareness of Earth Sciences degree programmes and related career opportunities. Within the framework of the *Piano Lauree Scientifiche* (PLS) Geologia, the Department of Earth Sciences "A. Desio" at the University of Milan has developed an integrated outreach strategy aimed at increasing the visibility of geosciences, supporting informed university choices, and reducing student dropout.

Our approach includes a range of activities designed to challenge stereotypes surrounding geologists' professional roles and promote awareness of the societal relevance of Earth Sciences. These include open days, laboratory visits, museum experiences, and events in which geoscience professionals present diverse career pathways through short talks and speed-mentoring sessions.

A second pillar involves hands-on laboratory experiences co-designed with schools, where students actively engage in scientific investigation. Activities include urban soil pollution assessment, applied geophysics experiments, urban geology fieldwork using digital mapping tools, micropalaeontology laboratories, and *I Racconti della Terra*, an interdisciplinary project that combines geoscience education with creative writing to foster science communication skills and broaden participation.

The programme also addresses the transition to university through tutoring initiatives, study-method training, and targeted support for first-year students, while dedicated professional development courses help secondary-school teachers integrate geoscience topics into their curricula.

By connecting outreach, experiential learning, teacher training, and retention strategies, this model addresses critical gaps in geoscience education while fostering a more inclusive and informed geoscience community.

Target "Teachers": The Geo-Unicam experience

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Keywords: teachers, hands-on labs, evaluate results.

Within the framework of the University of Camerino's PLS-Geology 2023-25 project, particular emphasis was devoted on the "Professional Growth of High School Teachers" initiative, involving both upper and lower secondary school teachers.

Therefore, a big effort was made to ensure continuity with recurring and diversified activities, varying in content and location, and in partnership, to facilitate the participation by teachers from different geographical areas. The proposed professional and training courses were promoted through the SOFIA platform and the USR (Ufficio Scolastico Regionale), as well as through a series of personal contacts of the promoters. Registration was also possible directlythrough the partners involved, or through the University of Camerino Teacher Training Center.

The first course (September 2024), entitled "The Geology of the Marche at School," organized in collaboration with the Da Vinci High School in Jesi (AN), consisted of seminars, workshops, and a field trip. It was divided into three sessions (two afternoon meetings and one full day activity), held partly at the university campus in Camerino and partly at the Jesi High School.

The second course, titled "Geosciences at School 2025-26," was designed with ANISN-Marche and consisted of two modules of four weekly afternoon sessions each, in October 2025 and February 2026, proposed at two schools: the IIS "Volterra-Elia" in Torrette di Ancona (coastal area) and the IIS "Filelfo" in Tolentino (hinterland).

The topics, agreed upon with ANISN based on the wishes of in-service science teachers, were covered during three-hour afternoon sessions, with a specific focus on practical or laboratory aspects.

In both the courses attended by approximately 40 teachers in total, satisfaction surveys and subsequent self-assessment questionnaires were administered to assess the results achieved. Analysis of the feedback collected is useful for planning future activities and indentifying possible strategies to improve effectiveness of the program, particularly for teachers without a specific background in geology.

Although the overall positive response to the activities and seminars offered, teachers still expressed difficulty in engaging with topics outside their original academic preparation. They also expressed specific requests regarding the topics to be covered, teaching tools and methodologies to be developed in future editions of the program.

Teaching Earth Sciences in Italy: Training experiences with secondary school teachers (PLS Geology, University of Turin)

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Keywords: geoeducation, sustainability, transdisciplinary.

The Piano Lauree Scientifiche project (PLS) aims at enhancing the enrollement to STEM degrees and to strengthen subject-specific theaching before students enter college.

The University of Turin takes part in the national project "PLS Geologia", lead by the University of Bologna. Each University developed the tasks of the project according to its strength and vision. The Earth Science Department of the University of Turin (DST) has offered, across the years, many training opportunity for secondary schools teachers, with the aim to strengthen the disciplinary competencies of the teachers (that very rarely hold a major or even a minor degree in Geological Sciences), to support laboratory and field activities for teaching Earth Sciences, and to overcome common misconception about Earth Sciences, both at the teachers and students level.

The courses ranged from a disciplinary approach to a transdisciplinary one. Disciplinary courses (e.g. Alpine Geology and Geology of Langhe, Roero and Monferrato courses) were offered in presence at DST, and complemented by a one-day fieldtrip, with the aim to test the didactical activities that can be replicated with the students. The strength of this approach is the ability to involve both teachers and their students in the knowledge about the area where they live, enhancing the sense of belonging and the interest in geological processes responsible for the geomorphology and deep time history of the territory they belong.

The interdisciplinary approach was at the core of the course, "*Non solo bio*. Teaching Earth Sciences through geosites of the Piemonte region". It has been offered through online lectures, in presence discussions, and in the field, where examples were discussed and teaching activities tested. It addressed the rich geodiversity of the region, and the need to protect and disseminate the geological knowledge of the geosites. Piemonte is home to a UNESCO geopark and its geodiversity is among the richest in Italy. This course also addressed the interdisciplinary subject of sustainability as seen through the lens of geoparks and geosites.

Finally, since Earth Sciences are at the core of sustainability issues for society and for sustainable development, we also offered the transdisciplinary course "*Educare al cambiamento con le geoscienze*", merging outdoor education with a transdisciplinary blend of science and humanities to address Earth Systems knowledge, to foster innovative teacher collaboration and develop new didactical strategies and tools. This was intended to raise awareness of the pervasive role of the geosciences in society among teachers from any discipline. We firmly believe that Earth Sciences play a central role in fostering systems thinking and in promoting an integrated understanding of global challenges.

Through this transdisciplinary approach, we aim to contribute to a sustainable transformation that is inclusive, responsible, and beneficial for all.

PLS at ISISS Piedimonte Matese (Southern Italy): Teaching subsurface exploration with ground penetrating radar in an agricultural context

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Keywords: PLS, agriculture, GPR.

In the framework of the *Progetto Nazionale Lauree Scientifiche* (PLS) - *Geologia 2023-2025*, the Department of Science and Technology (DST), University of Sannio, in cooperation with the National Institute of Geophysics and Volcanology - *Sezione Irpinia* (INGV), proposed a detailed program of laboratory training for students and teacher professional development pathways. Given the natural vocation of the Sannio and Irpinia territories, a wide range of field laboratory activities were organized and conducted, such as field geology excursions across the region, as well as activities in rural and urban geology.

In February 2025, we implemented a PLS-based training program at the *Istituto di Istruzione Superiore Statale (ISISS) Piedimonte Matese*, a comprehensive upper secondary school in the heart of the Sannio region. The school hosts several specialised institutes under one roof, including *Agraria*, *Alberghiero*, *Economico*, and *Tecnico* programmes, and serves the Matese area and surrounding Irpinia, playing a key role in vocational education. Its location in a territory rich in geological and geomorphological heritage makes it a natural hub for field-based Earth Sciences learning. ISISS Piedimonte Matese manages a teaching and experimental farm linked to its Agricultural Institute. Used as an open-air lab for agronomy and soil management, it exploits the area's geology for hands-on learning, connecting classroom theory with local agricultural and environmental practices. Considering the natural interests of ISISS students in agriculture and agro-industry, DST and INGV proposed a PLS initiative integrating a concise classroom-based session with extensive field-based training, fostering a direct connection between scientific research, educational practice, and the local territory. In March 2025, researchers from DST and INGV performed geophysical surveys at the ISISS Piedimonte Matese experimental farm. Using low-frequency Ground Penetrating Radar (GPR) (Famiglietti et al., 2024), the PLS field activity focused on mapping shallow subsurface geological features beneath the agricultural field, illustrating how GPR can be used as a practical tool to teach subsurface exploration in an agricultural context. Students were directly engaged in fieldwork through a step-by-step approach, building awareness from survey planning to preliminary data interpretation and strengthening the link between geoscience methods and everyday agricultural environments.

Famiglietti N.A. et al. (2024) - Ground Penetrating Radar (GPR) Investigations in Urban Areas Affected by Gravity-Driven Deformations. Geosciences, 14(8), 222, https://doi.org/10.3390/geosciences14080222.

School-to-Work Training (FSL): Projects to introduce students to academic scientific disciplines

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Keywords: FSL, Earth science, Roman area.

The proposed School-Work Training Program, entitled "Territorial Safety between Seismicity and Volcanism", is proposed to students of the Scientific High School "S. Cannizzaro" in Rome and is organized in collaboration with the Istituto Nazionale di Geofisica e Vulcanologia (INGV). The project aims to provide students with scientific knowledge and practical skills related to seismic and volcanic risk in Central Lazio, with particular focus on Rome and the Colli Albani volcanic district.

The program combines theoretical lessons, laboratory activities, field experiences, and independent project work to promote an interdisciplinary and experiential approach to Earth Sciences. Students will deepen their understanding of geological processes responsible for earthquakes and volcanism, explore the geological evolution of the Roman area, and learn about monitoring systems and risk prevention strategies developed by INGV researchers.

The training course is structured into four phases: (i) seminar and laboratory activities at the INGV Geosciences Museum in Rocca di Papa; (ii) a guided geological field trip to the Caffarella Park; (iii) a seminar at the school, focused on seismic and volcanic hazard assessment; and (iv) the development of a final group project. Through direct observations, scientific communication and collaborative work, students will strengthen their scientific literacy, critical thinking, and civic awareness concerning natural hazards and territorial safety.

In addition, the School-Work Training project (ISS Sandro Pertini di Genzano)"Artificial Intelligence and Climate Change: between Scientific Information and Digital Hallucinations" explored climate change issues in the Mediterranean area and the Castelli Romani through scientific outreach activities, workshops, and discussions with experts. A central component of the program is the critical analysis of information generated by Artificial Intelligence tools, with particular attention to the phenomenon of digital "hallucinations." Students compared responses produced by different AI systems and verify their reliability through authoritative scientific sources. The project aims to develop scientific, digital, and civic competencies, encouraging a critical and responsible use of emerging technologies while fostering greater awareness of environmental challenges affecting the local territory.

The described projects aim to foster active citizenship by encouraging responsible behaviour, awareness of environmental risks, and appreciation of the geological heritage of the Lazio region.

Geoscience awareness in educational and outreach contexts: A preliminary statistical analysis

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Keywords: geoscience, awareness, communication.

Communication and education in the geosciences are key elements fostering an integrated understanding of the Earth system. The main goals are to increase awareness of natural hazards and improve natural resource management. Despite this, several studies highlight a persistent misalignment between the societal importance of geology and the way this discipline is commonly perceived by the public.

This study explores how geological topics are received and interpreted by different audiences, representing an important step for the design of effective educational and outreach actions. Here we present preliminary results from a survey conducted within a broader PhD research project, focused on geoscience communication and outreach.

Two paper-based questionnaires, each consisting of 15 multiple-choice questions with four options, were developed and administered to a sample of approximately 570 children and 850 adults. Participants were involved in educational and outreach activities organized by the Department of Earth Sciences (DST) of Sapienza University of Rome. The survey was conducted in Rome, Bologna and Central and Northern Italy. The questionnaire for adults investigates geological awareness dividing the questions into five themes: Earth system processes, natural hazards, climate change, lifestyles, and the use of natural resources. The questionnaire for children was planned following the same strategy, obviously scaling the options to choose to the young age of the public, focusing the questions on general arguments devoted to rocks, fossils, minerals, volcanoes, and earthquakes.

The preliminary results, based on a continuously growing dataset, are presented separately for the two target groups. Among adults, responses indicate a tendency to interpret geoscientific topics primarily through interpretative frames, related to natural hazard mitigation and sustainability. These perspectives appear to reflect widely shared societal narratives, rather than an integrated understanding of geological processes operating across different spatial and temporal scales. Children's responses, while often grounded in intuitive or narrative reasoning, show an overall solid understanding of some key concepts, particularly when supported by direct and hands-on experiences. In both cases, understanding of geological topics appears heterogeneous, context-dependent, and influenced by school-based learning and media exposure.

These initial findings highlight the importance of developing educational and outreach strategies that take existing interpretative frames into account and promote integrated, experiential, and territorially contextualized activities. Data collection is ongoing and will be extended to additional contexts and methodological approaches, supporting the progressive refinement of outreach and educational actions within the PhD project.

The "Stage-PLS Geologia" at the University of Urbino Carlo Bo: A multi-day internship combining classroom and field activities in the Umbria-Marche Apennines

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Keywords: geosites, field activity, geotechnologies.

Among the activities of the Piano Lauree Scientifiche (PLS), the BSc degree programme in "*Geologia per la Sostenibilità Ambientale*" (L34) at the University of Urbino Carlo Bo has, over the years, consolidated the "*Stage-PLS Geologia*" activity, a multi-day internship held in the spring period. The internship is designed for secondary school students in their final two years and commonly lasts two or three days, with overnight stays at ERDIS Marche (Regional Agency for the Right to Education of the students) accommodation facilities or at Apennine refuges or agritourism farms.

The internship combines an initial part of laboratory work in the classroom and at research facilities within the University with field activity in the Apennines of the Umbria-Marche regions. Throughout the programme, students explore different aspects of Earth Sciences, including among others: (i) the classification and physical properties of minerals and rocks and their relationships with geodynamics and anthropogenic frameworks, (ii) the evolution of landscapes in response to interactions between endogenous and exogenous processes, (iii) surface and groundwater resources, (iv) critical raw materials for ecological transition, (v) geothermal energy as a renewable source, (vi) stones of cultural heritage and (vii) actions against climate change. These experiences also provide opportunities for learning practical skills such as orientation and use of topographic map, geological and geomorphological mapping, water sampling and analysis in ion chromatography, thin section rock analysis through polarized light optical microscopy. Monitoring and prevention activities related to hydrogeological hazards (landslides and floods) based on remote sensing and webGIS applications are also comprised, offering an opportunity to get involved in topics concerning the geologist's profession. During the internship, laboratory courses integrating new knowledge and land representation technologies (drones, augmented reality, digital twins) and aerial and satellite imagery visualizations lead to understand the mechanisms of land use variations and the interactions between human and geological time.

The field activities encompass visit of the most important geosites, geological and geomorphological areas such as the "*Marmitte dei Giganti*" along the Metauro river, the Furlo Gorge with the "*Calcare Massiccio*", the oldest outcropping formation of the Umbria-Marche succession, the Bottaccione Gorge, near Gubbio, where the Cretaceous-Paleogene mass extinction (e.g., dinosaurs) is recorded, the carbonate successions of Mount Nerone with the geosite of "*Fondarca*" and the geological and paleontological Museum of Apecchio at *Palazzo Ubaldini*.

The internship is also open to science teachers at the secondary schools to enhance dissemination and impact, while also gathering feedback on students regarding the "*Stage-PLS Geologia*" of the University of Urbino Carlo Bo.

The Geology PLS at the University of Padova: Collaborative experiences for student orientation and teacher training

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Keywords: PLS, schools, activities.

The PLS - Geology (*Piano Lauree Scientifiche*) of the Department of Geosciences at the University of Padua represents a well-established experience of collaboration with lower and upper secondary schools, aimed at actively guiding students in their educational choices and supporting teacher training through laboratory-based and participatory methodologies. In line with the national objectives of the PLS initiative, the project seeks to promote more informed university choices, reduce the gap between schools and universities, and highlight the role of Geosciences in understanding natural and environmental processes. In recent years, the Department has developed numerous activities for both students and teachers, including thematic laboratories, orientation pathways, interdisciplinary seminars, visits to scientific collections and laboratories, and professional development initiatives. These activities have been designed with a strong emphasis on experiential and interdisciplinary approaches, based on direct observation, the analysis of real samples and data, and the active involvement of participants. Particular importance has been given to the "*Le Giornate delle Geoscienze*" (i.e. Geosciences Days), events dedicated to secondary schools that engage students and teachers in practical activities, laboratory experiences, and opportunities for discussion with university students, PhD candidates, and researchers from the Department. These initiatives have fostered a greater awareness of geological disciplines and their applications, strengthening the relationship between schools and universities and promoting an orientation process grounded in direct experience. At the same time, the PLS has promoted teacher training programmes focused on current scientific and environmental issues, such as climate change, hydrogeological instability, urban geology, and sustainability. These training activities combine disciplinary updating with methodological innovation, supporting teachers in the design of educational pathways that can be effectively transferred to school contexts. Another important area of intervention has concerned tutor training, through activities dedicated to university students involved in the PLS programmes. These activities are aimed at developing communication, interpersonal, and teaching skills useful for managing school-related activities and facilitating the communication of scientific content. Both the "*Le Giornate delle Geoscienze*" and the teacher training initiatives included structured self-assessment phases based on specifically designed questionnaires, aimed at collecting qualitative and quantitative feedback, evaluating participants' appreciation of the activities, and guiding the continuous improvement of the educational and training proposals developed by the Department.

The Geological Sciences PLS activities at the University of Ferrara

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Keywords: PLS, students, orientation.

The Geological Sciences of the University of Ferrara in the last years defined several outreach and guidance for high school students following the PLS project. The PLS of Geological Sciences UNIFE (SGUNIFE-PLS) aims to promote interest in geosciences among high school students and support their transition to university. The program included interactive workshops and laboratory activities designed to introduce fundamental geological concepts. Students have the opportunity to engage with real-world problems such as natural hazards, climate change, and resource management, applied geophysics. Collaboration between university faculty and school teachers ensures that the activities are aligned with educational needs. On this point, the collaboration between the teachers and the university world should be strongly encouraged. The training of high school natural science teachers plays a key role in improving the quality of science education. Professional development programs provide updated knowledge in areas such as geology and environmental science. These initiatives also introduce innovative teaching methods, including inquiry-based learning and the use of digital tools. Innovative teaching methods, including hands-on experiments and digital tools, were emphasized. Collaboration between universities and schools helps teachers connect current research with classroom practice. SGUNIFE-PLS project also provided guidance on academic pathways and career opportunities in geosciences. Special attention is given to small degree programs, enhancing their visibility and attractiveness. The initiative fosters critical thinking and scientific curiosity. It also helps students develop practical skills useful for future studies. Overall, the PLS project aims reducing student dropout rates is a key priority, supported by targeted measures to improve retention. Special attention was given to students with specific needs through dedicated support actions and inclusive strategies. The last three years SGUNIFE-PLS team involved professors, laboratory technicists, post-doc researchers and PhD students and it was possible to engage with over 3,500 students, promoting Geological Sciences in all its aspects, both as a scientific discipline and in terms of career opportunities. The commitment and activities carried out in recent years have made it possible to maintain enrolment numbers and slightly increase them at the University of Ferrara. Finally, there is no magic solution to the low number of enrolments in Geological Sciences. However, orientation activities are certainly essential, as is the coordinated integration of initiatives among different universities and with the professional world.

Experiences from the PLS program in Palermo

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Keywords: student engagement, geoscience education, communication plan.

Within the framework of the *Piano Lauree Scientifiche - Geologia* (PLS), the Bachelor's Degree in Geological Sciences at the University of Palermo has developed different coordinated activities aimed at increasing student recruitment, supporting academic success, and strengthening connections between schools, universities, and society.

This contribution presents an overview of the main initiatives carried out at the Palermo site, structured around the five actions defined by the PLS program. Orientation activities have been implemented through both independent and collaborative initiatives, including multidisciplinary university events, targeted seminars, and the development of a Communication Plan aimed at enhancing the visibility and attractiveness of the degree program. Among the most significant initiatives, particular attention is given to the Communication Plan itself and to outreach formats such as "Cinema and Science" ("*Il cinema racconta le scienze*"), which have proven effective in engaging students and the wider public.

Laboratory-based practices have represented a central component of the program, with hands-on activities integrated into PCTO pathways and focused on current and socially relevant geoscience topics, fostering active learning and student engagement. Professional development opportunities for secondary-school teachers have been promoted through dedicated activities, with a particular emphasis on field-based experiences such as geological excursions, which have proven especially effective in strengthening disciplinary knowledge and teaching practices.

Finally, the contribution will highlight the main critical issues that emerged from these experiences, including challenges related to student awareness, engagement, and incoming competencies, as well as organizational aspects. Future perspectives and planned improvements for the next PLS cycle will also be discussed.

Historical seismology as a PLS-geologia outreach experience: Integrating geoscience education, laboratory activities and risk awareness in secondary school

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Keywords: historical seismology, geoscience outreach, PLS geologia.

The Historical Seismology Project (HSP), developed within the *Piano Lauree Scientifiche - Geologia* (PLS) through the collaboration between *Liceo Pietrobono* of Alatri and the Department of Earth Sciences of Sapienza Università di Roma for the Academic Year 2025/2026, is an interdisciplinary initiative aimed at increasing geoscience awareness among secondary-school students and teachers. Combining scientific outreach, active learning, field experiences, and orientation activities, it promotes STEM education with a focus on Earth Sciences and geological risk prevention.

The HSP project investigates the historical and geological seismicity of the Province of Frosinone, particularly the Alatri area, which has been affected by significant earthquakes. Through the study of earthquakes, tectonic processes, and historical records, students will explore the relationships among geological hazards, landscape evolution, urban development, and collective memory. Collaboration with local libraries, historians, universities, and scientific institutions such as INGV and CNR will help students understand the value of integrating historical and scientific data in risk assessment.

Seminars and outreach activities led by university professors and technical experts will address geological hazards, seismic risk management in Lazio, and earthquake distribution. Optional extracurricular field excursions to Morino and nearby villages in Abruzzo will allow students to observe evidence of the 1915 Marsica earthquake and develop practical skills in hazard recognition, environmental monitoring, and territorial analysis.

A key aspect of the HSP project is its inquiry-based and laboratory-oriented approach. Students will create educational products combining scientific knowledge and technology, including a seismic recording device based on the Arduino platform and physical models of the Somma-Vesuvius volcanic system. Supported by a special education teacher and sculptor artist, these activities will integrate geological mapping and volcanic stratigraphy with reflections on volcanic and seismic risk, while promoting teamwork, creativity, problem-solving, and science communication skills.

Project outcomes will be presented during a public school event dedicated to STEM laboratory activities and disseminated through institutional and social channels. The initiative aims to encourage students' interest in geosciences and environmental studies, support teacher professional development, and strengthen cooperation among schools, universities, research institutions, and local communities. In line with *PLS-Geologia* objectives, it highlights the role of geoscience outreach in citizenship education, risk awareness, and sustainable territorial knowledge.

Geoscience dissemination through laboratory activities, field work and augmented reality

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Keywords: geoscience promotion, interactive labs, field activities.

The environment in which we live is often subject to natural phenomena (e.g., floods, landslides, earthquakes,volcanic eruptions) that can occur as extreme events. These events are becoming more frequent and catastrophic due to the combination of the recent climate crisis and human overexploitation of land and natural resources. In this context, the dissemination and outreach of geosciences may play a crucial role in raising awareness of how our planet evolves, thereby contributing to better preparedness and potentially reducing the impact of future extreme events.To comply with this task, the Department of Earth, Environmental and Resources Sciences (DiSTAR) at the University of Naples Federico II (UNINA) is carrying out an intensive outreach program designed to inform high school students. Some activities are framed under the supervision of the *Scuola Politecnica e delle Science di Base* (SPSB), which coordinates dissemination events promoted by the UNINA. Most dissemination activities are carried out both within DiSTAR and in the field. An interactive laboratory (GEOLAB) has been set-up at DiSTAR, allowing students to explore mountain building, relief evolution, microscope thin sections, water-level variation in aquifers, and rock identification. In addition, students are guided through the laboratories of the DiSTAR to become familiar with different research activities. Field activities includes visits to iconic landforms of the Campi Flegrei, such as the volcano Monte Nuovo, where students apply research techniques, including measurement of surface temperature with a thermal camera. Dissemination also adopts augmented reality and 3D reconstruction, which have been used in the areas of Cuma and Rione Terra.

Overall, more than 1,200 students per year have visited our department over the last four years. They come from high schools across the Campania region, mainly from the metropolitan area of Naples, but we hosted also high schools from other regions (Puglia). To assess the effectiveness of our initiatives, we distributed a questionnaire to first-year students enrolled on the bachelor's degree program at DiSTAR. As a result, we found that around 25% of these students attended our dissemination activities while they were still in high school before enrolling on UNINA geoscience bachelor. This result increases our confidence in the efficacy of the proposed activities and highlights the need for a dissemination plan to secure a primary role of geoscience and geoscientists in the future.

PLS-GEO at the University of Siena

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Keywords: geoscience outreach, field-based learning, science education.

The PLS-Geology program at the Università degli Studi di Siena is developing a structured, interdisciplinary model for geoscience outreach, orientation, and academic support, building on consolidated experience within the Piano Lauree Scientifiche (PLS). The current phase adopts a proactive and scalable approach to strengthen the transition from secondary school to university and to enhance public awareness of geosciences.

Outreach activities are expanding across upper high schools in the provinces of Siena, Arezzo, and Grosseto through interactive presentations, in-class talks, and orientation summer schools focused on Earth Sciences, supported by integrated communication strategies involving school networks and institutional channels.

To extend engagement beyond schools, dissemination actions target public spaces: large, non-permanent posters in transport hubs and strategic urban areas incorporate QR codes linking to video content on geological research and career pathways. A dedicated graphic project includes 20 QR codes connected to 20 short videos, grouped into seven thematic actions (YouTube Shorts: https://www.youtube.com/@geologiasiena4713/shorts), also designed for billboard formats. Videos were produced by undergraduate and PhD students, promoting peer-to-peer communication, and distributed via YouTube Shorts (simultaneous upload) and Instagram Reels (gradual release).

Experiential learning remains central. Laboratory activities at the Department of Physical, Earth and Environmental Sciences are integrated with field experiences at scientifically relevant sites. Recent initiatives include the 2025 excursion to Elba Island, with dedicated video production, and an upcoming (October 2026) excursion to Mount Vesuvius. These are aimed at high school students approaching University, fostering observation, scientific reasoning, and awareness of geoscience careers.

Student support is reinforced through competence self-evaluation tools (USiena Game) and discipline-specific modules linked to placement tests via the OrientAzione portal. For enrolled students, alignment and integrative courses strengthen foundational knowledge and reduce drop-out risk. Teacher training is also central: the interdisciplinary PLS School “La scienza in 4D”, focused on time across disciplines, promotes innovative teaching and cross-disciplinary collaboration.

Overall, the program is evolving into an integrated, multi-level strategy that strengthens the geoscience education pipeline, supports informed enrolment and student progression, and consolidates collaboration between schools and university within a research-driven framework, while highlighting ongoing challenges in sustaining engagement with digital content.

Discovering the geology of the Alta Val Zebrù (Northwestern Italy)

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Keywords: geological mapping, virtual geology, inclusive geology.

A virtual inclusive tour (https://sites.google.com/unimib.it/sentiero-geo-valzebru/home) along the trails of Stelvio National Park in the upper Val Zebrù (Italy), centered on the *Giro del Confinale* loop. This route connects Val Zebrù with Valle dei Forni, passing through the most significant and scenic mountain huts of upper Valtellina. Through seven virtual geological stops ranging from Baita Pastore to the Zebrù Passes, students and teachers can explore the area's unique geological features (Montrasio et al., 2012; Servizio Geologico d'Italia, 2012). Through the website and/or by visiting these points of interest, everyone will have the opportunity to discover and observe rocks that tell the story of ancient tropical islands, extinct volcanoes, and major faults, while also evaluating the effects of global climate warming on Alpine glaciers.

Montrasio A. et al. (2012) - Note Illustrative della Carta Geologica d'Italia alla scala 1: 50.000, F. 024 Bormio. 150 pp., ISPRA - Serv. Geol. d'It., Roma, https://doi.org/10.15161/oar.it/211469.

Servizio Geologico d'Italia (2012) - Carta Geologica d'Italia alla scala 1:50.0000, F. 024 Bormio. ISPRA, Roma.

S36.

Geosciences at School

CONVENERS & CHAIRPERSONS:

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GeoHunters: A game-based learning tool for geothermal energy education

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Keywords: geothermal exploration, game-based learning, public engagement in Earth Sciences.

Geothermal energy, despite being a reliable and widespread renewable resource, is still relatively little known and often perceived as complex or abstract by students. Game-based learning offers an effective way to bridge this gap, making scientific concepts more accessible while fostering engagement, curiosity, and active participation. *GeoHunters* is an educational, team-based serious game designed for primary and secondary schools, workshops, and informal learning settings, targeting students aged 10 to 16.

The game introduces participants to geothermal energy through an immersive simulation that combines scientific reasoning, strategic planning, and collaborative decision-making. Players take on the role of subsurface explorers and geothermal professionals working in teams within a fictional territory. By answering multiple-choice quizzes, they earn in-game resources that allow them to finance geological, geochemical, and geophysical surveys. These investigations progressively reveal clues about underground geothermal resources. Based on the collected data, teams must decide which geothermal installations to build, aiming to maximize economic and environmental benefits while balancing territorial, technical, and regulatory constraints.

Developed by CNR-IGG as part of its research and outreach activities, *GeoHunters* addresses the need to improve awareness and understanding of geothermal energy - one of Italy's most distinctive yet often underestimated renewable resources. The game highlights the diversity of geothermal technologies and applications, from electricity generation to heating and cooling for buildings, districts, and industrial processes, emphasizing how different uses require specific temperature ranges and geological conditions.

The activity unfolds in three main phases: knowledge acquisition through quizzes, strategic planning of exploration surveys using a map-based approach, and interpretation of results to support final decision-making. This structure mirrors real scientific and professional workflows, allowing students to experience key steps of geothermal exploration and development in a playful but scientifically sound way.

GeoHunters supports learning objectives related to Earth Sciences, renewable energy, and the energy transition, while fostering transversal skills such as critical thinking, data interpretation, collaboration, problem solving, and resource management. It can be used as a complement to curricular modules on geothermal energy or within broader educational paths focused on active citizenship and sustainability. The game has no specific prerequisites, features adjustable difficulty levels, and can be completed in 30-50 minutes, making it flexible and accessible across different educational contexts.

Reconstructing Earth's past through the study of rocks and fossils: A PLS laboratory experience between schools and universities

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Keywords: school collections, optical microscope, students and teachers.

As part of the Scientific Degree Plan (PLS) - Geology 2023-2025, the University of Camerino (School of Science and Technology, Geology Section) has developed, in collaboration with the "E. Medi" Scientific High School in Senigallia (AN), a laboratory-based educational project aimed at fifth- and third-year high school students majoring in Applied Sciences. The initiative is part of an active agreement between the two institutions and aims to strengthen a conscious orientation towards geological disciplines and, more generally, STEM subjects. The project was divided into two activities aimed at school science teachers, regarding: (i) the use of the polarizing microscope; (ii) rock formation environments in relation to different geodynamic contexts; and (iii) the organization of the school's geo-palaeontological collection. Each involved class also participated in three dedicated activities: (iv) a workshop on igneous and metamorphic rocks, including macroscopic recognition, classification, and an introduction to the use of the polarizing microscope on thin sections; (v) a workshop on sedimentary rocks, focused on reconstructing depositional environments and palaeoclimatic conditions; (vi) a workshop on fossilization processes, with analysis of representative samples and discussion of the preserved palaeoenvironmental information. The activities were conducted using the school's rock and fossil collection, supplemented by instrumentation and materials provided by the university. The methodological approach adopted was inquiry-based, with a strong emphasis on learning by doing and the development of observational and interpretive skills. Students were asked to deduce the tectonic environments in which the rock samples were formed, such as ocean ridges or subduction zones, and engaged in simulations of the various phases of a palaeontological investigation, from specimen identification to accumulation processes, and finally to palaeoenvironmental and palaeoclimatic interpretation. The effectiveness of the program was evaluated through questionnaires and structured observations. The results showed an improvement in lithologic recognition skills and understanding of the main geological processes involved in the formation of different rock types. Furthermore, most students reported an increased interest in geosciences. Teachers highlighted the effectiveness of integrating laboratory activities with theoretical content, as well as the value of direct interaction with the university context. The project confirms the strategic role of school-university collaborations in promoting authentic scientific skills and informed guidance, proposing a replicable model for teaching geosciences based on direct experience and the use of specialized instrumentation.

Discovering geology through history, territory and senses. An educational experience between imperial marbles, cosmatesque mosaics and...”smelled” rocks in Rome

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Keywords: geoscience education, experiential learning, cultural heritage.

Pushing gen-Z students from scientific high schools to chose Geology as academic path is a big challenge in Italy. Pushing students who attend non scientific high schools, or who are less likely to follow an academic career at all, to learn and like Geology for life is even a bigger, and much more pivotal, challenge. As a bio-anthropologist and school teacher in a suburban professional school in Rome, I believe in the needed effort to bring science, curiosity and knowledge about the sourrounding world to youngsters who are, or are commonly represented as, those with fewer higher education opportunities. Under this perspective, I organized a school outdoor activity, which I present in this occasion, on the discovery of different types of rocks through the discovery of roman history and territory. The activity was taylored on 15 years old students with no or little expertise in Geology and roman hystorical heritage. We visited the “Santarelli polychrome marbles collection” in Musei Capitolini to appreciate live igneous, sedimentary and metamorphic rocks described in books, as Romans imported different kinds of them from the Near East and North Africa to decorate villas. We then visited the nearby Basilica San Clemente to see those same colorful rocks in the cosmatesque floor mosaics, as medieval sites were built fragmenting and re-shaping ancient roman construction material. This represented an easily reproducible opportunity to introduce students to rock cycle in Geology and to that of materials across history, and to connect citizens of peripheral areas to the city centre art heritage. Nonetheless, a spontaneous and unexpected students’ reaction in front of rocks brought the attention on how much physicality and...”senses” are core aspects to consider for a sucessful educational process, in Science and beyond.

The synergy of Earth and life: ISPRA's multidisciplinary approach to linking geo- and biodiversity in geoscience outreach

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Keywords: geoscience, outreach model.

As a multidisciplinary technical-scientific institution, ISPRA is uniquely positioned to promote a holistic understanding of the territory, where the study of the geological environment is naturally interconnected with biological and historical research. This contribution presents ISPRA's outreach model, which moves beyond a traditional compartmentalized view of science to highlight the intrinsic link between geodiversity and biodiversity.

The integrated strategy is developed through the Passeggiate geologiche (Geological walks) and its participation in national dissemination initiatives such as the Settimana del Pianeta Terra, Festival delle Scienze di Roma, Settimana della Scienza and the Giornata Nazionale delle Miniere. By focusing on almost protected areas like the Saline di Tarquinia (Viterbo) and Tor Caldara Nature Reserves (Rome), and the Allumiere and Tolfa mining district (Rome), these activities demonstrate how the geological substrate serves as the essential foundation for single ecosystems and human story.

A significant focus is dedicated to coastal dynamics and marine biology, where the study of the Quaternary evolution of environments like the La Frasca beach (Viterbo) allows the public to understand the deep connection between coastal geology and the preservation of marine ecosystems. This narrative approach transforms the perception of geology from a "curiosity" into a fundamental science for understanding the natural cycles that connect surface and deep-sea environments.

The basis of this approach is also the production of multimedia reportages (https://www.isprambiente.gov.it/it/progetti/cartella-progetti-in-corso/divulgazione-scientifica/settimana-del-pianeta-terra-1/reportage), a series of video documentaries designed to describe the complexity of the Italian landscape. By combining on-site interaction through field excursions - ranging from the fluvial ecosystems of the Tiber River to ancient mining sites of Allumiere area - with digital documentation, ISPRA promotes engaging and socially relevant geological and environmental culture. This framework is fundamental for increasing scientific literacy and encouraging new generations to adopt environmental awareness and sustainability.

Geo2EAS: Episodes of Situated Learning (ESL) as active learning of Geophysics and Geology

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Keywords: natural risk reduction, Episodes of Situated Learning (ESL), lifelong learning.

To enhance learning and positively impact student engagement, while strengthening the educational relationship between teachers and students, our experience has shown that Episodes of Situated Learning (ESL; EAS in Italian; Rivoltella, 2013) constitute an effective method. Over the past ten years, the Istituto Nazionale di Geofisica e Vulcanologia (INGV) has tested that ESLis an innovative and meaningful approach to natural risk reduction plan for schools. ESL, on the basis of the flipped class model, is a participative methodology in which students develop a digital product as a final result of an active learning process. The main aim of the ESLes designed by INGV researchers is to spread core concepts on geophysical and geological phenomena (earthquakes, tsunamis, floods and landslides, etc.), stimulating students to implement first hand effective products to communicate what they have learnt on natural risk reduction, both with their peers and with adults. Students had the opportunity to interact with researchers and, for a short period of time, to become researchers themselves through cooperative learning activities. This collaborative relationship between students and scientists enabled the sharing of scientific knowledge and the access to databases from which students gathered data to design artefacts aimed at disseminating key scientific concepts (Piangiamore & Maramai, 2024). This experience involved about 5000 students from both middle (ISCED 2) and high schools (ISCED 3) from all over Italy, always welcomed with great interest from both students and teachers, even in remote learning during the pandemic and during online special scientific events (European Researchers' Night, World Water Day, World Earth Day and World Ocean Day). Within this framework, Geo2EAS, a new INGV project developed in collaboration with the University of Pavia, has recently been launched. The project focuses on Earth Science teacher training and is funded by the latest Ministero dell'Università e della Ricerca-DCS call for the Dissemination of Scientific and Technological Culture. Geo2EAS will develop a teacher training involving ESL experts through digital laboratory activities and a summer school for teachers on the use of the ESL method, promoting multidisciplinary studies and mutual exchange. The materials produced will support teachers in actively introducing a wide range of topics into the classroom such as: Geoscience, Environmental Geophysics, Geomagnetism, Polar Aurora, Antarctica exploration, Climatology, Natural Risk, Climate Change, Environmental Sustainability, Anthropisation, Land Use, Landscape and Geomorphology, Geology, Anthropocene debate, Women in Science, Myths and the Origin of the Earth. Finally, to facilitate their dissemination and classroom implementation, the EASes will be collected in an illustrated book and in an e-book edition in both Italian and English, adding also teaching notes and commentary for educators.

Piangiamore G.L. & Maramai A. (2024) - When the Past Teaches the Future: Earthquake and Tsunami Risk Reduction through Episodes of Situated Learning (ESL). Geosciences, 14, 65, https://doi.org/ 10.3390/geosciences14030065.

Rivoltella P.C. (2013) - Fare Didattica con gli EAS - Episodi di Apprendimento Situato. Ed. La Scuola SEI, 256 pp.

From ocean connections to Ocean Literacy: A teaching experiment with high school students

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Keywords: ocean literacy, ocean connections, high school students.

The Ocean Literacy movement originated in the United States in the early 2000s with the aim of promoting a widespread understanding of the ocean and its multiple interactions with human activities by the end of the education cycle. Over time, this movement has expanded globally, broadening its focus from knowledge acquisition to a more comprehensive framework that also includes emotional, experiential, and cultural dimensions.

Among these, personal connections to the ocean have proven particularly effective in fostering environmentally responsible behaviours, in line with the Sustainable Development Goals of the UN 2030 Agenda and the UN Decade of Ocean Science for Sustainable Development (UNESCO-IOC, 2021).

Building on a previous study conducted with students from the coastal area of Friuli Venezia Giulia (Realdon et al., 2026), we designed and implemented an educational intervention based on the concept of ocean connection. The project involved two groups of students from Monfalcone (Gorizia), a town characterized by a strong multicultural presence, including a large Bengali community employed in the local shipbuilding industry. One group attended a vocational high school and consisted mostly of students with migrant backgrounds, while the other group attended a liceo high school and was predominantly composed of students from Italian families.

The intervention consisted of a five-day extracurricular, theory-practice workshop involving a multi-class group of students interested in marine topics. Prior to the workshop, students completed an exploratory prompt ("What is the sea for you?"), along with a pre-test assessing knowledge (both groups) and, for the liceo group, attitudes and behaviours. A post-test was administered at the end of the intervention.

The educational activities were based on hands-on, inquiry-oriented learning inspired by the seven principles of Ocean Literacy (Realdon, 2023a; 2023b). In addition, the vocational school group participated in a coastal fieldwork experience.

Results show patterns of connection similar to those identified in the previous study, with emotional and descriptive responses being the most frequent, alongside some differences between the two groups. Initial knowledge levels were higher in the liceo school group, which was already engaged in a marine-focused project. However, both groups demonstrated a significant increase in knowledge in the post-test. The high school group also showed improvements in attitudes and behaviours toward the marine environment.

These findings suggest that an educational approach centred on fostering connections with the ocean can be effectively adapted to diverse educational settings, age groups, and even inland contexts.

Realdon G. (2023a) - Practical ocean literacy for all: Earth science. Science in School, 63, https://www.scienceinschool.org/article/2023/practical-ocean-literacy-earth-science/.

Realdon G. (2023b) - Practical ocean literacy for all: ecology and exploration. Science in School, 64, https://www.scienceinschool.org/article/2023/practical-ocean-literacy-ecology-and-exploration/.

Realdon G. et al.. (2026) - Ocean Literacy Beyond Knowledge: Investigation of Ocean Connections Among a Sample of Italian School Students. Sustainability, 18(9), 4223, https://doi.org/10.3390/su18094223.

UNESCO-IOC(2021) - Ocean Literacy Framework for the UN Decade of Ocean Science for Sustainable Development 2021-2030. IOC Ocean Decade Series, 22 (78), https://unesdoc.unesco.org/ark:/48223/pf0000377708.

The Content of Earth Sciences in Science Textbooks for Calabrian Elementary Schools

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Keywords: earth sciences, textbook, experimental activities.

This study analyzes the approach taken to Earth Science content and its respective experimental activities in science textbooks adopted in elementary schools in the province of Cosenza, Calabria (municipalities of Fiumefreddo Bruzio, Belmonte Calabro, and Longobardi). The qualitative and documentary research examined six science textbooks for the 4th and 5th grades for the 2025-2026 school year. The results reveal a significant underrepresentation of the area: Earth Science content occupies only between 7% and 8% of the total volume of the books, while specific experimental activities in this field represent a mere 2% of the total experiments proposed. A predominance of content and experimental activities related to the teaching of Physics and Chemistry was identified. The presence of Earth Science topics in a fragmented manner across the disciplines of History, Geography, and Biology was also identified, hindering student comprehension and leaving the teacher with the task of articulating all these contents. Furthermore, the activities proposed by textbooks lack an investigative character, limiting themselves to memorization or verification of simplified concepts. Given this scenario, what are the possible paths to overcome these deficiencies in elementary school (grades 1-5)? This article proposes a collaborative work methodology between researchers and teachers through the monitoring of activities in science classes throughout the school year, the exchange of knowledge, and the continuing professional development of teachers in the field of Earth Sciences. The objectives encompass the development of investigative experimental activities contextualized to the local reality and the Calabrian territory (addressing topics such as hydrogeological, volcanic and seismic activity-related risks, minerals and rocks, geological time scale and geological formation of the Calabrian territory), the continuing education of teachers in Earth Sciences through modules of practical content knowledge in accordance with the new Italian national curriculum guidelines and the encouragement of STEM education.

Shaping environmental technicians: A transdisciplinary Master's model for bridging geoscience and professional practice

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Keywords: environmental-technician, geo-hazards, sustainability.

Modern environmental challenges demand professionals who can connect companies, public institutions, and the territory. Traditional academic curricula often fail to integrate hard sciences with the regulatory and technical skills required by the job market. To fill this gap, the University of Calabria offers the 2nd Level Master's "Methodologies and Techniques for Environmental Protection and Management" (META), now in its second edition, funded under Territorial Agreements for advanced training in companies (Art. 14 bis, D.L. 152/2021) - CUP H22C24000120001. The program trains "Environmental Technicians" - versatile experts capable of managing interactions between human activities and ecosystems. Its transdisciplinary curriculum combines environmental geochemistry, geothermics, water treatment, petrography, geobiology, and mineralogy. A distinctive feature is the focus on often-overlooked geo-environmental health hazards, including dedicated modules on "Asbestos and Health" and "Natural Radioactivity/Radon". These are complemented by training in data processing, geostatistics, GIS-based spatial analysis, and a comprehensive overview of European and Italian environmental legislation. Teaching uses a blended learning approach to support professional development. The program culminates in a mandatory internship (part of the 1500-hour workload) within companies, where students directly apply skills such as designing monitoring networks for water, soil, and air pollution, and planning remediation interventions. We present this educational model as a case study for higher education in geosciences.

The Planet in one room: The EARTH LAB of Earth Science Department of Pisa

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Keywords: geoscience education, lifelong learning, STEM education.

In the last decade an increasing awareness is growing in academic institutions regarding (1) the need to cultivate cooperation with school, and (2) the need to provide school and academic teachers with effective didactic tools for Earth Sciences. Fostering the cooperation and reciprocal understanding between Universities and Schools is particularly necessary for Geosciences, often marginalized at school among the Natural Sciences. In this framework, at the Earth Science Department of University of Pisa, a room, which we named EARTH LAB, has been dedicated specifically to the aim of welcoming and empowering activities for schools, as well as for Lifelong Learning, professional development, and as an additional opportunity for university courses.

Earth Lab is furnished with didactic models which can be used, by teachers or with the aid of researchers, in presence or remotely, to clarify geological and environmental concepts, intended to span the spectrum of Earth sciences. Portable collections of minerals and rocks can be asked by teachers, together with the support to use them effectively at school. Digital tools, videos, 3D viewers with didactic purposes are also available. The walls host modular panels showing photographs of geological subjects and activities collected by the Earth Science Department's researchers, designed not only to disseminate Geosciences to the general public, but also to support flexible and interactive teaching activities.

More than simply a room, Earth Lab is an opportunity for every school and university teachers and students to meet and grow together in understanding and value the Earth Planet.

Earth Science for everyone: The Nirano Mud Volcanoes (Fiorano Modenese, Italy) as an open-field laboratory for environmental and geological awareness

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Keywords: environmental geology, mud volcanoes, open-field laboratory.

Mud volcanoes (MVs) represent a fascinating manifestation of "sedimentary volcanism". Characterized by the ascent of deep-seated mud and water driven by gases, these geological phenomena mimic the shape of igneous volcanoes while offering a completely unique setting. In Italy, the Nirano Mud Volcanoes (NMV) field, known as the "Salse di Nirano" Natural Park, stands out as one of the most extensive and significant systems. Historically, intense scientific research—ranging from hydrocarbon prospection to earthquake precursor monitoring (Ferrari et al., 2026)—has characterized this area, establishing it as a prime reference in literature for worldwide studies (Antunes et al., 2022).

This work highlights the NMV field as an inclusive, multi-disciplinary, open-air laboratory accessible to the general public—spanning curious children, student groups, and lifelong learners. Geology is too often perceived as a static, textbook subject, whose changes are difficult to observe and comprehend due to the vast differences in time scales. At Nirano, however, visitors can witness firsthand how dynamic geological forces actively shape the landscape and dictate local biodiversity. The hypersaline conditions generated by the mud emissions create a unique micro-environment, beautifully demonstrating how tightly geology and nature are intertwined.

To bridge the gap between society and science, hands-on educational activities have been developed following a multi-level approach. The University of Ferrara serves as a perfect example: each year, geology master's students put into practice a complete geochemical workflow. Beginning with in-situ screening (measuring temperature, pH, and electrical conductivity), they learn the rigorous protocols required for correct and representative sampling of fluids, muds, and sediments to avoid contamination. Back in the laboratory, students engage in sample preparation and advanced analytical techniques, utilizing XRF for major and trace element bulk geochemistry, and EA-IRMS to determine stable isotope compositions, which are crucial for fingerprinting the origins of fluids, organic matter, biogeochemical and geological interactions.

In parallel, younger explorers and families can safely "get their hands dirty" under the supervision and guidance of the personnel of the park. Through interactive field experiences—such as using simple portable probes to check water salinity or observing gas bubbling—participants of all ages can unravel the secrets of the Earth's crust, fluid circulation, and fault formations. Ultimately, utilizing the Nirano open-field laboratory fosters a deeper environmental awareness, proving that earth science is not just for scientists, but a fundamental tool for understanding and protecting our planet.

Antunes V. et al. (2022) - Insights into the dynamics of the Nirano Mud Volcano through seismic characterization of drumbeat signals and V/H analysis. J. Volcanol. Geotherm. Res., 431, 107619, https://doi.org/10.1016/j.jvolgeores.2022.107619.

Ferrari E. et al. (2026) - Multidisciplinary monitoring of mud volcanoes: a new perspective on fluids and seismicity link from the Salse di Nirano (Italy). Nat. Hazards, 122(7), 311, https://doi.org/10.1007/s11069-026-08071-3.

From classroom to field: A professional Master's pathway for managing naturally occurring asbestos in geo-environmental risk

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Keywords: naturally occurring asbestos, water and soil contamination, professional master's education.

Naturally Occurring Asbestos (NOA) in ophiolitic rocks can release fibers into water, soils, and air through weathering - yet exposure pathways via water and soil are often overlooked compared to airborne monitoring. Waterborne and soil-borne asbestos pose significant risks, as fibers can later become airborne in domestic and occupational settings, and no safety threshold exists for water or soil. To address this skill gap, the University of Calabria has developed the 2nd Level Master's "Methodologies and Techniques for Environmental Protection and Management" (META), under Territorial Agreements for advanced training in companies (Art. 14 bis, D.L. 152/2021) - CUP H22C24000120001. The programme trains "Environmental Technicians" capable of managing risks at the interface between human activities and ecosystems. META is practice-oriented, combining blended learning with a mandatory internship where students apply skills such as pollution monitoring network design and remediation planning. Its transdisciplinary curriculum integrates geosciences with targeted modules like "Asbestos and Health", focusing on NOA management. Students learn field identification of asbestos minerals, laboratory analysis, fibre dispersion modelling, and regulatory risk assessment, filling a critical educational void. As geo-environmental hazards grow in frequency and complexity, META offers an effective model for building a disaster risk management (DRM) workforce that bridges science, technical skills, and regulation.

From critical raw materials to classroom engagement: An interactive FSL experience in geoscience dissemination

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Keywords: geoscience communication, critical raw materials, FSL.

The increasing demand for critical raw materials required for the energy transition has renewed attention toward mining and georesources. However, these topics are often poorly represented in secondary school education and commonly associated only with environmental impacts. Improving awareness of the role of geosciences in sustainable development is therefore essential, particularly among younger generations. Within the framework of FSL (Formazione Scuola-Lavoro) activities, we developed an interdisciplinary dissemination and orientation program aimed at introducing secondary school students to georesources, mining sustainability, and the professional role of geologists through an interactive approach. The program was founded by PNRR, Mission 4, with the title: “PNRR pathways: active orientation in school-university transition”, designed for students enrolled in the third, fourth or fifth year of upper-secondary school. The activities have a duration of 15 hours, of which at least two thirds must be held in person, for groups of at least 20 students. The program included seminars, laboratory activities, guided discussions, multimedia content, Google Earth-based exercises, and visits to university research facilities. The project was designed to promote active participation and dialogue between researchers and students, linking geological topics with environmental, economic, and social issues. To date, the initiative has involved 25 secondary school classes and more than 450 students. Anonymous post-activity questionnaires showed an overall highly positive response. Students particularly appreciated the laboratory visits, hands-on experiences, and direct interaction with researchers and university facilities. Feedback also highlighted the importance of an engaging and informal communication style in maintaining attention and stimulating curiosity, even among students initially unfamiliar with geosciences. The results demonstrate that integrating sustainability, raw materials, and applied geosciences into interactive educational activities can significantly improve student engagement and contribute to a more informed perception of mining and georesources, while also supporting orientation toward STEM disciplines.

From students to students: Developing ideas for sustainable geo-tourism in Friuli Venezia Giulia leveraging AI as a co-thinking tool through the rule "Think-Talk-Check-Craft"

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Keywords: sustainable tourism, AI.

An educational project conducted in small groups by students from the "N. Copernico" Liceo Scientifico in Udine to develop innovative ideas for sustainable tourism that enhances the Friuli Venezia Giulia region. A rigorous protocol was adopted for the use of Artificial Intelligence, intended as a "dialogue partner" and not a substitute for critical thinking. Students were trained to follow the "Think-Talk-Check-Craft" methodology for each phase of the project, as proposed by the journal "Science in School" (Issue 77, April 17, 2026).

From global investigation to teaching: A scientific communication model emerging from the IODP experience

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Keywords: IODP, RET, scientific ocean drilling.

The International Ocean Discovery Program (IODP) represents one of the longest-running and most influential international geoscience research infrastructures. Over more than sixty years of scientific ocean drilling, the program has produced an unparalleled archive of geological, geophysical, and paleoenvironmental data, contributing fundamentally to the understanding of plate tectonics, paleoclimate evolution, and Earth system processes. Alongside its scientific mission, IODP has progressively developed a broad Education and Public Outreach (EPO) strategy aimed not only at disseminating results, but also at involving educators directly in authentic scientific practices.

This contribution presents the experience of the 2025 Ocean Core Teacher-Researcher and Curriculum Experience (TracX) workshop, hosted at the Gulf Coast Repository of Texas A&M University. The workshop brought together teachers, researchers, technicians, and educators within one of the three major IODP Core Repositories, where ocean drilling cores and related datasets are preserved and continuously studied. Participants worked collaboratively on authentic scientific datasets, sediment cores, and X-ray analyses while simultaneously designing educational activities for secondary school students.

The paper discusses TracX as an example of the Research Experiences for Teachers (RET) model, previously developed in polar and ocean drilling projects, in which teachers become temporarily embedded within research environments. In this framework, scientific data are not treated as simplified educational illustrations, but as the central operational object shared by researchers and educators alike. The same datasets used to formulate scientific hypotheses and reconstruct geological processes become the starting point for inquiry-based educational activities and scientific communication.

A specific case study focused on the interpretation of X-ray images from sediment cores collected during IODP Expedition 341 (Gulf of Alaska). The resulting educational activity produced with the help of AI, used grayscale analysis of radiographic images to guide students toward the interpretation of sediment density variations, depositional environments, and ice-rafted debris processes. The activity illustrates how authentic scientific practices can be translated into accessible and meaningfull educational experiences without reducing the complexity of the underlying science.

The IODP experience suggests that research infrastructures and Core Repositories can function not only as scientific archives, but also as cultural and educational environments where scientists and educators collaboratively build new forms of geoscience communication grounded in data, inquiry, and shared interpretation.

The Rocca di Papa Museum of Geosciences (MuGeos) of the National Institute of Geophysics and Volcanology (INGV) as a space to guide teachers toward innovative and inclusive teaching: The example of ERASMUS+ A.C.I.I.S

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Keywords: geoscience, school, inclusion.

The Geoscience Museum of Rocca di Papa (MuGeos) promotes scientific dissemination and education as part of the Third Mission of the National Institute of Geophysics and Volcanology (INGV), aimed at spreading scientific knowledge. Founded in 1886 as a Geodynamic Observatory as a consequence of 1883 devastating Casamicciola earthquake, the MuGeos is located 30 km south of Rome, in the center of the Colli Albani volcanic district, a quiescent volcanic complex whose last eruptive activity dates back to about 20.000 years ago. Since 2022, MuGeos has carried out activities for both students, teachers and generic public. In January 2026, MuGeos welcomed 34 participants to an international training course entitled "Drama for Learning Science - the Science Playground" within the framework of the Erasmus+ A.C.I.I.S. (Academy for Creative, Innovative and Inclusive Schools) project. The group consisted of primary and secondary school teachers from Austria, Poland, Slovenia, Croatia, and Italy. The INGV researchers and technologists involved in the training presented various activities to be replicated in the classroom, with the aim of transferring knowledge of Geosciences in an innovative and inclusive way through Theater, Scientific Narrative and Geomythology, Music, Laboratories and Educational Games, and MuGeos Museum Equipment. Theater was proposed as a tool for knowledge and innovative synergy between Earth Sciences and Performing Arts to transform abstract scientific concepts into sensory experiences, breaking down cognitive, sensory, and linguistic barriers in line with the philosophy of "Inclusive Schools", because this method also allows students with Special Educational Needs (SEN) and disabilities to access scientific knowledge through alternative communication channels instead of the purely logical-verbal one. The Kamishi-Bai technique (Japanese paper drama) was proposed for the first years of primary school and applied to the knowledge and mitigation of seismic risk. Music is a universal language understood by everyone; through it, the laws of physics become understandable and accessible without using mathematical formulas, explaining earthquakes through the analogy between seismic waves and sound waves. Game-based learning was also proposed as a powerful educational tool; from the early years of life to more advanced ages, it retains its formative value, transforming into a universal language capable of engaging, teaching, and stimulating curiosity.

Minerals in Your Life: Geoscience outreach for a sustainable future

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Keywords: geoscience education, critical raw materials, sustainable development.

In recent years, the topic of mineral raw materials has returned to the center of international debate, not only because of the geopolitical and economic implications related to resource supply, but also due to the strategic role minerals play in the energy transition and in the development of sustainable technologies. Nevertheless, despite their constant presence in everyday life, minerals often remain "invisible" in public perception, especially among younger generations. Mobile phones, computers, electric vehicles, wind turbines, photovoltaic panels, medicines, paints, buildings, and even books themselves are the result of a long supply chain that begins with geological resources and mining activities.

Starting from these reflections, the outreach volume *Minerals in Your Life* was developed within the scientific communication activities promoted by the experts of the European Geological Surveys gathered in EuroGeoSurveys (2014). Ten years after the publication of the first edition, the book has been updated to reflect the profound changes that have occurred in the relationship between society, technology, and mineral resources, particularly in the framework of the European Green Deal, the energy transition, and the growing demand for critical and strategic raw materials required to achieve climate goals by 2050.

This contribution presents the second edition of the book as an innovative geological outreach tool aimed at schools. The volume combines scientific content, descriptive cards dedicated to minerals and materials, historical references, curiosities, and accessible language designed for students, with the goal of bringing younger generations closer to geosciences and sustainability issues. Alongside the mineralogical descriptions, a comic strip accompanies readers in discovering the "silent" presence of minerals in everyday life through the adventures of three characters — Gaia, Norman, and Lucy — who symbolically represent the relationship between environment, technology, and society.

The adopted approach aims to overcome the traditional perception of mining activities as something distant or exclusively environmentally impacting, instead showing how geological resources constitute the indispensable material foundation of contemporary civilization and future green technologies. Scientific outreach in schools therefore represents a fundamental tool for fostering greater awareness of the role of geology in sustainable development, of the importance of raw materials for the energy transition, and of the need to combine technological innovation, environmental protection, and intergenerational responsibility.

EuroGeoSurveys (2014) - Minerals in your life. EGS Publ., ISBN-10: 9090281479.

Digital geosciences in the field: An outdoor learning experience along the Ticino River

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Keywords: digital geosciences, outdoor learning, Ticino river.

Outdoor education practices are increasingly recognized as key components of both teaching methodologies and professional training, promoting experiential learning through activities carried out beyond the traditional classroom and in direct interaction with natural, cultural, and social environments. Previous research has shown that field-based activities can significantly enhance students' interest, engagement, and overall satisfaction when compared with conventional classroom instruction.

Within this framework, the present study describes the design of an educational nature trail along the urban stretch of the Ticino River in Pavia and the Via Francigena, with the aim of investigating the educational potential of outdoor education in geoscience teaching. The project seeks to foster meaningful, participatory, and interdisciplinary learning about fluvial environments, while also encouraging the development of transferable skills, active citizenship, and environmental awareness.

The proposed itinerary extends for approximately 2 km, starting from the Covered Bridge of Pavia and continuing westward along the Borgo Ticino riverbank. The trail includes nine thematic stops dedicated to geosciences, botany, zoology, ecology, human-environment interactions, and the historical evolution of the city. To support the educational experience, a digital platform developed through Google My Maps provides route tracking, points of interest, multimedia resources, and teaching materials.

The integration of direct field experience with digital tools, together with structured educational worksheets containing learning objectives and follow-up activities, enables teachers to act as active facilitators of the learning process, thereby enhancing the effectiveness of outdoor education in geoscience education.

The new Italian National Guidelines: An opportunity to foster Earth Sciences in upper secondary schools

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Keywords: Earth science education, upper secondary school, STEM.

Earth Sciences are often marginalised within the broader framework of Natural Sciences education. In many school contexts, biological topics receive greater attention, while geological processes, Earth system interactions, and environmental dynamics are treated as secondary subjects. This imbalance is significant because Earth Sciences represent one of the most interdisciplinary and STEM-oriented branches of Natural Sciences, integrating mathematics, physics, chemistry, environmental modelling, spatial reasoning, data analysis, and systems thinking. At the same time, global challenges such as climate change, natural hazards, energy transition, resource management, and sustainability increasingly require citizens capable of understanding complex Earth systems. Recent studies highlight how geoscience education plays a central role in promoting sustainability competencies and scientific literacy, while remaining underrepresented in school curricula and teacher education pathways (Metzger, 2024; Ribeiro et al., 2025).

Despite their educational potential, Earth Sciences are still frequently perceived by teachers as a minor component of Natural Sciences. Research has shown a progressive decline in the visibility and curricular relevance of Earth Science education, despite its importance for sustainability education and informed citizenship. One possible reason is that many science teachers do not possess a specific geological background and may therefore feel less confident in addressing geoscientific topics through inquiry-based or laboratory-oriented approaches (Gravina & Iannace, 2023). Consequently, the STEM potential of the discipline often remains underexploited in classroom practice.

The recent launch of the new Italian National Guidelines represents an opportunity to strengthen the role of Earth Sciences within secondary education. However, this opportunity can only be fully exploited through targeted professional development initiatives aimed at non-specialist teachers and teachers with a geological background. Teacher training should reconsider excessive disciplinary fragmentation and partially remodel traditional content-oriented approaches in order to better demonstrate how Earth Sciences can foster systems thinking, problem solving, critical reasoning, sustainability awareness, and interdisciplinary STEM competencies among students (Metzger, 2024). This also requires reflection within the national geological community on which contents, methodologies, and laboratory activities are most meaningful for school education and how they can be disseminated among present and future generations of teachers. A possible model for innovative teaching activities is proposed by Gravina and Iannace (2026), whose action-research study highlights curriculum design in Italian upper secondary schools can strengthen disciplinary understanding and transversal STEM competencies while increasing teachers' confidence in addressing Earth system topics.

Gravina T. & Iannace A. (2023) - Earth science teaching in Italian upper secondary school: The floor to Natural Science teachers. In: The Geoscience paradigm: resources, risk and future perspectives. Abstract Volume, Joint Congress of Società
Geologica Italiana (SGI) and Società Italiana di Mineralogia e Petrologia (SIMP), 19-21 settembre 2023, Potenza, Italy.
Gravina T. & Iannace A. (2026) - Supporting Earth Science Teaching through Curriculum Design: An Action Research Study in Italian Liceo Schools. EGU26-4004, Copernicus Meetings, Vienna, Austria, 3-8 May 2026.
Metzger E.P. (2024) - Reimagining Geoscience Education for Sustainability. Earth Sci. Syst. Soc., 4, 10116.
Ribeiro T. et al. (2025) - Earth System Science and Education: From Foundational Thoughts to Geoethical Engagement in the Anthropocene. Geosciences, 15(6), 224.

Evaluating the impact of a summer school on Earth Science teaching practices

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Keywords: Earth Science education, upper secondary school, teacher survey.

This paper presents the design, implementation and evaluation of a Summer School aimed at upper secondary school teachers of Natural Sciences, with a specific focus on Earth Science education. The programme combined disciplinary seminars and laboratory-based activities with the presentation of ready-to-use teaching resources explicitly designed for classroom implementation.

To investigate the impact of the Summer School, a follow-up study was conducted through two questionnaires administered at mid-school year and at the end of the school year. The data collection focused on the teaching activities that participants reported having implemented after the training, rather than on general perceptions.

Findings show that many teachers introduced changes in their classroom practices by adopting or adapting the proposed activities, suggesting that the availability of structured materials can support the transfer of training into practice. At the same time, the data point to a structural constraint related to content selection within Natural Science departments, which can limit the inclusion of Earth Science topics despite their presence in national guidelines. These results provide indications for the design of future teacher training initiatives, particularly in view of the upcoming implementation of the new national guidelines for Liceo and the reform of Technical Institutes, where a more systematic integration of Earth Sciences will be required.

Educational spaces to explore the geothermal resources of the Aeolian Islands: The IRGIE project experience, an example of collaboration between researchers and teachers

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Keywords: geothermal energy education, researcher-teacher collaboration, geo-resources awareness.

The role of geosciences in recent years has increasingly focused on raising social awareness of the reciprocal influence between Earth's processes and resources and human actions, with the goal of guiding communities toward a respectful and responsible relationship with the planet. In this sense, the scientific community, in collaboration with the educational system, can provide a significant contribution to conveying this message and spreading the culture of Earth Sciences.

Here, we present the educational actions developed in the framework of the IRGIE project (Inventory of Geothermal Resources of the Aeolian Islands), led byINGV and funded by the *Regione Siciliana*, with the aim of increasing public knowledge and awareness of geothermal energy, with the long-term goal of promoting strategies aimed at achieving the energy independence of the Aeolian Islands.

In this perspective, IRGIE project represents a good example of educational pathways based on close collaboration between the research community and the school system and dedicated to geothermal energy and the heat of the Earth. Primary and secondary schools across the Aeolian archipelago were involved in the project, offering teachers educational pathways focused on exploring geothermal resources and their sustainable use, while valuing teachers' role as educational experts. These pathways, were designed with the following objectives:

- to promote the learning of fundamental concepts related to geothermal energy, stimulating scientific curiosity and awareness of the energy resources available in the local territory among students;
- to encourage the development of critical thinking regarding the risks, benefits, and sustainability aspects connected with the use of natural resources;
- to strengthen active collaboration among teachers, students, families, and the scientific community.
- The educational program, based on consolidated teaching methodologies used for natural risk reductio (https://www.edurisk.it/), was structured around several key elements:
- teacher training, preparatory to the educational activities, with the support of INGV researchers;
- active involvement of teachers in designing the pathways, in order to integrate scientific content with the specificities of the individual classes;
- a multidisciplinary and interdisciplinary approach, which allows the integration of geothermal themes with curricular subjects such as science, geography, civic education, history, and technology;
- the development of didactic tools for different school levels and grades.

The IRGIE Project represents a concrete example of how an educational methodology, initially designed and tested for different topics, such as geological risks, can be effectively transferred and adapted to communicate and promote other themes within the geosciences, such as geothermal energy.

Teaching the nature of science through the historical debate on impact craters

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Keywords: nature of science, history of geology, impact craters.

The history of the recognition of the meteoritic origin of Barringer Crater (Arizona, USA) represents an effective educational framework for teaching both the scientific method and the Nature of Science (NOS) through the history of Geology. The proposed didactic pathway reconstructs the scientific debate surrounding the crater origin, from the first geological surveys in the late nineteenth century to the definitive confirmation of the impact hypothesis through the discovery of shock minerals such as coesite and stishovite in the 1960s (Kring, 2017).

The case effectively illustrates how Science develops through competing hypotheses, reinterpretation of evidence, debate, and technological advances. Grove Karl Gilbert interpreted the crater as volcanic after geophysical measurements failed to reveal a buried iron mass, whereas Daniel Barringer argued for an impact origin based on geological observations and meteoritic fragments distributed around the crater (Kring, 2017). In 1929 Barringer consulted astronomer Forest Ray Moulton, who agreed on the meteoritic origin but proposed that the impactor had fragmented and vaporized during atmospheric entry, making further drilling useless. Barringer reportedly died shortly after reading Moulton's conclusions (Kring, 2017).

This historical narrative is particularly useful for overcoming the common misconception that Science proceeds linearly from question to conclusion. Many students perceive Science as a rigid sequence of steps, while scientific inquiry is actually dynamic, creative, and non-linear (Thanukos et al., 2010). The Barringer case also highlights the educational importance of scientific error: Gilbert's incorrect volcanic interpretation and Barringer's mistaken expectation of a buried meteorite demonstrate that Science is neither automatic nor infallible, but a human process shaped by evidence, disciplinary backgrounds, and debate.

The approach is coherent with the new Italian National Guidelines for secondary schools, which recommend adopting a historical-epistemological perspective to reconstruct how scientific knowledge develops through hypotheses, experiments, and theory revision. Research on historical storytelling in science education shows that integrating "science stories" improves students' understanding of creativity, uncertainty, and the social dimensions of Science (Klassen, 2009).

The still unresolved debate concerning the Sirente crater in central Italy, alternatively interpreted as either a meteoritic impact or a structure linked to pastoral activities (Stoppa, 2006), further demonstrates that scientific knowledge is tentative but durable and continuously revised through new evidence and discussion within the scientific community.

Barringer and Sirente craters therefore provide powerful examples for promoting scientific literacy and student engagement in Earth Sciences through an authentic understanding of how Science works.

Klassen S. (2009) - The construction and analysis of a science story: A proposed methodology. Sci. Educ., 18, 401-423.

Kring D.A. (2017) - Guidebook to the Geology of Barringer Meteorite Crater, Arizona (a.k.a. Meteor Crater). Lunar and Planetary Institute, Houston, 1-4 pp.

Stoppa F. (2006) - The Sirente crater, Italy: impact versus mud volcano origin. Meteorit. Planet. Sci., 41, 467-477.

Thanukos A. et al. (2010) - Science 101: building the foundations for real understanding. Science, 330, 1764-1765, https://doi.org/10.1126/science.1186994.

From students to science communicators: The "Aperiscienza" geoscience outreach experience

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Keywords: geoscience outreach, science communication, geoheritage education.

The project described here is a *Formazione e Scuola-Lavoro (FSL)* experience developed by a third-year class of the *Liceo Statale "L. Ariosto"* (Ferrara, Italy) during the academic years 2025/26-2026/27, in partnership with the Department of Environmental and Prevention Sciences (DISAP) of the University of Ferrara and other local institutions. The overarching theme is "The Information Society: digital communication, media and journalism", and students are called upon not merely to learn about science communication, but to practice it in a real public context, designing posters, building a dedicated website, producing podcasts, conducting interviews with researchers, and writing newspaper articles for a public engagement initiative entitled *Aperiscienza: idee e storie del territorio* ("Science Aperitif: ideas and stories from the territory"), thereby fostering active public engagement with geoscience and local geoheritage (Rodrigues et al., 2023).

Aperiscienza consists of seven public events held between April and October 2026 in sites of scientific, historical or environmental significance in the Ferrara area: the Abbey of Pomposa, the Po Delta lagoon town of Comacchio, the University Botanical Garden, and the church of Santa Maria in Vado. The topics addressed span Earth and environmental sciences: coastal and wetland dynamics in the Po Delta ecosystem, the long interaction between landscape and human settlement over a millennium, sustainable management of marine resources, and the interface between environmental modelling and quantitative thinking. These are not abstract subjects for the students; they are the living geography and ecological heritage of their own territory.

Students engage with each event at multiple levels. They attend as critical audience members, prepared through prior training in media literacy and science communication techniques (journalistic writing, podcast production, verbal and paraverbal effectiveness, recognition of media manipulation strategies). They then act as communicators themselves, translating scientific content for a broader public through the media formats they have mastered. Interviews conducted with the scientists and speakers serve as primary sources for their podcasts and articles, fostering genuine dialogue between secondary school students and university researchers.

This dual role, as learners and as producers, is the defining pedagogical feature of the project and reflects contemporary models of geoscience communication based on participation, dialogue and societal engagement rather than one-way dissemination (Illingworth, 2023). It places students at the centre of the public understanding of geoscience, giving them direct ownership of how Earth science knowledge circulates in their community. The model demonstrates that secondary-school students, when structurally integrated into university-led public engagement, can become effective and motivated agents of science communication, while simultaneously developing transferable competencies in critical thinking, digital media, and territorial awareness.

Rodrigues J. et al. (2023) - How Can Geoscience Communication Foster Public Engagement with Geoconservation? Geoheritage, 15, 24, https://doi.org/10.1007/s12371-023-00800-5.

Illingworth S. (2023) - A spectrum of geoscience communication: from dissemination to participation. Geosci. Commun., 6, 131-139, https://doi.org/10.5194/gc-6-131-2023.

Transforming public perception of hydrogeology through citizen science: Replicable dissemination and results from the Acqua Sorgente Project

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Keywords: citizen science, hydrogeology, scientific dissemination.

Effectively communicating the societal relevance of geological sciences is essential for fostering environmental stewardship and supporting sustainable decision-making. To shift the public perception of geology from an academic curiosity to an empathetic, foundational discipline, innovative and interactive outreach strategies are required. The Acqua Sorgente national citizen science project, launched by the Italian Alpine Club (CAI), serves as a concrete model of utilizing public engagement to bridge the gap between society and hydrogeological science, emphasizing the key role of geology in land management and natural cycles. By actively involving citizens and trained volunteers in monitoring mountain water springs, the initiative transforms passive observers into active participants in geological data collection. Through dedicated applications, participants record critical hydrogeological parameters such as spring location, flow rate, temperature, and electrical conductivity. This practical, interactive approach not only generates an open-source national database utilized by research institutions but also cultivates a deeper emotional connection between the outdoor community and the changing hydrological cycles affecting mountain territories. Beyond its raw scientific contributions, Acqua Sorgente prioritizes comprehensive outreach through targeted school projects and public educational events. These activities are designed to foster water awareness and inspire future generations to pursue formal education in Geological Sciences. To date, the project has validated data from more than one thousand springs across Italy, demonstrating the high efficiency of public-scientific interaction. An evaluation of these outcomes confirms the project's success in enhancing geological literacy and community cohesion. Ultimately, Acqua Sorgente offers a fully scalable, open-source framework and workflow, providing adaptable guidelines to facilitate similar geological dissemination initiatives across diverse regional and international contexts.

Web virtual worlds and spherical photos for the study of geology

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Keywords: web virtual worlds, virtual geological field trip, sites of geological interest.

Historically, geology education has found its ideal laboratory in the natural environment, where direct observation of outcrops allows students to translate theoretical concepts into an understanding of geological processes. During COVID there was a strong increase of interest in finding new ways to continue training activities in the field for university students and, in school, logistical, economic, and physical barriers often limit access to sites of geological interest. This has driven the exploration of innovative digital solutions such as Virtual Geological Field Trips (VGFT) (Hu & Zhang, 2025) supported by Google Maps technologies - specifically 360° spherical photos - web virtual worlds, and virtual reality (Zulhilmi et al., 2025). VGFTs allow, for example, the exploration of remote, dangerous, or politically inaccessible sites from any device connected to the internet.

In this study, an activity carried out with a third-year lower secondary school class of 24 students (aged 13-14), was based on the creation of an educational path within a web virtual world using the Framevr 3D platform. This platform integrates 360° spherical photos downloaded from Google Maps. These photos appear as mini-spheres placed on a world map or on national and local maps: when clicked, they "open" to completely surround the environment. To maximize educational effectiveness, geologically-relevant sites were selected, with high-quality spherical images and clear scientific exemplary value. The sites were divided into different categories focusing on: 1. Particular events in Earth's history. 2. Specific geological structures. 3. Types of rocks. 4. Anthropic geology, resources, and geological curiosities. The areas can be explored freely, using either desktop/notebook PCs or virtual reality headsets, which increase the sense of immersion in the geological environment. Each zone is accompanied by panels with explanatory content, additional "flat" photos, models, and simple quizzes to self-verify learning. This virtual world can be expanded in the future with other spherical photos taken from the internet or captured with dedicated cameras directly at local geological sites.

Based on knowledge tests and satisfaction questionnaires, the activity proved to be pleasant and effective. The use of 360° spherical photos offered a learning experience beyond simple visualization, allowing students to develop a sense of "presence" and spatial awareness fundamental to the interpretation of simple geological structures. However, it is intended that the study of geosciences cannot dispense with "in the field" or laboratory activities (such as rock identification): therefore, VGFTs are intended as an integration and not a replacement for traditional activities (Ramos et al., 2026).

Hu R. & Zhang Y. (2025) - A New Approach to Field Learning-Virtual Field Trips: A Systematic Review. J. Comput. Assist. Learn., 42, https://doi.org/10.1002/jcal.70170.

Ramos A. et al. (2026) - Sustainability in Geoscience Education: Comparing Virtual and Traditional Field Trips with 10th-Grade Students in Portugal. Sustainability, 18, 781, https://doi.org/10.3390/su18020781.

Zulhilmi A. et al. (2025) - Usability and motivational impact of a fast-paced immersive virtual-reality lecture on international middle-school students in geoscience education. Geosci. Commun., 8, 197-211, https://doi.org/10.5194/gc-8-197-2025.

From epistemology to practice: A research-based approach to geoscience education through foundational nuclei and shared teaching tools

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Keywords: foundational nuclei, epistemology, geological reasoning.

The absence of a coherent theoretical framework that makes explicit the epistemological and cognitive specificities of geological thinking undermines curriculum design, teacher education, and assessment alike. The Italian national curriculum guidelines (*Indicazioni Nazionali*) offer a telling case: geoscience content appears dispersed across science, geography, and technology, without explicit reference to the foundational nuclei that characterise geological reasoning — deep time, Earth as a system, abductive and retrodictive inference, and the relationship between geoscientific knowledge and risk citizenship. Without these nuclei made explicit, teachers lack the conceptual tools to design meaningful learning sequences, and university courses in teacher education lack a disciplinary anchor around which to organise geoscience pedagogy.

This contribution presents a research-based framework examining three interconnected dimensions: the epistemological nature of geosciences as historical and integrative sciences employing distinctive forms of reasoning; the cognitive challenges these specificities pose for learners, including deep time comprehension, spatial reasoning, and systems thinking; and the pedagogical implications for curriculum design and teacher education. Drawing on these foundations, the research proposes a set of shared teaching materials — structured activity sheets organised around the four foundational nuclei — designed to make geological thinking visible, teachable, and transferable across different school levels and contexts.

Assessment is treated not as an afterthought but as a design constraint: if geological reasoning is the target, then tasks must be constructed to elicit and evaluate that reasoning explicitly. The IESO written and practical tests are discussed as operational examples of this principle, demonstrating that translating an epistemological framework into concrete task design is both possible and replicable. The recent IESO 2026 (Turin, August 2026), organised under the auspices of IUGS and ANISN, provides a concrete case study for this reflection.

The framework and materials are intended as a starting point for a shared research agenda in geoscience education, with implications for curriculum revision, teacher training, and the development of discipline-specific didactic tools.

The invisible science: The need to be heard in geoscience communication between risk, education and public engagement

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Keywords: geoscience communication, risk communication, public engagement.

The communication failure of geosciences is not accidental but structural, rooted in three interconnected problems that the discipline has yet to fully confront. The first is epistemological: geosciences operate on temporal and spatial scales that exceed direct human experience, employ retrodictive and abductive reasoning that differs fundamentally from experimental science, and are intrinsically interdisciplinary — characteristics that make them cognitively demanding to communicate and easy to misrepresent. The second is disciplinary: the progressive fragmentation into increasingly specialised sub-fields has eroded the shared narrative that once made geology a coherent cultural presence, leaving geoscientists unable to build the cross-disciplinary coalitions and public visibility that other sciences have developed. The third is pedagogical: a tradition of nomenclature-heavy, bottom-up teaching has produced generations of specialists who were never taught to make geological thinking visible, narratable, or socially relevant.

These three failures converge most visibly in risk communication. When earthquakes, volcanic crises, or flood events demand rapid, clear, and trustworthy public communication, geoscientists frequently find themselves ill-equipped — not for lack of knowledge, but for lack of communicative tools and shared frameworks. The L'Aquila case and the recurring difficulties in communicating volcanic unrest at Campi Flegrei are symptoms of a deeper problem: a discipline that has not invested in building a communicative identity robust enough to function under public scrutiny. Forensic geology offers a parallel example — a field of direct legal and social relevance that remains largely invisible in public discourse precisely because it lacks a coherent narrative framework.

This contribution proposes a research-based innovative framework for moving beyond the deficit model toward dialogic and contextual communication, integrating narrative strategies, transdisciplinary connections, and new outreach formats. The core argument is that learning to communicate is not an optional skill for geoscientists but a disciplinary responsibility, one that must be integrated into both university training and public engagement practice. Concrete strategies are proposed: making geological reasoning explicit and narratable; constructing unexpected connections between geoscience and everyday life, history, art, and technology; and building a shared disciplinary identity capable of sustaining meaningful public dialogue.

The Summer School for Geoscience Education at UNICAM

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Keywords: geoscience education, school, teachers.

Earth science teaching in Italian schools has always been limited, both in terms of the topics covered and the time devoted to them. This is a well-known problem rooted in a series of factors beyond teachers' control. The factors influencing this problem are primarily the teachers' non-geological background, which often results in a lack of familiarity with the more in-depth topics of Earth sciences. This also makes it difficult to engage students' attention and interest in field or laboratory experiences.

The UNICAMearth Research Group at the University of Camerino has long been committed to providing educational support to science teachers. Helping teachers find keys to understanding the various topics covered in school, providing examples of lessons, simple and replicable laboratory activities, or ideas for field trips can make everyday teaching easier and more interesting. The activities offered to teachers annually consist of in-person seminars and workshops, field trips with their students, webinars on current topics, refresher courses, and even a doctorate program dedicated to Geoscience education. In addition, a residential Summer School is organized periodically in July, which hosts approximately 50 teachers and includes various seminars and workshops, geo-scientific theater, one or two excursions, an astronomy seminar, and sky observation. Elective activities also include visits to the Frasassi Caves, the University Botanical Garden, and the city with its historical and artistic monuments. These latter activities are useful for providing interdisciplinary hints and suggestions for school visits. After the 4-days of Summer School, a questionnaire is administered, aimed not only at assessing participant satisfaction (always very high), but also at identifying areas for improvement, or for further exploration of the topics covered, and suggestions for new activities. Teachers greatly appreciate the space dedicated to astronomy, which offers a different seminar each year, field trips, and workshops (ranging from paleontology to the use of virtual worlds, from cartography to minerals, from the ocean to games). Seminars on current topics are highly appreciated, especially those offering interdisciplinary insights: georesources and circular economy, plastics and microplastics in the sea and sand, climate change and coastal erosion, geological hazards and risks, etc. Recurring requests, however, include those that are least expected, such as the teaching of minerals and rocks, a topic that is often boring in school. The challenge, with these initiatives for schools, is therefore to provide interpretations and interdisciplinary hints, such as linking minerals and rocks to their genetic environments, industrial applications, and cultural heritage. This is just an example of the type of support geologists can make available to teachers.

Creative strategies for tsunami prevention with comics: A way to apply Episodes of Situated Learning (ESL) for natural risk reduction education

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Keywords: tsunami risk reduction, episodes of situated learning.

Raising awareness on natural hazards and local vulnerability can help increase community resilience. In line with the UN Decade of Ocean Science, the Istituto Nazionale di Geofisica e Vulcanologia (INGV) has organized activities for schools aimed at reducing tsunami risk. In this context, Tsunami Danger! is an Episodes of Situated Learning (ESL, EAS in Italian, Rivoltella, 2013) designed to help students understand key scientific concepts about tsunamis and promote appropriate behaviors to be adopted in the event of a tsunami.

Tested during activities for World Oceans Day 2026, it is primarily aimed at middle schools (ISCED 2). Students' task is the design of a creative communication product using the comics technique. Over 600 students from all over Italy participated in the initiative, along with a group of about 30 scouts from Sicily and a group of about 40 children aged 6 to 13 from a volunteer center in Madagascar. With a focus on cooperative learning, students created about 120 comics on safe behaviors in the event of a tsunami, most of which were realized using apps of their choice and others have been drawn entirely by hand (e.g., from Madagascar).

The positive outcome of the experiment and the quality of the comics confirm the effectiveness of this teaching method in promoting active citizenship best practice and social responsibility, stimulating a meaningful approach to automate best civil protection practices to reduce natural risks.

This activity has therefore become an integral part of the CON.I.RI (Living with Natural Risks) participatory project between schools and research institutions, within the Future Responsible Citizens (FCR 2.0) educational program. Since 2020 CON.I.RI is the educational path on seismic and hydrogeological risk reduction by INGV within the FCR and FCR 2.0 environmental educational projects in collaboration with AssoCea Messina APS. It can be considered a way to act on behaviors vs seismic and water-related Disaster Risk Reduction at school. And the experiment on tsunami risk involves more than 2,000 students in primary and middle school for the school year 2025/26. Tsunami Danger! is well-suited for both in-person classroom activities and online sessions and can be replicated anywhere and applied to any other natural hazard worldwide

Rivoltella P.C. (2013) - Fare Didattica con gli EAS - Episodi di Apprendimento Situato. Ed. La Scuola SEI, 256 pp.

"Stories from the forest": A transdisciplinary workshop integrating a narrative-based methodology with outdoor education

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Keywords: trasformative learning, ecological narrative, outdoor education.

The increasing gap between younger generations and the natural environment represents a critical challenge for contemporary education, particularly in the context of global socio-environmental crises. Reconnecting students with nature and with geosciences requires pedagogical paradigms that merge emotional, cognitive, and experiential dimensions. Integrating storytelling with outdoor and place-based education emerges as a promising approach to promote contextualized learning and cultivate ecological identity, empathy, and responsibility.

Empirical research demonstrates that narrative transportation can effectively shape environmental intentions and attitudes by eliciting empathy with nature, producing transformative effects beyond factual or didactic instruction (Liu, 2023). Likewise, studies indicate that narrative-based environmental education improves children's environmental awareness and emotional connection to ecological systems, although measurable behavioral changes often require sustained engagement over time (Yang et al., 2022). Narrative formats such as storytelling, ecological tales, and digital narratives serve as powerful pedagogical tools: they facilitate emotional resonance, bridge personal experience and ecological understanding, and vitalize learners' capacity for ethical environmental action.

The workshop "Stories from the Forest" with students of the Degree Course in Primary Education Sciences at the University of Turin is an experience than combined literary analysis and direct immersion in nature. Participants first explored children's books featuring forests as central settings or symbolic elements, then engaged in a two-day field experience in the Gravio Valley (Orsiera Rocciavrè Natural Park), characterized by rocks, woods, abandoned villages, and diverse wildlife. Through observation, drawing, and sound recording, students collected sensory and natural materials subsequently incorporated into the writing of original educational stories. These narratives were designed as didactic tools for students, demonstrating how a transdisciplinary approach can foster an emotional, experiential, and outdoor mode of environmental education.

To evaluate the outcomes, both qualitative and quantitative indicators were employed to detect narratives expressing empathy, biophilia, geophilia, and an understanding of the environment as an active co-protagonist. Results revealed a marked enhancement in the students' sense of ecological connection following the immersive experience.

In conclusion, the study underscores the pedagogical potential of integrating storytelling and outdoor learning as synergistic practices in environmental education. By engaging imagination, empathy, and sensory experience, these methods cultivate deeper ecological awareness and lay the foundation for environmentally responsible behavior in both future teachers and their students.

Liu J-X. (2023) - The influence of narrative transportation on university students' environmental intentions: A serial mediation of empathy with nature and environmental attitudes. J. Clean. Prod., 431, 139763, https://doi.org/10.1016/j.jclepro.2023.139763.

Yang B. et al. (2022) - Narrative-Based Environmental Education Improves Environmental Awareness and Environmental Attitudes in Children Aged 6-8. International Jour. Int. J. Environ. Res. Public Health., 19, 6483, https://doi.org/10.3390/ijerph19116483.

FREELAND methodology as a guidance for schools for the participatory regeneration of neglected places

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Keywords: STEAM, urban environment, high school education.

FREELAND is a European project funded by the Erasmus+ Programme (https://www.freelandproject.eu/) which engages students in the regeneration of neglected spaces through a methodology for secondary schools which fosters the application of an integrated STEAM teaching and the involvement of the local community and stakeholders.

FREELAND has created diverse educational resources for teachers and students to make learning more attractive and connected to reality while stimulating active citizenship. Neglected places in the school town become learning outdoor contexts and local stakeholders the external audience to interact with.

Educational modules on six macro-themes (i.e. climate change, urban ecosystems, pollution, social impact, resilient cities and sustainable cities) and eight laboratories based on Inquiry Based Learning engage the students in socio-environmental activities to explore environmental and social characteristics of a specific place, identify the critical aspects and stimulate creative solutions for the "revitalization" or the "aesthetic improvement" of the chosen place.

In total 285 students and 19 teachers have been involved in the FREELAND piloting in three countries: 150 students and 8 teachers in Italy (108 students in Prato and 43 students in Baronissi, with 5 and 3 teachers, respectively, 74 students and 4 teachers in Rjieka, Croatia and 60 students and 5 teachers in Gdansk, Poland. Teachers' subjects vary from Physics and Sciences to Drawing and Arts and Literature). FREELAND piloting mainly consists in the application of the methodology and the educational resources in the chosen neglected space. In Prato, the courtyard of the school was chosen as the place to regenerate, in Baronissi the "Grandfathers' park" in accordance with the municipality, a neglected public green space behind the school was selected in Rjieka and the school garden in Gdansk.

In all schools, students investigated some characteristics of the places in science laboratory and through hands-on activities and data analysis in different subjects: they measured the surface temperatures and air temperatures for the microclimate analysis, they tested the soil fertility through the "underwear test" and assessed plant biodiversity to characterize the quality of the green components, some classes measured CO_2 and particulate for the acquaintance of air quality, and detected the noise level. Social aspects were also investigated through interviews to elders, visitors of the places and stakeholders, to raise awareness of the area and its possible improvements.

Students are able to visualize the results in automated graphs on the project platform "Chart" tool which makes data visualization easy (https://www.freelandproject.eu/charts/line) and they can design any regeneration of their place in a 3D studio tool (https://www.freelandproject.eu/studio) with future elements and colors.

Connecting STEM disciplines through Earth Sciences: The "Traversata con le STEM" initiative (DST, University of Pisa)

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Keywords: career guidance, STEM education, field-based learning.

"*Traversata con le STEM*" is a career guidance initiative organized by the Department of Earth Sciences at the University of Pisa and aimed at fourth-year students in science-focused high schools in northern Tuscany who excel in science disciplines. The project was created with the goal of identifying young people with a strong interest and aptitude for mathematics, physics, and chemistry—even if they are not necessarily oriented toward Earth Sciences—by offering them an educational experience that highlights the deep connections between these disciplines and the study of the Earth system. The initiative, fully funded by the Department, involves a three-day scientific and nature-based excursion through the Apuan Alps, from the Versilia coast to Garfagnana, scheduled to take place between June 22 and 24, 2026. During the field trip, a select group of students from various schools (IIS Galilei Artiglio, Viareggio; Liceo Scientifico Antonio Vallisneri, Lucca; Liceo Scientifico Guglielmo Marconi, Carrara) will be accompanied by university professors and student tutors from the university on an immersive learning journey that will combine field observation, scientific exploration, and informal engagement with the academic world.

This program aims to promote learning in a natural environment as a tool for informed decision-making, fostering the development of transferable skills, critical thinking, and scientific curiosity. The topics covered throughout the program will include significant issues of social relevance, such as coastal erosion, climate change, natural resource management, landscape evolution, and earthquake risk prevention. Through guided activities and interdisciplinary discussions, students will gain an understanding of how mathematical models, physical processes, and chemical reactions find concrete application in the study of geological and environmental processes.

"*Traversata con le STEM*" also aims to strengthen the relationship between universities and secondary schools by offering a career guidance model based on direct experience, human interaction, and active participation. The project thus seeks to promote a contemporary and interdisciplinary view of Earth Sciences, highlighting their central role in understanding the major environmental challenges of the present and future, and helping to guide students toward informed and motivated scientific university pathways.

S37.

Submarine landscapes and the sub-seafloor: Processes, interactions, and geohazards for the Italian Seas

CONVENERS & CHAIRPERSONS:

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Fluid escape and submarine slope instability in the Palermo offshore (Southern Tyrrhenian Sea)

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Keywords: pockmark, fluid flow, bathymetry.

This study investigates a sector of the Palermo offshore, focusing on the complex relationships between pockmarks and submarine landslides through the analysis of morphobathymetric data acquired by Multi Beam Echo Sounder (MBES) and sparker seismic profiles collected during the CARG and MAGIC surveys (Lo Iacono et al., 2011).

The study area is characterized by pockmarks emitting freshwater of continental origin. Consequently, fluid discharge is interpreted as intermittent and controlled by the recharge of the continental aquifer during meteorological events. The analysis of MBES data together with seismic profile interpretation enabled us to: (1) quantitatively estimate the thickness, area, and volume of sedimentary bodies affected by fluid migration; (2) identify a weak layer potentially acting as a sliding surface for landslides associated with pockmarks; and (3) recognize fluid migration pathways along normal fault planes linked to recent geological structures, mainly oriented N-S. We propose that the different "U/V-shaped" geometry of the reflectors beneath the pockmarks results from the reduction in sediment cohesion caused by fluid migration, which increases sediment susceptibility to gravitational instability. In the Palermo offshore, where steep slopes characterize the seafloor, landslide scarps surrounding the pockmark field suggest that active fluid escape may contribute to slope failure initiation. The identification of the areas and volumes of altered sediments, together with a critical evaluation of previous studies, allowed the development of a conceptual model for the potential retrogressive evolution of these sectors and the calculation of the pockmark-related Factor of Safety (Skempton & DeLory, 1957). The results indicate that pore overpressure within intra-pockmark areas exerts a strong control on slope stability and can therefore be regarded as a predisposing factor for submarine gravitational processes.

Lo Iacono C.L. et al. (2011) - Submarine canyon morphologies in the Gulf of Palermo (Southern Tyrrhenian Sea) and possible implications for geo-hazard. Mar. Geophys. Res., 32, 127-138.

Skempton A.W. & DeLory F.A. (1957) - Stability of natural slopes in Londonclay. In: Proceeding of the 4th International Conference on Soil Mechanics and Foundation Engineering, Butterworths Scientific Publications, 378-381.

Palaeo-sea-level indicators in the Southern Tyrrenian Sea: Insights into Relative Sea-level Changes from the Last Glacial Maximum to the Holocene

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Keywords: sea-level markers, relative-sea-level curve, Last Glacial Maximum.

A relative sea-level (RSL) curve represents changes in sea level, typically at the scale of a sedimentary basin. It accounts for both global eustatic sea-level changes and local or regional factors, including tectonic vertical movements (subsidence or uplift), Glacial Isostatic Adjustment (GIA), ocean circulation, and climate. For the Central Mediterranean, several RSL curves have been proposed by integrating eustatic sea-level changes with GIA models; some of them also include corrections for local vertical movements since the Last Glacial Maximum (LGM). However, these curves rely on a limited number of geological and chronological markers distributed over timescales ranging from several hundred to several thousand years, which constrain their accuracy and resolution. This study shows sea-level markers recognised on high-resolution multichannel seismic profiles acquired in the Sant'Eufemia Gulf (SEG; southeastern Tyrrhenian Sea) serving as benchmarks for sea-level changes. Integrating seismic data with calibrated radiocarbon dating of gravity cores reveals that these sea-level markers formed during the LGM and during subsequent sea-level rise. Paleo sea-level markers integrated with benthic foraminiferal assemblages and granulometric trends from core samples spanning 14.5 ka to the Holocene allow the construction of an RSL curve for the southeastern Tyrrhenian region from the LGM to the Holocene using a multi-proxy approach. This is because the investigated area has experienced minimal long-term net vertical land movements, which simplifies the analysis of the impacts of RSL change on nearshore evolution. The RSL curve exhibits a non-linear pattern characterised by seven distinct step-like segments, each representing rapid sea-level rise events punctuated by intervals of stillstands or slight sea-level falls. This pattern indicates episodic accelerations and pauses in sea-level rise, reflecting complex interactions of glacial meltwater input and GIA. Subsequently, the RSL curve was compared with a suite of synthetic RSL curves generated by various GIA models covering the period from the LGM to the Holocene. Among these models, the ANU14-HV, ANU04-MED, and ANU14-LV demonstrate the closest match to our data. Our findings shed new light on RSL change for the Central Mediterranean from the LGM to the Holocene, improving predictive modelling capabilities and elucidating broader implications of climate change. Finally, the characteristics of the seismic data, combined with the rigorous and detailed workflow well described in this work, ensure reproducibility for future research focused on RSL change, including regions with tectono-sedimentary dynamics different from those of our study area.

CARG Sheet No. 524 Foce del Sinni (marine area): Preliminary reconstruction of side-scan sonar seabed acoustic facies on the inner to middle shelf of the Ionian coast of Basilicata (southern Italy)

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Keywords: side scan sonar facies, CARG project, Basilicata southern Italy.

New side-scan sonar data acquired in the offshore sector of the CARG Sheet No. 524 "*Foce del Sinni"* cover approximately 150 km^2 of the inner to middle shelf along the Ionian coast of the Basilicata region (southern Italy), between 10 and 80 m water depth, and represent the first phase of the marine survey planned for this sheet. The study area lies in the northwestern Gulf of Taranto, a key transitional sector between the Southern Apennines frontal system and the Calabrian Arc, where Late Pleistocene-Holocene stratigraphic architecture and present-day seafloor morphology reflect the interplay among sediment supply, coastal dynamics, and gravity-driven processes (Meo et al., 2026). Preliminary analysis indicates a seabed largely characterized by low backscatter, consistent with the widespread occurrence of fine-grained unconsolidated bottom sediments, mainly mud and sandy mud, locally interrupted by slightly higher-backscatter patches likely related to textural variability, localized sandy inputs, and/or discontinuous benthic cover. Within a regional stratigraphic framework, the surveyed area can be referred to the upper highstand wedge recognized along the northwestern Gulf of Taranto shelf (Carbone et al., 2012). Near the Sinni River mouth, the side-scan sonar mosaic outlines a mottled and heterogeneous acoustic facies tentatively interpreted as a river-influenced delta-front/prodelta sector, where fluvial sediment supply interacts with wave- and current-driven reworking. Elsewhere, the seafloor is predominantly smooth, although elongated acoustic lineaments locally occur together with sub-circular to amphitheatre-shaped features and narrow high-backscatter linear elements. These morphologies are tentatively interpreted as small erosional and channelized forms, possibly related to incipient gully development, headward erosion, and localized remobilization of unconsolidated deposits (Ceramicola et al., 2024). At around 15 m water depth, widespread circular acoustic anomalies, progressively fading northward, define a patchy acoustic facies that may be associated with sparse *Cymodocea nodosa* colonization, whose presence has been reported in the northern part of the study area (Meo et al., 2019). However, direct ground-truth data are still required to support a robust classification and interpretation. Overall, this new dataset provides a first-order basis for refining seabed facies mapping and for constraining the relationships among highstand sedimentation, fluvial input, seafloor geomorphology, and sedimentary reworking in the *Foce del Sinni* offshore sector.

Acknowledgements: This research has been supported by the funds of the CARG Project - Geological Map of Italy at 1:50,000 scale.

Carbone S. et al. (2012) - Note Illustrative della Carta geologica d'Italia alla scala 1:50.000, F. 523 Rotondella. ISPRA, https://doi.org/10.15161/oar.it/212455.

Ceramicola S. et al. (2024) - Geohazard features of the Gulf of Taranto. J. Maps, 20(1), 2431073, https://doi.org/10.1080/17445647.2024.2431073.

Meo et al. (2019) - Seabed characterization off the Bradano river mouth (North-western Ionian Sea) by acoustic investigations and sampling. In: Chiocci F.L., Budillon F., Ceramicola S., Gamberi F., Senatore M.R., Sulli A. (Eds.), Abstract Book della Società Geologica Italiana, "La geologia marina in Italia, Terzo Convegno dei geologi marini italiani - Roma, 21-22 febbraio 2019", 52, https:// doi.org/10.3301/ABSGI.2019.02.

Meo A. et al. (2026) - Ongoing Deformation at the Southern Apennine Front: Insights from the Gulf of Taranto (Italy). Geosciences, 16(4), 141, https://doi.org/10.3390/geosciences16040141.

Pantelleria SW bank (Sicily Channel): New evidence based on an integrated multidisciplinary study

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Keywords: volcanic bank, hydrothermal fluids, bio-mound.

The submarine landscape of the Pantelleria SW bank (Sicily channel) includes its intrinsic morphology along with the sedimentary and oceanographic dynamics, the distribution of benthic ecosystems and possibly fluid seepages of hydrothermal origin. Here we present an integrated geophysical and geochemical investigation on this site which is located in a region of active volcanism, tectonic deformation, sustained hydrodynamic regime and highly diverse benthic communities (Catalano et al., 2009; Martorelli et al., 2011).

The bank lies approximately 20 km southwest of Pantelleria island, at the western edge of the Pantelleria tectonic graben, and consists of an elliptical edifice about 8 km long and 2 km wide, raising of about 250 m above the surrounding seafloor set at about 500 m depth. Its NW-SE elongated trend likely reflects the alignment of several volcanic vents that have constructed the main edifice. Sub-bottom data show a set of mostly NW-SE and N-S oriented volcano-tectonic faults that offset the hemipelagic/volcano-clastic sequence lying above the volcanic basement and favour gas migration.

The flanks of the edifice are subjected to vigorous bottom currents that probably control the genesis and spatial distribution of a multitude of elongated coral mounds 70 m long in average, raising few metres above the surrounding seafloor in the 300-450 m bathymetric range. Along the southwest flank of the edifice, we have observed a pockmark field and active venting of bubbling gases. Dissolved gases collected at the seafloor close to active vents contain significant amounts of H_2 and elevated concentrations of CO_2 and He relative to the air-saturated water. The helium isotope ratio (Rc/Ra 0.35) indicates a dominant crustal signature in venting fluids with a limited contribution from the mantle. These observations highlight the role of Pantelleria SW Bank as a natural laboratory for investigating the impact of volcanic, tectonic, and fluid flow processes on shallow submarine edifices and how they shaped benthic communities.

Catalano S. et al. (2009) - Late Quaternary deformation on the island on Pantelleria: New constraints for the recent tectonic evolution of the Sicily Channel Rift (southern Italy). J. Geodyn., 48, 75-82, https://doi.org/10.1016/j.jog.2009.06.005.

Martorelli E. (2011) - Contourites offshore Pantelleria Island (Sicily Channel, Mediterranean Sea): depositional, erosional and biogenic elements. Geo-Mar. Lett., 31, 481-493, https://doi.org/10.1007/s00367-011-0244-0.

Landslide susceptibility mapping along the Central-eastern Tyrrhenian margin: A high-resolution WoE-based assessment

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Keywords: submarine landslide, seafloor topography, hazard zonation.

The Landslide Susceptibility Index (LSI) is a semi-quantitative measure of the relative likelihood of landslide occurrence across a given area, based on the statistical or deterministic integration of predisposing factors. It enables the spatial ranking of areas prone to slope failure, providing a predictive tool for hazard assessment and risk mitigation.

In submarine environments, the application of the LSI has expanded with the increasing availability of high-resolution seafloor Digital Terrain Models, enabling finer-scale analyses. This is further driven by the recognition of widespread landsliding along continental margins (Camerlenghi & Urgeles, 2013) and the growing demand for geohazard-resilient offshore infrastructure.

In the Mediterranean Sea, it has been applied at the basin scale to map regional susceptibility patterns (Innocenti et al., 2021) or to refine hazard zonation by highlighting the role of local stratigraphic and geomorphic controls (Scacchia et al., 2024).

Within the agenda of the RETURN (Multi-Risk Science for Resilient Communities under a Changing Climate) - Spoke2, focused on ground instabilities, the Rischiare Project developed a regional-scale landslide susceptibility assessment along the continental margin between the Gulf of Gaeta and the Gulf of Salerno—an area exposed to volcanic, seismic, and hydro-meteorological hazards and bordered by densely populated coasts—using the Weight of Evidence (WoE) method. This method uses a Bayesian-based bivariate statistical approach to quantifies the relationships between landslides and predisposing factors and estimates LSI, allowing a continuous spatial assessment of potential failures.

This analysis is part of the activities and tools developed under the RETURN agenda to investigate predisposing and triggering factors of offshore landslide instability, aiming to define future hazard scenarios.

In the study area, the WoE approach integrates a comprehensive landslide inventory (approximately 1200 events occurring between 10 and 800 m water depth) with a set of predisposing factors, including physiographic units, sediment texture, slope angle, water depth, slope orientation, plan and profile curvature, and distance from channel and gully networks. Different combinations of these variables were tested to produce five susceptibility maps - each depicting five classes of landslide susceptibility - at a 10 m spatial resolution.

The predictive performance of each map was assessed using the Area Under the Curve (AUC) statistical value. Despite the high predictive performance of all models (AUC values exceeding 0.8), the resulting susceptibility maps are quite variable, with a proportion of territory classified as very high susceptible to failures ranging from a minimum of 0.10% to a maximum of 3.95%.

These results highlight that, beyond statistical performance, susceptibility maps must be critically evaluated to ensure geomorphological plausibility (Steger et al., 2016), and that a precautionary susceptibility scenario should be assumed to protect offshore infrastructure and promote coastal resilience.

Innocenti C. et al. (2021) - Submarine landslides: mapping the susceptibility in European seas. Q. J. Eng. Geol. Hydrogeol., 54(1), https://doi.org/10.1144/qjegh2020-027.

Scacchia E. et al. (2025) - Shallow-water submarine landslide susceptibility map: The example of Capo d'Orlando continental margin (Southern Tyrrhenian Sea). J. Mar. Sci. Eng., 13(7), 1350, https://doi.org/10.3390/jmse13071350.

Steger S. et al. (2016) - Exploring discrepancies between quantitative validation results and the geomorphic plausibility of statistical landslide susceptibility maps. Geomorphology, 262, 8-23, https://doi.org/10.1016/j.geomorph.2016.03.015.

Urgeles R. & Camerlenghi A. (2013) - Submarine landslides of the Mediterranean Sea: Trigger mechanisms, dynamics, and frequency-magnitude distribution. J. Geophys. Res. Earth Surf., 118, 2600-2618, https://doi.org/10.1002/2013JF002720.

The marine geology of the Messina Strait and the 1908 earthquake: Is a new fault interpretation approach required?

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Keywords: 1908 Messina earthquake, active tectonics, marine geology.

In December 1908, a Mw 7.1 earthquake struck the region surrounding the Messina Strait, proving to be the most destructive earthquake in Italian history. Due to the poor spatial coverage and instrumental technology of the time, only limited seismological and geodetic data are available for that earthquake; these data, however, allow to roughly delineate, within some uncertainties, the size and orientation of the extensional rupture surface. Interestingly, all the different studies of contemporary data infer a blind, low-angle, east-dipping fault straddling the Strait (Pino et al., 2009). Modern GPS data and the low magnitude recent seismicity of the region confirm the presence of a diffuse crustal extension accounting for about 3 mm/yr in a NW-SE direction, but do not help locating the main seismogenic fault.

Since the 1908, numerous studies have been devoted to identifying the seismogenetic fault responsible for this large earthquake. Although for extensional earthquakes with M ≥ 7.0 a surface rupture is expected, the search for fault ruptures produced by the 1908 earthquake in Sicily and Calabria has yielded no convincing evidence.

Contributions from marine geology became more and more relevant through the years, and multibeam bathymetric acquisitions have provided a high-resolution image of the seafloor morphology in the Strait, revealing steep slopes and an asymmetric drainage network directly connected to terrestrial rivers (Ridente et al., 2014; Goswami et al., 2017). On the other hand, the investigation of the marine subsurface is still limited, mainly due to the physiographic characteristics of the Strait which make multi-channel seismic surveys difficult. Following the marine geology studies, many faults and fault systems have been proposed in the literature as potential candidates for the origin of the 1908 earthquake, in places resulting in conflicting interpretations (Argnani & Pino, 2023). A critical review of published and unpublished data will be presented to address issues related to the major faults in the Messina Strait region. The very existence of some of these faults, although well-established in the literature, may be questionable and some of them turn out to be nonexistent.

Marine geology data suggest the presence of Pliocene-Middle Pleistocene synsedimentary faults in the Strait, but these faults appear to be inactive and sealed by younger sediments. The 1908 earthquake, therefore, may be part of a relatively recent deformation system.

Earthquakes originating from low-angle blind faults, even those of large magnitude, may not necessarily produce a surface rupture. This makes the search for the surface trace of the seismic fault unpromising, even considering the results of previous research. Perhaps it would be more productive to analyze the subtle morphological response to recent deformation in the Strait of Messina region to determine whether or not it is compatible with a low-angle blind fault.

Argnani A. & Pino N.A. (2023) - The 1908 Messina Straits earthquake: Cornerstones and the need to step forward. Seismol. Res. Lett., 94, 557-561, https://doi.org/10.1785/0220220355.

Goswami R. et al. (2017) - Linking subaerial erosion with submarine geomorphology in the western Ionian Sea (south of the Messina Strait), Italy. Basin Research, 29, 641-658, https://doi.org/10.1111/bre.12196.

Pino N.A. et al. (2009) - The 28 December 1908 Messina Straits earthquake (Mw 7.1): a great earthquake throughout a century of seismology. Seismol. Res. Lett., 80(2), 243-259.

Ridente D. et al. (2014) - High-resolution morphobathymetric imaging of the Messina Straits (southern Italy). New insights on the 1908 earthquake and tsunami. Geomorphology 208, 149-159, https://doi.10.1016/j.geomorph.2013.11.021.

A Python-based automated workflow for morphometry of pockmark populations

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Keywords: pockmarks, morphometric analysis, geohazard.

Submarine pockmarks represent one of the most widespread geomorphological expressions of seafloor fluid escape and commonly occur in high-density fields composed of hundreds to tens of thousands of individual depressions. Under these conditions, traditional manual morphometric analyses become extremely time-consuming and difficult to reproduce, limiting the possibility of performing statistically robust regional-scale investigations. In this contribution, we present an open-access Python-based automated workflow specifically developed for the quantitative morphometric characterization of pockmark populations from Digital Elevation Models (DEMs) and polygonal vectors.

The workflow enables the automatic extraction of a comprehensive set of planimetric, geometric, elevation-based, and volumetric parameters, including area, perimeter, major and minor axes, elongation indices, slope statistics, internal depth, and excavated volume. The method is designed to minimize operator-dependent bias while ensuring reproducibility and scalability across datasets characterized by different spatial resolutions and geological settings. Major and minor axes are calculated through an iterative centroid-based intersection approach, whereas pockmark volumes are estimated through reconstruction of a pre-existing seafloor surface constrained by the surrounding bathymetry.

The workflow was tested on two contrasting Mediterranean case studies: (i) the tectonically and volcanically active Graham Bank region in the Sicily Channel, investigated through high-resolution multibeam bathymetry, and (ii) the passive north-western Sardinian continental margin, analysed using regional-scale EMODnet bathymetric grids. Validation against manual measurements demonstrates a high degree of consistency between automatic and manual morphometric estimates, particularly for the major axis, with generally negligible relative differences. Slightly larger discrepancies observed for the minor axis mainly reflect the intrinsic sensitivity of this parameter to polygon irregularities and operator interpretation.

The proposed workflow provides a standardized and reproducible framework for the construction of large morphometric databases suitable for spatial, statistical, and comparative analyses of pockmark populations. Beyond submarine pockmarks, the methodology is inherently transferable to any negative landform represented by closed polygons and associated DEMs, including sinkholes, collapse depressions, and analogous terrestrial or planetary morphologies. The workflow therefore represents a flexible tool with broad applicability in marine geomorphology, environmental studies, and geohazard assessment.

3D Architecture of fault-fluid vent interactions in the offshore Campi Flegrei resurgent dome Using UHR 3D seismic dataset

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Keywords: Campi Flegrei, seismic attribute analyses, fault-fluid vent interactions.

The Gulf of Pozzuoli hosts the offshore sector of the resurgent dome of the Campi Flegrei caldera, where tectonic deformation, hydrothermal circulation and volcanic unrest strongly influence the shallow subsurface. Despite numerous previous geophysical and geological studies (e.g., Sacchi et al., 2014; Corradino et al., 2021; Natale et al., 2022), the metre-scale geometry of the apical fault network, the vents distribution and the interplay between faults, stratigraphy and fluid migration remain poorly mapped.

This study employs an unpublished ultra-high-resolution (UHR) 3D seismic reflection dataset from the Gulf of Pozzuoli. By combining amplitude interpretation with selected seismic attribute analyses, we resolve a dense network of high-angle normal faults and associated fluid vents (ranging from fluid pipes to blow-out structures) that affect both the shallow intracaldera sedimentary sequences overlying the Neapolitan Yellow Tuff and the seafloor. Given the volcanic context and previous work on submarine fluid emissions in the area, these vents are interpreted as hydrothermal vents.

The fault network defines a tectonic depression characterised by pervasive faulting and horst-and-graben morphology, displaying a broadly radial pattern that converges toward the resurgence centre. The hydrothermal vents, in contrast, show an architecture in which the feeding system is not directly imaged: only the main conduits crossing the stratigraphic levels and their upward terminations in palaeo-pockmark features can be observed. Their distribution is only partly controlled by the mapped fault network — some seal-bypass structures exploit fault planes as preferential fluid pathways, whereas others are laterally offset from the major structures.

From a seismic point of view, the intrusive fluid pathways appear as vertical disturbance zones characterised by amplitude blanking, hyperbolic reflections, bright spots, and cross-cutting relationships with the primary reflectors. In some cases, spectral decomposition and the generation of frequency blend volumes tuned to selected frequencies allowed us to define a 3D geometry of the conduits and chimney pathways up to the pockmark areas, together with their relationships with the stratigraphy. The feeding source of the hydrothermal system is generally not imaged, pointing to a deeper origin for the seal-bypass structures.

Overall, the structural relationships suggest that the hydrothermal fluid structures are linked to the ongoing resurgence-related deformation expressed by the radial fault pattern. While both the radial pattern and the occurrence of hydrothermal vents have long been described in the study area, this is the first time that the 3D fault-fluid vent interactions are mapped and refined at such detail, providing a high-resolution model in which deformation and hydrothermal activity can be precisely unravelled.

Corradino M. et al. (2021) - Resurgent uplift at large calderas and relationship to caldera-forming faults and the magma reservoir: New insights from the Neapolitan Yellow Tuff caldera (Italy). Journal of Volcanology and Geothermal Research, 411, 107183.

Natale J. et al. (2022) - Fault systems in the offshore sector of the Campi Flegrei caldera (southern Italy): Implications for nested caldera structure, resurgent dome, and volcano-tectonic evolution. J. Struct. Geol. 163, 104723.

Sacchi M. et al. (2014) - The Neapolitan Yellow Tuff caldera offshore the Campi Flegrei: Stratal architecture and kinematic reconstruction during the last 15 ky. Marine Geology, 354, 15-33.

Underwater mass-movements, active tectonics and seismicity: Some examples from southern Tyrrhenian sea continental slopes

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Keywords: submarine landslides, seismo-genetic faults.

Active faulting, erosion along gullies/canyons, mass-movements or different combinations of them can have serious impact on human infrastructures in coastal, shallow water and in the deep-sea environments.

Here we analyse some of these processes occurring along the continental slopes of south-east and southern Tyrrhenian Sea which are region characterized by active tectonics and deep to medium-shallow seismicity (Chiarabba et al., 2025). The dataset includes very high resolution multibeam and sub-bottom data acquired by ROV during pre-cable lay surveys complemented with traditional shipborne surveys.

The south-eastern Tyrrhenian slope margin associated to the Calabrian-Peloritan arc is characterized by active deformation. Off the northern sector of the arc (in the Paola slope basin) such deformation occurs as a sinistral mega shear zone whereas in the southern sector (Gioia and S.Eufemia slope basins) normal faults perpendicular to the arc prevail. In the Paola basin we have observed active faults trending NNW-SSE and displacing of few metres Holocene hemipelagites. In some cases faulting can be clearly seen also on high resolution multibeam bathymetry as morphological steps.

In the offshore of Capo Vaticano promontory active faults, NW-SE oriented (Loreto et al. 2015) seem the main trigger of at least three translational/rotational, slides with volumes in the order of 0.15 to 0.25 km^3 that have left tens of metres deep scars over the slope between 600 and 800 m depths.

Incipient failures followed by disintegrative mass movements are currently observed at the Angitola and Gioia-Mesima canyons (Gamberi et al., 2010). The most apparent features are fissure cracks at the canyon's edges and abundant rock falls found at the toe of the canyon's walls and in the canyon thalwegs.

Along the southern Tyrrhenian slope margin (in the Cefalù intra-slope basin) some sectors are dissected by major fault scarps. One of these scarp, NE-SW aligned and here named Cefalù-Finale, shows a vertical drop ranging from 450 m to 200 m. Our data analysis has revealed two roto-traslational slides just in correspondence of such escarpment. One of these slides corresponds to an amphitheatre-like scar with an area of about 1.5 km^2 and shows both conservative and disintegrative behaviours. Part of the slide body is still partially hosted into the amphitheatre and shows evidence of multi-phase deformation (creep, internal levees, pressure ridges) whereas another part has been disintegrated and exported downslope as rafted blocks and debris flows.

Chiarabba C. et al. (2025) - Seismicity and deformation of the mobile continental lithosphere: An overview on the Alpine and Apennines orogens. Earth Science Reviews, 271, 1-25, http://doi.org/10.1016/j.earscirev.2025.105299.

Gamberi F. et al. (2011) - Mass-transport complex evolution in a tectonically active margin (Gioia Basin, Southeastern Tyrrhenian Sea). Marine Geology, 279, 98-110, http://doi.org/10.1016/j.margeo.2010.10.015.

Loreto M.F. et al. (2015) - Geophysical investigation of Pleistocene volcanism and tectonics offshore Capo Vaticano (Calabria, southeastern Tyrrhenian Sea). Journal of Geodynamics, 90, 71-86, http://dx.doi.org/10.1016/j.jog.2015.07.005.

Stratigraphic evolution of the Gulf of Orosei shelf-slope system: Interplay between tectonics and glacio-eustatic fluctuations

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Keywords: seismic stratigraphy, tectonic uplift, continental shelf.

The stratigraphic architecture of the continental shelf and upper-slope depositional system in the Gulf of Orosei (eastern Sardinian margin, western Mediterranean Sea) has been investigated in relation to the recent tectonic evolution of the area. This margin developed during the Miocene opening of the Tyrrhenian Sea. The continental shelf is narrow, and the heads of the submarine canyons occur at water depths of 50-80 m. Since the Late Pliocene, both the margin and the adjacent onshore sector have undergone gradual uplift.

Reflection seismic data reveal the presence of a thick seismic unit cropping out at the seafloor. In the distal slope sector, this unit is characterized by pelagic sedimentation, whereas in the proximal shelf sector it displays prograding cliniform geometries. The seismic reflectors are clearly truncated by an erosional surface. This stratigraphic configuration is interpreted as the result of: (i) deposition of a Pliocene sedimentary cover above the acoustic basement; (ii) development of a progradational wedge representing the palaeo-margin of the Pliocene continental shelf; and (iii) onset of a post-Pliocene regressive phase linked to a relative sea-level fall, which caused subaerial exposure and erosion of the upper part of the Pliocene succession.

The regressive phase is also documented onshore by the transition from Lower Pliocene marine deposits of the Fuili Formation to Upper Pliocene-Pleistocene continental deposits, and can be correlated with the regional tectonic uplift affecting the area. From the Middle Pleistocene onward, eustatic sea-level fluctuations associated with Milankovitch cycles became the dominant control on stratigraphic architecture. During lowstand periods, incised valleys and shelf-edge deltas developed. Fluvial sediments were (i) channelled through the Cedrino River incised valley toward the head of the Orosei Canyon, (ii) directly supplied to the Gonone Canyon, and (iii) transported across the shelf to form shelf-edge deltas, transgressive strand plains, and deltaic systems. Seismic stratigraphy indicates that these depositional processes operated through at least three glacio-eustatic cycles.

Overall, the stratigraphic stacking pattern of the Gulf of Orosei continental shelf and upper-slope depositional system reflects the interplay between tectonic and eustatic processes acting at different temporal scales. Long-term tectonic activity controlled the overall physiography of the basin and the stratigraphic architecture of the Pliocene depositional sequence, whereas higher-frequency eustatic fluctuations governed the development of incised valleys, shelf-edge progradational systems, and transgressive deltaic and coastal deposits across the shelf.

Pockmarks and contour currents in the northern Tyrrhenian Sea

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Keywords: fluid circulation, contouritic moat, bedform.

Pockmarks are the most widespread seafloor evidence of fluid circulation in the submarine environment. In areas with subsurface fluid circulation, the presence of pockmarks depends mostly on the lithology of the subseafloor, the distribution of tectonic structures and sedimentary processes. The same factors play also an important control on pockmark morphometric charycteristics, such as dimension, shape, spacing. Remarkably, the role of geomorphic features indicative of bottom currents in controlling the location and the geometry of pockmarks has been recently brought into light. Pockmarks and contouritic geomorphic elements have been previously reported from the northern Tyrrhenian Sea and analized, mainly from the point of views of their regional distribution. In this paper, we present the results of the analysis of multibeam data, acquired by the ISMAR institute in the late 90s, which show different modes of interaction between pockmarks and contourite geomorphic elements. The numerous depressions with elliptical shape suggest bottom-current reworking of original circular pockmarks. The close association between modified and un-modified pockmarks is indicative of local variations in the velocity of the bottom currents, whereby the local increase of the current velocity can be induced by the seafloor topography. In the study area, many of the pockmarks form trains aligned along contouritic moats. The moats correspond to narrow corridors with reduced sedimentation or erosion, where current speed is higher than in the surrounding areas. They are most likely floored by relatively coarser-grained sediment than the adjacent mounds and can thus represent more permeable belts able to capture ascending fluids. They are also areas of stratigraphic discontinuities and reduced sediment thickness leading to a local reduction of the lithostatic pressure which can initiate and localize the escape of fluids. Pockmarks also develop in contourite terraces, which similarly to the moats, are sites of reduced sedimentation and of possible erosion. Pockmarks trails forming curved features surround the summit of the Tritone Seamount, and are possibly shaped by localized secondary circulation including fast turbulent eddies, generated by the seafloor topography. In one case, pockmarks develop in the troughs of large-scale bedforms. They are mainly elongated parallel to the bedform troughs and are likely the result of lithologic variations due to the current dynamics in the tractional features. In general, our analysis shows that the stratigraphic and lithologic framework of the contourite geomorphic elements control the preferential location of the pockmarks and their morphometry.

Integrated geomorphological, sedimentological and ecological analysis of the watershed-coastal continuum of Catanzaro Lido (Ionian Calabria)

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Keywords: submarine geomorphology, canyon, closure depth.

The marine area of the Catanzaro Geological Sheet, along the Ionian margin of Calabria, represents an example of a watershed-coast continuum where fluvial transport processes interact with longshore, cross-shore and gravitational processes along the edges of the canyon slopes over very short spatial scales.

Within the framework of the CARG Project, the submerged area of the Catanzaro Sheet was investigated through the integration of high-resolution multibeam bathymetry, acoustic backscatter data and sediment sampling, in order to support geomorphological, morpho-sedimentological and ecological seafloor mapping. Multibeam data allowed the reconstruction of the morpho-bathymetric setting of the area, highlighting canyon heads, channelized features, shelf breaks and erosional or depositional landforms. Backscatter data, calibrated through sedimentological analyses of the collected samples, enabled the identification of the main sedimentary facies and the definition of the morpho-sedimentological arrangement of the seafloor.

The emerged area is characterized by one of the major urban centers of Calabria (Catanzaro Lido), including strategic infrastructures such as the harbour, and is directly connected to a submerged sector controlled by processes acting along the slope of the Squillace Canyon, which incises the continental margin across a very narrow continental shelf that becomes extremely reduced, or locally absent, at the mouth of the Corace River.

This distinctive geomorphological and urban setting strongly influences coastal morpho-dynamic processes, leading to a peculiar morpho-sedimentological and ecological zonation, as well as to a direct coupling between the sediment transport processes of the Corace River and the sedimentary and gravity-driven dynamics associated with the Squillace Canyon.

Special attention was paid to the transition between the shoreface and the inner shelf. This boundary was defined by integrating closure depth, wave base and breaking depth with morpho-sedimentological and ecological evidence. This approach improves the definition of the boundary between coastal and shelf depositional environments within the morpho-sedimentological framework adopted in the CARG Project.

The results highlight the importance of a multidisciplinary approach combining geological, sedimentological, ecological and marine-coastal engineering data for the characterization and surveying of coastal marine environments. This integrated perspective provides a holistic understanding of the watershed-coastal continuum in peculiar settings such as the marine area of the Catanzaro Sheet, which is fundamental for the assessment and sustainable management of coastal and marine geohazards.

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Coupling between deep fluid migration and sedimentary processes in shaping submarine landscapes: the Crotone Mud Volcano (Northern Ionian Sea)

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Keywords: mud volcanism, overpressured fluids, Plio-Quaternary.

Mud volcanoes are dynamic features of sub-marine landscape, acting as focused pathways for fluid and sediment transfer from deep stratigraphic levels to the seafloor. They are particularly widespread in accretionary prisms, where overpressure, tectonic compression, and fluids generation interact over multiple spatial and temporal scales. The Calabrian Accretionary Prism (CAP, Northern Ionian Sea) represent a key area to investigate these processes, although the interplay between deep-fluid migration, margin architecture, and present-day seepage remain poorly constrained. This complexity is further enhanced by sediment routing systems, such as channel-levee complexes and submarine canyons which transfer sediment from the shelf to the slope and interact with seep-related processes.

Here, we investigate the Crotone Mud Volcano (CMV), a ~ 1.2 km in diameter, crater-like structure at 610 m water depth within the inner CAP, by integrating 3D seismic data with sedimentological and geochemical analyses on sediment cores. Seismic data reveal a vertically continuous conduit crosscutting the Pliocene-Quaternary succession and rooting at ~2.5 km depth in Miocene strata affected by a depletion zone. This architecture indicates a long-lived system, where overpressure is primary generated at greater burial depths (> 5 km) and sustained by thermogenic fluids. The CMV records multiple phases of episodic activity, including a-symmetric rims development, collapse, and reworking, evolving associated with shelf-edge progradation and slope sedimentation. During the Late Pliocene and Pleistocene, interaction with channel-levee systems influenced the morphological expression of the CMV. Major eruptive phases are expressed by massive mud breccia composed of centimetre-sized marlstones and semi-lithified carbonate mud clasts of Early Miocene in age, associated with diagenetically altered foraminiferal assemblages derived the Miocene-Pliocene formations. Besides, pore-water sulphate profiles suggest that the sulphate-methane transition zone (SMTZ) occurs at ca. 4 m below sea floor at the CMV rims suggesting weak, diffusion-dominated regime. Whereas, at the central sector stronger sediment reworking and more active fluid circulation inhibited the preservation of the SMTZ. Water-column data and near-seafloor samples acquired in 2023 indicate intermittent gas release and a thermogenic methane signature. Overall, our results highlight how interactions between deep fluid migration, sediment routing, and near-seafloor processes control the evolution of submarine landscapes and seep-related morphologies in convergent margins.

CARG Sheet No. 524 Foce del Sinni (marine area): Preliminary evidence of outer shelf sedimentary undulations and gravity-driven deformation. First insights from sub-bottom profiles

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Keywords: sediment undulations, sub-bottom profiles, Gulf of Taranto.

The offshore sector of CARG Sheet No. 524 Foce del Sinni (Gulf of Taranto, southern Italy) lies within a key transition zone between the outer Southern Apennine front and the Calabrian Arc, where Late Pleistocene-Holocene stratigraphic architecture and present-day seafloor morphology reflect the interaction among sediment supply, tectonic inheritance, and gravity-driven processes (Meo et al., 2026). In this sector, a preliminary analysis of morphobathymetric data and sub-bottom profiles reveals a ca. 47 km2 field of sediment undulations affecting the outer shelf and locally the shelf-edge domain. Although similar seafloor undulations are commonly interpreted as current-related sediment waves, the acoustic facies observed in the study area suggest a more complex origin. The undulated sector is characterized by a wavy seafloor associated with internally weakly stratified to locally disturbed acoustic facies. These facies are arranged in packages bounded by low-angle, basinward-dipping discontinuities that are tentatively interpreted as slip surfaces. In several seismic profiles, these discontinuities occur as a set of superposed slip surfaces, developed at slightly different stratigraphic levels and progressively losing continuity upward within the shallow succession, thus outlining the internal architecture of a shallow deformational body. On this basis, the observed morphology is tentatively interpreted as mainly related to slow gravity-driven deformation of unconsolidated fine-grained sediments, likely involving creeping or slow sliding, and not simply to depositional bedform construction. At the same time, some sub-bottom lines suggest that the deformational body is overlain by a thin drape of more regular and laterally continuous reflectors, locally displaying low-relief, short-wavelength undulations. These may indicate a later depositional or bottom-current reworking phase superimposed on an older gravity-driven morphology. From this perspective, the outer-shelf morphology documented in this sector appears more comparable to mixed-process examples, in which seafloor undulations have been interpreted as the combined result of creeping and depositional reworking, than to purely current-generated sediment waves (Rebesco et al., 2009). This interpretation is also consistent with previous studies that interpret similar outer-shelf undulations as the expression of shear-dominated failure with limited downslope displacement, rather than exclusively erosional or depositional processes (Iorio et al., 2014; Aiello et al., 2017). Overall, the new dataset provides the first evidence of widespread shallow sediment deformation on the outer shelf of the Foce del Sinni marine sector and highlights the need to integrate seafloor morphology with acoustic facies analysis in order to distinguish deformation-related undulations from transport-related bedforms. This research has been supported by the funds of the CARG Project—Geological Map of Italy at 1:50,000 scale.

Aiello G. et al., (2017) - On the occurrence of the Neapolitan yellow tuff tephra in the northern Phlegraean fields offshore (eastern Tyrrhenian margin; Italy). Italian Journal of Geosciences, 136(2), 263-274, https://doi.org/10.3301/IJG.2017.06.

Iorio M. et al. (2014) - Multi-proxy analysis in defining sedimentary processes in very recent prodelta deposits: the Northern Phlegraean offshore example (Eastern Tyrrhenian Margin). Rendiconti Lincei, 25(2), 237-254, https://doi.org/10.1007/s12210-014-0303-3.

Meo A. et al. (2026) - Ongoing Deformation at the Southern Apennine Front: Insights from the Gulf of Taranto (Italy). Geosciences, 16(4), 141, https://doi.org/10.3390/geosciences16040141.

Rebesco M. et al. (2009) - Morphobathymetric analysis and evidence of submarine mass movements in the western Gulf of Taranto (Calabria margin, Ionian Sea). International Journal of Earth Sciences, 98(4), 791-805, https://doi.org/10.1007/s00531-009-0429-1.

Revealing active deformation in a low-strain-rate region through a multidisciplinary land-to-sea approach: Northeastern Sicily and its offshore (Central Mediterranean)

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Keywords: Low Strain Rate regions

Identifying active tectonic structures within Low Strain Rate regions (LSRRs) remains a major challenge in modern seismotectonics, as surface processes commonly obscure the subtle geomorphic signatures of slow deformation. In this study, we investigate the Tyrrhenian margin of the Peloritani Mountains (NE Sicily), a sector traditionally regarded as a rigid block situated between the high-strain domains of the Messina Strait and the Aeolian-Tindari-Letojanni Fault System (ATLFS). Using a multidisciplinary "land-to-sea" approach that integrates GNSS velocity fields, high-resolution InSAR data from the European Ground Motion Service (EGMS), and offshore seismic reflection profiles, we identify a previously unmapped active fault system. Our results reveal a NNW-SSE-trending right-lateral strike-slip belt extending from the on shore Peloritani ridge into the offshore Milazzo Gulf. Offshore, seismic profiles image positive flower structures affecting Late Pleistocene-Holocene deposits and exerting strong structural control on the linear geometry of the submarine canyon network. Onshore, geodetic analyses support this kinematic framework. GNSS data indicate a relative southward motion of the eastern sector, consistent with dextral strike-slip deformation, while InSAR vertical velocity fields highlight sharp gradients and localized uplift/subsidence anomalies (<2 mm/yr) spatially aligned with the offshore fault structures. Despite the low strain rates, the offshore widespread occurrence of fluid escape features along the fault planes suggests that overpressurized fluids may promote fault lubrication and aseismic creep, potentially explaining the scarcity of large-magnitude earthquakes in the instrumental record. These findings redefine the study area as an active transitional domain accommodating th e eastward propagation of ATLFS deformation, and provide new constraints on the geodynamic evolution and seismic hazard of the central Mediterranean region.

Giant sediment waves, overbank deposits, and sharp thalweg deviations at the Bisagno Canyon Head (Gulf of Genoa)

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Keywords: Canyon Head, giant sediment waves, overbank deposits.

The integration of existing seismic data with new ultra-high-resolution Sparker lines and processed multibeam bathymetric data, collected within the framework of the Italian CARG Project, allowed a detailed reconstruction of the morphology and recent stratigraphic setting of the Polcevera and Bisagno canyon head areas intersecting the continental shelf of the Gulf of Genoa.

The new data show active erosion and landslide scars affecting the deep sectors of the canyon flanks and several sectors of the shelf edge bordering the canyon heads. Seabed instability and canyon heads retreat are often associated with fluid escape phenomena coinciding with inherited NW-SE and NNE-SSW fault systems.

Here, in the upper slope area bordering the southwest sector of the Bisagno Canyon, at depths between 120 and 150 meters, two giant seafloor waves, NW-SE elongated, are detected. This large-scale submarine landform shows high lateral continuity (up to 1 km) and, within the area where they are partially flanked, around 400 metres in wavelength and height up to 10-15 metres. Seismic lines better reveal the depositional character (stratigraphic architecture) of these sediment waves which, towards the canyon flanks, joined to canyon levee with well-developed overbank deposits.

The association of these seabed landforms and stratigraphic features, are useful clues for reconstructing the present or recent past Bisagno canyon heads dynamics, likely conditioned by active tractive/turbidity current flows as well as associated sediment spillover onto the canyon levees.

Based on reconstruction of the Late-Quaternary shoreline in the Genoa Gulf, the triggering of submarine tractive/turbidity flows within the canyon heads can be attributable to hydrodynamic processes related to storm waves produced during the last glacial maximum, when the canyon head intersected a narrow or absent shelf, directly interacting with the littoral dynamics.

In the canyon area, turbidity flow events can also be associated with active large mass movements identified in some sectors of the canyon head. Based on seismic line interpretation, seabed instability and canyon-head retreat are often associated in this area with fluid-escape phenomena coinciding with inherited NNE-SSW and NW-SE fault systems. These latter likely control the direction of the thalweg canyon, producing its sharp deviation.

Our reconstructions provide a basis for understanding the complex interactions controlling the observed bedforms and related processes. Further investigation of the processes involved in the system could improve our understanding of the origin and evolution of these submarine landforms. Future studies should also assess the links between fluid-escape processes, seismic and tectonic activity along the margin, and related geo-environmental hazards, such as erosion and large landslides near the canyon heads. This knowledge is essential for the assessment and management of marine geohazards.

Seafloor mapping in heterogeneous acoustic environments using SAM and CoCa foundation models

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Keywords: Side-Scan Sonar (SSS), spatial and language-guided segmentation, seafloor mapping.

High-resolution Side-Scan Sonar (SSS) imagery interpretation is a key component of modern marine geological mapping, particularly in shallow coastal environments subject to strong natural dynamics and increasing anthropogenic pressure. Within European monitoring frameworks such as the Marine Strategy Framework Directive (MSFD), the growing availability of detailed acoustic datasets emphasizes the need for robust, reproducible and scalable interpretation workflows.

This study investigates the application of recent computer-vision foundation models to the segmentation and classification of seafloor geomorphological features in high-resolution SSS mosaics, focusing on nearshore settings along the Apulian coastline (southern Italy). Three study areas were analyzed - Torre Guaceto (BR), Leporano (TA) and Zapponeta (FG) - encompassing acoustically heterogeneous environments characterized by the coexistence of ripple fields, rocky outcrops and *Posidonia oceanica* meadows, as well as acoustically homogeneous sandy seabeds hosting sparse and localized coralligenous formations.

Two complementary segmentation strategies based on the Segment Anything Model (SAM) framework were evaluated (Kirillov et al., 2023). The first adopts a supervised spatially guided approach, where bounding-box point-wise prompts are used to generate feature-specific masks (Ravi et al., 2025); the second explores a language-conditioned zero-shot segmentation strategy in which, without task-specific training, natural-language prompts guide mask generation (Carion et al., 2025). In both cases, the resulting segments are embedded using a pretrained, frozen Contrastive Captioner (CoCa) vision-language model (Yu et al., 2022) and subsequently classified using either linear or multilayer perceptron (MLP) probes.

Results show that spatially prompted segmentation provides high and stable classification performance in morphologically complex environments, effectively discriminating between coexisting seabed classes. Conversely, text-prompt-driven zero-shot segmentation proves particularly effective in acoustically simpler settings, enabling rapid detection of features with well-separated backscatter signatures, such as sandy deposits and coralligenous formations.

Overall, the proposed workflows show how foundation model-based prompt-driven segmentation can support semi-automated and reproducible geomorphological interpretation of SSS data, significantly reducing manual annotation effort while preserving geological consistency. These results highlight the potential of language- and spatially guided AI frameworks as flexible tools for coastal seabed mapping, habitat assessment and MSFD-oriented environmental monitoring.

Carion N. et al. (2025) - SAM 3: Segment Anything with Concepts. Presented at the The Fourteenth International Conference on Learning Representations.

Kirillov A. et al. (2023) - Segment Anything. Presented at the Proceedings of the IEEE/CVF International Conference on Computer Vision (ICCV), arXiv, Paris, pp. 4015-4026, https://doi.org/10.48550/arXiv.2304.02643.

Ravi N. et al. (2025) - SAM2: Segment anything in images and video. Presented at the Thirteenth International Conference on Learning Representations (ICLR 2025)

Yu J. et al. (2022) - CoCa: Contrastive Captioners are Image-Text Foundation Models, https://doi.org/10.48550/ARXIV.2205.01917.

Submarine landscapes affected by bottom current-driven sedimentary processes and geohazards

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Keywords: bottom currents, contourite and mixed contourite-turbidite systems, submarine geohazards.

Bottom currents are increasingly recognized as major agents controlling the morphology, sedimentary architecture, and geohazard potential of continental margins and deep-marine basins. The interaction between thermohaline circulation, dense water cascading, tidal and geostrophic currents, tectonic deformation, and gravity-driven processes generates highly dynamic submarine landscapes, where contouritic and mixed contourite-turbidite systems strongly influence sediment redistribution and slope stability.

The overview of the main geomorphological and sedimentary features shaped or modified by bottom-current activity illustrates how bottom currents contribute to the formation of contourite drifts, erosional moats, furrows, sediment waves, plastered drifts, and canyon-drift interactions, often in combination with downslope gravity flows and tectonically controlled slope deformation.

Bottom currents have a significant role in preconditioning and amplifying marine geohazards. Current-induced erosion and sediment remobilization may enhance slope instability, reactivate submarine landslides, influence canyon evolution, expose shallow gas accumulations, and affect the integrity of offshore infrastructures and communication cables. Recent advances in multibeam bathymetry, sub-bottom profiling, seismic imaging, seabed monitoring, and numerical oceanographic modeling are improving our capability to identify active sedimentary processes and reconstruct the evolution of submarine landscapes at multiple spatial and temporal scales.

In summary, the recognition of contouritic processes as key components of continental margin dynamics provides new perspectives for understanding the coupling between oceanographic circulation, sediment transport, and submarine geohazards, with broader implications for benthic habitat distribution and offshore georesources in rapidly changing marine environments.

Preliminary study of biocenoses and macrozoobenthic composition to create an integrate map in an understudied area of the Calabrian Ionian Sea

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Keywords: habitat mapping, macrozoobenthos, biocenosis.

The application of integrated multidisciplinary approaches combining remote sensing techniques, geomorphological interpretation and biological analyses is becoming increasingly important for benthic habitat mapping. In this study, a coastal marine area adjacent to the urban centre of Catanzaro Lido, along the Ionian margin of Calabria region, was investigated. The site exhibits high environmental heterogeneity and is influenced by significant anthropogenic pressure due to the presence of both the urban centre, immediately adjacent to the shoreline, and the harbour. Concurrently, south of the urban complex, one of the region's most significant rivers (the Corace River) flows out along a sandy coastline that has been partially impacted by the development of seaside tourism. The survey combined high-resolution multibeam bathymetry and acoustic backscatter with direct sediment sampling for sedimentological and biological ground-truthing. Multibeam and backscatter data were used to identify morpho-acoustic units and their corresponding morpho-sedimentary facies, while sediment samples provided direct constraints on grain-size distribution and macrozoobenthic composition. Sediment collection was performed using a Van Veen grab (0,05 m^2), sieved through a 1 mm mesh and fixed in 70% ethanol. In the laboratory, the samples are sorted to separate the living components (*biocenosis*) from the skeletal remains (*thanatocoenosis*). These are then identified to the lowest possible taxonomic level. Across a total of 17 samples, 351 individuals belonging to 57 distinct taxa were recorded for biocenosis. These results provide a preliminary checklist of species for this poorly investigated Ionian sector, offering essential data on the ecological status of the seafloor and the distribution of benthic habitats. The resulting habitat map represents a bio-sedimentological product, in which the spatial distribution of benthic assemblages is constrained by the coherence between acoustic response, substrate characteristics and macrozoobenthic composition. In comparison with the existing lacunae and inaccuracies inherent in contemporary geo-mapping portals, this monitoring initiative has brought to light the existence of hitherto unrecorded habitats. It is noteworthy that the recovery of well-preserved shells of the gastropod *Smaragdia viridis* may suggests the presence of seagrass meadows in the area. At the same time, the detection of indicator species for unstable and disturbed environments, including *Varicorbula gibba* and *Ditrupa arietina*, support the interpretation of a transition towards facies characteristic of the "Biocenosis of Superficial Muddy Sands in Sheltered Areas" and "Coastal Detrital" biocenoses. Overall, this study highlights the value of integrating morpho-acoustic, sedimentological and macrozoobenthic datasets for benthic habitat mapping and for the interpretation of shallow submarine landscapes affected by both natural dynamics and anthropogenic pressure.

Deciphering anomalous seafloor depressions in the Latium continental shelf: morphological characterization and debated origins

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Keywords: continental shelf, pockmark, morphology.

High-resolution geophysical surveys were undertaken to characterize a marine area of about 87 km² located in the Latium continental shelf, 11 km off the coasts of Terracina and Gaeta (Central Tyrrhenian Sea). Multibeam echosounder and backscatter data were acquired and unexpectedly revealed a field of subtle circular depressions of uncertain origin.

A total of 48 depressed features occur in the north-eastern sector between -100 and -115 m, on a seafloor of silty sand and clayey silt. They display circular to elliptical planforms, locally coalescing into trains, with maximum diameters of 40-230 m and shallow relief (mean depth ~0.40 m, maximum 0.65 m). Their main axes are preferentially oriented E-W and NE-SW. Fifteen of those features present a central peak of hard substratum marked by high backscatter, a few of which rise above the depression rim.

Three hypotheses are evaluated about their origin (1) Erosional scour derived from the interaction between seafloor topography and bottom currents is supported by the asymmetric erosion of nearby morphologic highs. (2) An anthropogenic origin as dumping craters is suggested by angular boulders within some features. However, central material is absent from many of the depressions, weakening the first two hypotheses. This observation instead supports (3) a fluid-escape origin, consistent with the circular geometry, the alignment into trains and the widespread occurrence of pockmarks along the Italian continental margins in the same bathymetric range and seafloor sediment composition (Spatola et al., 2025). Their shallow relief points to reduced sediment thickness, consistent with other low-relief pockmarks documented in the literature (Böttner et al., 2024). Bottom currents act as a subsequent modifying agent that elongates the depressions along the flow direction.

The fluid-escape hypothesis could be corroborated by the occurrence in the area of *Fageapseudes retusifrons*, a tanaid typical of chemically reduced habitats (hydrothermal vents, methane seeps, mud volcanoes), indicating possible active fluid seepage (Cunha et al., 2013; La Valle et al., in press). The area also hosts previously unreported lower-circalittoral rocky reefs with habitat-forming species, qualifying it as a biodiversity hotspot (La Valle et al., in press). This study reports the first occurrence of pockmarks in this sector of the Central Tyrrhenian Sea. Beyond their scientific relevance, these features represent potential geohazards confirming the importance of their systematic mapping in the framework of marine spatial planning and environmental management.

Böttner C. et al. (2024) - The enigmatic pockmarks of the sandy southeastern North Sea. Geochem. Geophys. Geosyst., 25, https://doi.org/10.1029/2024GC011837.

Cunha M. et al. (2013) - Macrofaunal assemblages from mud volcanoes in the Gulf of Cadiz: abundance, biodiversity and diversity partitioning across spatial scales, Biogeosciences, 10, 2553-2568, https://doi.org/10.5194/bg-10-2553-2013.

La Valle P. et al. (in press) - Reef Habitats: New Findings in the Central Tyrrhenian Sea (Mediterranean Sea). Biol. Mar. Mediterr., 30.

Spatola D. et al. (2025) - First pockmark susceptibility map of the Italian continental margins. Mar. Pet. Geol., 176, https://doi.org/10.1016/j.marpetgeo.2025.107337.

Pockmarks on the Italian seamounts: First large-scale morphometric characterisation from the Tyrrhenian, Ligurian, and Sicily Channel

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Keywords: pockmark, multibeam, seamount.

Pockmarks are among the most common geomorphic expressions of seafloor fluid escape, widely documented across marine environments from continental shelves to deep basins (Hovland et al., 1988). Despite their widespread occurrence, their distribution and morphometric variability in the deep-sea (e.g., seamount settings) remain poorly understood due to the scarcity of high-resolution marine geophysical data. A recent review of the Italian seas, focussed mostly on continental shelf and slope settings, documented around 6,000 pockmarks (Spatola et al., 2025). Due to the lack of bathymetric data with the adequate resolution, the analysis however did not involved the deep-sea environments. This shortage was recently overcome with the acquisition of high-resolution multibeam bathymetric data as part of the PNRR Marine Ecosystem Restoration (MER) project. The latter targeted 70 seamounts in the Tyrrhenian Sea, Ligurian Sea, and Sicily Channel, covering an area of ~13,000 km² and resulted also in the collection of Sub-bottom CHIRP profiles and ROV observations, during several expeditions carried out in 2025, aboard the R/V NG Surveyor. A total of 5,053 pockmarks (722 in the Ligurian Sea, 3,860 in the Tyrrhenian Sea, and 471 in the Sicily Channel) were identified and morphometrically characterised by using an open-source semi-automated Python-based workflow, enabling consistent extraction of planimetric area, volume, height, internal slope, elongation index, and planform shape.

Morphometric analysis reveals pronounced variability across the three basins. Pockmark sizes span from normal to mega-class features, with areas ranging from 86 m² to ~3.15 km² and heights from less than 1 m to 97 m. Average wall slopes are consistent across basins (7.2°-7.8°), and planform geometries are dominated by slightly to moderately elongated forms (67-76% of total). Preferred orientations align with the distinctive regional tectonic lineaments of the different basins: NW-SE in the Sicily Channel, NE-SW in the Tyrrhenian Sea, and ESE-WNW in the Ligurian Sea. Thus our research shows that the geodynamic context is the first-order control on pockmark elongation and spatial distribution. In some of the seamounts, however, bottom currents exert a secondary but locally relevant morphological influence.

The spatial distribution and clustering of giant and mega-pockmarks around fault systems and volcanic edifices suggests that focused, structurally controlled fluid expulsion drives the formation of the largest features as suggested elsewhere by Pilcher, and Argent, (2007). Our findings provide new quantitative constraints on fluid escape processes in seamount settings and contribute to a broader understanding of deep-seated fluid migration and seafloor escape in the central Mediterranean.

Hovland M. & Judd A.G. (1988) - Seabed pockmarks and seepages: impact on geology, biology and the marine environment (Vol. 293). London: Graham & Trotman.

Pilcher R. & Argent J. (2007) - Mega-pockmarks and linear pockmark trains on the West African continental margin. Marine Geology, 244(1-4), 15-32.

Spatola D. et al. (2025) - Pockmark Distribution and Genesis in the Mediterranean and Black Seas: A Regional Synthesis.

Mega-pockmarks in the Northern Tyrrhenian Sea: Morphometry, controls, and geohazard implications

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Keywords: pockmark, fluid flow, bathymetry.

We report the first occurrence of twelve mega-pockmarks in the Etruschi Seamount and surrounding sectors of the northern Tyrrhenian Basin, central Mediterranean Sea. These features stand out from a total of 230 mapped depressions based on their exceptional dimensions: major axes exceeding 1,000 m, internal depths greater than 100 m, and volumes on the order of $\sim 10^8$ m³. Morphometric analysis, performed following the semi-automated Python-based workflow proposed by Spatola & Bianchini (2026), shows that size classes are primarily differentiated by vertical parameters, internal depth and volume, rather than by planform geometry. A log-log regression between maximum axis length and internal depth yields a robust positive power-law relationship ($R^2 = 0.75$), consistent with global scaling trends documented in the literature. Their spatial organization reveals a coupled morphogenetic system governed by three main controls: tectonic structures, slope instability, and bottom-current reworking. NNE-SSW-oriented pockmark strings suggest structural discontinuities acting as preferential fluid pathways, while isolated depressions reflect more diffuse seepage conditions. Progressive enlargement and local coalescence are closely linked to slope failure processes and bottom-current activity. The recognition of mega-pockmarks in the northern Tyrrhenian Sea has direct implications for regional geohazard assessment. Focused fluid migration can reduce sediment shear strength and precondition slopes to localized failure, a risk particularly relevant for submarine infrastructure such as telecommunication cables. High-resolution bathymetry and multitemporal surveys are essential to monitor their morphological evolution and assess associated hazards.

Spatola D. & Bianchini M. (2025) - Morphometry of Pockmark Populations. Zenodo. https://doi.org/10.5281/zenodo.19589747.

The importance of paleoclimatic records in Pliocene-Pleistocene sediments for the stability of continental margins. Examples from some parts of the Mediterranean and Antarctic continental margins

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Keywords: landslides, continental margins, climate evolution

Sedimentary sequences record the geological history and the sedimentary response to a range of processes linked to the areal climatic evolution and the time of sedimentation. Some particular tectonic, oceanographic and climatic conditions can lead to the formation of sedimentary sequences containing 'weak layers' due to drastic changes in facies or due to the formation of levels with high organic or tephra contents. These sequences can provide very important ecosystem and chronological informations but can alter the geotechnical and geomechanical characteristics of the sequences under deposition. These sequences, involved then in diagenetic, tectonic, geomorphological and geodynamic processes, can therefore be particularly important in controlling continental margins stabiity, marine landslide formation and continental margin evolution. Some examples of unstable and potentially sensitive marginal zones, linked to the Plio-Pleistocene to Holocene climatic evolution from the Ligurian Coast (Mediterraneo) and from the Antarctic continental margin are here reported.

New evidence for Pleistocene explosive volcanism in the Tyrrhenian Sea from a volcaniclastic layer drilled in the Vavilov Basin (IODP 402, Site U1612)

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Keywords: volcaniclastic deposits, magmatism, Tyrrhenian Sea.

Volcaniclastic sediments are an important component of core samples from submarine regions, and their petrological and geochemical investigation is diagnostic of their volcanic source, thereby permitting tephrostratigraphic correlations. During the recent IODP Expedition 402, focused on the Vavilov Basin in the center of the Tyrrhenian Sea, a volcaniclastic layer was drilled from Hole U1612A, Core 13R, at a depth of ca. 113 meters below the seafloor (Malinverno et al., 2025). The biostratigraphic age profile obtained for Hole U1612A constrains the formation of the layer to the upper Pleistocene (0.94-1.24 Ma). In this study, we examined three thin sections representative of this volcaniclastic layer, coupling the petrographic observation with geochemical analyses of its components. The layer is composed of abundant coarse- to ash-sized volcanic components, including highly vesicular glass shards, crystals, and lithic fragments. The clastic nature of this deposit, coupled with the absence of sedimentary structures, suggests that the layer represents a volcaniclastic turbidite *sensu lato*. The glass fragments exhibit a trachytic composition, with SiO_2 and alkalis (Na_2O+K_2O) contents in the range of 60-64 wt% and 4-9 wt%, respectively. The igneous crystals include clinopyroxene (Mg# 70-90), amphibole, mica, plagioclase (An 37-85), and sanidine. The major-element composition of the glass and mineral phases will be used in conjunction with trace-element analyses (currently in progress) to determine whether the igneous crystals and the glass fragments are cogenetic or have different provenance. Furthermore, because the analysed vesicular glass shards were likely generated during an explosive volcanic eruption, their geochemical signature will be used to correlate their volcanic source with that of volcanic rocks formed during coeval explosive volcanic activity in the Tyrrhenian Sea region.

Malinverno A. et al. (2025) - Site U1612. In: Zitellini, N., Malinverno, A., and Estes, E.R. (Eds), Proceedings of the International Ocean Discovery Program Volume 402, publications.iodp.org1-45, https://doi.org/10.14379/iodp.proc.402.103.2025.

S38.

Mapping the future: the CARG project and modern geological cartography as gateways to territory knowledge

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From basin to inner ramp: facies evolution of the early- middle Eocene "nummulitic limestones" in the Lessini shelf (NE Italy)

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Keywords: Lessini shelf, Eocene, nummulitic limestones.

During the Eocene, a large carbonate platform domain, the Lessini shelf, extended across the present-day Lessini Mountains and Berici Hills (NE Italy). This study investigates the stratigraphic and depositional framework of the so-called "nummulitic limestones," a term encompassing diverse Ypresian-Bartonian neritic carbonates exposed between Verona and Vicenza provinces in the Veneto region (Fabiani, 1915; Schaub, 1962; Ungaro, 2001). It consists of limestones, marly limestones, and marls rich in skeletal components, predominantly larger benthic foraminifera (LBF), and is locally interbedded with volcanic deposits, including lava flows, hyaloclastites, and reworked volcaniclastic sandstones. The "nummulitic limestones" hosts outstanding *Fossil Lagerstätten* (e.g., Pesciara di Bolca and Fosse di Novale) and has been extensively quarried as dimension stone, yielding well-known varieties such as Nanto Stone, Avesa Stone, Gallina Stone, and Chiampo "Marble".

Facies analysis integrated with biostratigraphic correlation across multiple localities of the Lessini shelf allowed the identification of distinct lithofacies associations. These include: (i) marls and marly-limestones rich in planktic foraminifera, often with glauconite; (ii) rudstone-floatstones with LBF, commonly associated with red algae; (iii) packstone-grainstones with abundant porcelaneous foraminifera and acervulinids. These lithofacies, dated to the early-middle Eocene, are consistently distributed over more than 40 km, from the Verona surroundings to the eastern Berici Hills, and may be interpreted as representing basinal, outer to middle and inner-ramp depositional settings within a carbonate ramp system.

Furthermore, a clear regressive trend pointing out a carbonate ramp progradation, locally overprinted by Eocene volcanism, can be recognized. Proximal depositional settings were located toward the N-NW, whereas more distal paleoenvironments developed toward the S-SE. Strong lithologic and stratigraphic affinities across the study area support the existence of a continuous depositional system extending for over 40 km, disrupted only by volcanic activity of the Veneto Volcanic Province (VVP). However, carbonate deposits locally intercalated with submarine volcanic deposits show comparable lithofacies.

These first results provide a clearer and more robust definition of the "nummulitic limestones" and establish a basis for their formal stratigraphic revision, potentially leading to subdivision into multiple formations or members.

Fabiani R. (1915) - Il Paleogene del Veneto. Mem. Ist. Geol. R. Univ. Padova, 3, 1-336.

Schaub H. (1962) - Contribution à la stratigraphie du Nummulitique du Veronais e du Vicentin. Mem. Soc. Geol. It., 3, 59-66.

Ungaro S. (2001) - Le biofacies paleoceniche ed eoceniche dei Monti Lessini (Veneto, Italia). Ann. Univ. Ferrara, Sez. Sci. Terra, 9(1), 1-40.

Accretion, mélange formation, and pre-orogenic pulses: The Morello Unit as a window into Ligurian wedge evolution

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Keywords: accretionary prism, Ligurian Units, Northern Apennines.

The Morello Tectonic Unit (MU) in the Tuscan Apennines preserves an exhumed, shallow portion of the Ligurian accretionary wedge, recording the transition from oceanic sedimentation to accretion. On the Tyrrhenian side, the MU overthrusts Adria foredeep deposits with interposition of Sub-Ligurian units (coherent Canetolo Unit and Vincigliata tectonic mélange - VU) materializing the plate interface. Toward the Adriatic side, the MU progressively becomes dismembered, occurring as metric- to kilometre-scale blocks within the Sestola-Vidiciatico Unit (SVU), a mélange marking the plate interface in this sector. This geometry reflects an along-strike transition from a coherent thrust sheet to tectonically disrupted blocks within the subduction channel. Toward the Umbrian-Marchean sector, the SVU pinches out and the MU is unconformably overlain by late Eocene-Oligocene Epiligurian deposits. In turn, the MU is overthrust by more internal Ligurian units (Monteverdi and Gottero).

The type locality (Calvana-Morello ridges, NW Florence) exposes ophiolitic basement overlain by Upper Jurassic-Lower Cretaceous pelagic sediments and a Cretaceous-Eocene hemipelagic to turbiditic succession (Sillano, Monte Morello, Pescina formations). Detailed 1:10,000 mapping and new biostratigraphy reveal a discontinuous stratigraphic record marked by early Eocene hiatuses and unconformities. These are associated with mass-transport deposits (MTDs) containing ophiolitic detritus derived from gravitational dismantling of intrabasinal structural highs. Similar MTDs occur from the Campanian onward, documenting repeated tectonic pulses from the Late Cretaceous to early Eocene, likely linked to early convergence stages preceding full wedge accretion.

Structural analysis identifies two main contractional phases superimposed on this earlier synsedimentary tectonic record. D_1 (middle-late Eocene, Ligurian Tectonic Phase) corresponds to shallow-level accretion of the MU through isoclinal folding and thrusting, incorporating both sedimentary mélanges derived from MTDs and tectonically disrupted ophiolitic slices by offscraping. A post-D_1 phase (Oligocene-Miocene) reflects collisional overprint and further structural reorganization. These relationships constrain the deformational evolution of the wedge from early convergence through accretion to later collisional stages.

The MU demonstrates that tectonic inheritance within the Ligurian basin—recorded by unconformities, hiatuses, and MTDs—strongly influenced the architecture of the accretionary wedge. Intrabasinal deformation initiated well before final accretion, indicating a protracted and dynamic basin evolution rather than a stable pre-accretion setting. This challenges simplified models of passive sedimentation prior to the middle-late Eocene Ligurian Tectonic Phase and highlights the importance of early deformation in controlling wedge development.

Geological mapping of submerged areas of the "Asinara" CARG sheet (n. 425)

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Keywords: CARG, submerged area, Asinara Island.

The Geological Survey of Italy, within the national CARG Programme (geological and geothematic cartography), in collaboration with other research institutes and universities (National Research Council CNR-ISMAR of Napoli, CNR-IAS of Oristano and the University of Cagliari) carried out the surveying of the submerged area surrounding the Asinara Island (CARG Sheet n. 425).

The bathymetry of the area was derived by Hydrographic Institute of the Navy data and by a multibeam survey performed by CNR-ISMAR and CNR-IAS for the Project MaGIC. Additional existing data include maps realized for the Asinara National Park by several institutes, among which the National Institute of Oceanography and Experimental Geophysics (OGS) that also provided a full set of seismic lines.

For the survey aimed at producing the geological map of submerged areas according to CARG guidelines, 13 chirp sub-bottom profiles and 9 sparker seismic profiles were acquired along the eastern sector of the island, and 26 sediment samples were collected by means of a Van Veen grab to define the seabed granulometric composition. On the western side of the island, 9 sparker seismic profiles and 14 sediment samples were collected. Sample locations were chosen in order to groundtruth the acoustic facies evidenced by the multibeam backscatter. Moreover, coastal areas were characterized by means of underwater surveying and the use of aerial photography.

Bathymetric analyses reveal strong morphological differences between the western and eastern sectors of the island. The western sector is more articulated and complex, characterized by rocky reliefs and limited sedimentary areas, while the eastern sector shows gentler bathymetric gradients, with sandy bottoms. The integration of backscatter data, with sediment sampling and underwater surveying, allowed to identify a variable composition of the seabed. The eastern side shows a consistent presence of marine phanerogams with a seabed mainly characterized by unconsolidated sediments ranging from bioclastic sand and gravel to silty sand. Conversely, the western side is mainly characterized by rocky outcrops (generally undifferentiated offshore but identified, in near shore areas, as lithostratigraphic units recognized on land), the presence of coralligenous deposits and very limited sediment areas confined in low - relief sectors.

Finally, seismic surveys complemented by ministerial seismic data, allowed to identify three main units: a Plio-Quaternary sequence, an Oligo-Miocene succession and an acoustic basement. Moreover, sparker and sub-bottom profiler data allowed to recognize the most recent depositional system (post Last Glacial Maximum) within the study area.

Stratigraphy and sedimentology of the Jurassic “calcari di Monte Mutolo” succession at Monte Tiriolo, Calabria, southern Italy: insights from CARG Sheet 575 “Catanzaro”

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Keywords: Jurassic limestone, calcari di Monte Mutolo, CARG Project Sheet 575 Catanzaro.

This study investigates the Jurassic carbonate succession exposed in the Monte Tiriolo area, at the south-eastern termination of the Sila Piccola Massif, Calabria, Italy. The work was conducted within the framework of the CARG (Geological CARtography) Project - Geologic and Geothematic cartography, sheet n. 575 “Catanzaro”. The succession is assigned to, and regionally correlated with, the calcari di Monte Mutolo (MUO), which forms part of the Mesozoic cover of the Sila-Serre nappe together with Verrucano Peloritano.

The MUO constitutes the main bedrock framework of the relief and is exposed in abandoned quarries and natural rock faces, where observations are constrained by vegetation cover and near-surface gravitational processes. Field mapping, measured stratigraphic logs, core-log data of non-exposed intervals and thin-section analyses are integrated to define the stratigraphic and sedimentological architecture of the succession and to propose a depositional model.

The succession displays marked lithological and textural heterogeneity. Its lower part consists of massive to poorly bedded limestones and dolomitised limestones, organised into metre- to multi-metre-thick beds and affected by fracturing and brecciation. Upward, the succession passes into more regularly bedded limestones, arranged in medium- to thin-bedded strata and composed of alternations of calcarenites and calcilutites, with nodular intervals, stylolites, calcite veins and ferruginous impregnations. Thin-section observations document a transition from grain-supported microfacies, including strongly recrystallised oolitic grainstones, to peloidal-bioclastic packstones and wackestones, and finally to mudstones and grain-poor wackestones. The analysed samples contain miliolids and other benthic foraminifera, planispiral foraminifera, fragments of molluscs, echinoderms and dasycladalean algae, together with ossicles of pelagic crinoids, cf. Saccocoma. Rare spheroidal elements are identified as calcispheres. The occurrence of *Saccocoma* and calcispheres within the upper mud-supported facies records open-marine sedimentation and constrains these deposits to outer-platform to proximal-slope settings.

The data document a deepening-upward Jurassic carbonate succession, from oolitic shoals and shallow inner-platform deposits to low-energy, mud-supported open-marine facies. This evolution records a platform to platform-margin system affected by progressive opening of marine conditions and later modified by dolomitization, recrystallisation, pressure solution and tectonic deformation.

These results identify the MUO as a key archive of Jurassic carbonate-platform evolution in the Calabrides. By linking inner-platform, shoal and open-marine facies, this study provides new constraints for correlating Calabrian sedimentary succession with other Alpine Tethyan sectors and reconstructing the architecture of the Jurassic southern Tethyan margin.

Geological map of the transition zone between the Northern Apennines frontal structures and the Po Plain: new results from CARG Sheet 160 Pavia

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Keywords: Northern Apennines front, CARG Project, geological map.

In this contribution, we present the first complete version of the Geological Sheet 160 "Pavia" (CARG Project), which covers a 583 km² area in southwestern Lombardy (northern Italy). The area represents a key sector for investigating the tectono-stratigraphic relationships between the exposed Northern Apennines and its outermost buried structures of the central Po Plain. The 1:50.000 scale geological map is the result of original field mapping at 1:10,000 scale of the exposed units and Quaternary deposits, integrated with petrographic and biostratigraphic analyses. Surface and subsurface (seismic reflection profiles, deep well data) geological data were examined jointly to reconstruct the geometry of the buried thrust system affecting the Plio-Pleistocene succession, and to correlate the exposed and buried stratigraphic units.

The bedrock succession is mainly composed of arenaceous and marly deep-marine turbidites of the Val Luretta Formation, tectonically overlying younger units along a south-dipping, north-verging thrust fault with a predominant WSW- ENE trend. In the eastern sector of the study area, N-S-trending transfer faults displace the thrust system causing a northward displacement of the structures. North of the main thrust front, a Tortonian-Pliocene sedimentary succession crops out. Facies associations document a general shallowing-upward trend, from deep- to shallow-marine depositional environments. The chronostratigraphic framework of the pre-Quaternary units was constrained through integrated biostratigraphic analyses on 49 samples, undertaken on calcareous nannoplankton and foraminifera.

Quaternary deposits were mapped as Unconformity-Bounded Stratigraphic Units where possible. Geological and geomorphological mapping was integrated with shallow borehole data, remote sensing analyses, sedimentological observations, and palaeo-hydraulic reconstructions, allowing the identification of depositional units and the reconstruction of subsurface stratigraphic relationships. Chronological constraints derive from radiometric dating and archaeological evidence.

From a tectonic point of view, the integration of surface and subsurface dataset highlights a south-dipping, north-verging thrust system affecting both exposed and buried units, with multiple splays and blind thrusts active until at least the Early Pleistocene. These results provide new constraints on the geometry and the evolution of this sector of the Northern Apennines front, demonstrating the effectiveness of combining field-based geological data with subsurface data to link outcropping and buried portions of orogenic belts.

Evidence of subaerial exposure and rapid drowning in the Austroalpine succession (Val Roia, Resia Pass, Italy): Implications for the Jurassic rifting of the Alpine Tethys

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Keywords: stratigraphy, geological mapping, rifting.

Field activity in the frame of the CARG project (Sheets Malles Venosta - Passo di Resia) documented the presence of a major stratigraphic gap between early-dolomitized carbonate platform faces of the Dolomia Principale and a bedded, cherty Jurassic succession structurally belonging to the Scharl Nappe, exposed just below the Oetztal Nappe in Val Roia, Bozen-Bolzano (Italy). Sedimentological evidence indicates a major subaerial exposure of the Dolomia Principale documented by different facies: 1) conglomerates with red matrix and rounded pebbles up to 10-15 cm in size; 2) red breccias with poorly selected angular clasts embedded in a red matrix and 3) vertical fractures and cavities crossing the uppermost part of the Dolomia Principale up to a few tens of meters from the top of the unit. These facies are interpreted as evidence of a long-lasting subaerial exposure, documented by transportation of rounded pebbles by water on the top of the exposed platform (facies 1), presence of lateritic paleosols with regolith (facies 2) and karst cavities and fractures (facies 3). Despite the strong Alpine deformation, the transition from the exposed platform top and the overlying unit is locally preserved. The subaerial exposure and associated deposits are unconformably covered by strongly deformed and transposed cherty limestones. Lenses of Rosso Ammonitico facies up to 1.5-2 m thick containing deformed Pliensbachian-Toarcian ammonoids occur on top of the tilted blocks of Dolomia Principale along the unconformity. According to these biostratigraphic constraints, it follows that the basinal Jurassic succession, despite similar facies, is significantly younger that the Allgau Formation of the Central Austroalpine. Facies associations and ages suggest the presence in the Resia Pass area of a structural high persisting later than the documented drowning (since the Hettangian) of other parts of the Austroalpine domain. This situation demonstrates the existence of complex topography created by the Jurassic rifting and a time-transgressive drowning of the highs bordering the subsiding grabens. Small outcrops of red radiolarites also occur in the area and are now in study. The reconstruction of the presence of areas with different Jurassic evolution can provide the chance to detail the distribution of fault-controlled highs and lows, as well as to identify and date tectonic events documented by differences in the stratigraphic evolution of coeval successions. These results strongly support the importance of detailed geological surveys, able to provide new data that, besides improving the local geology, are able to shed light on the regional evolution of complex geological settings.

Biochronology, paleoenvironmental and geodynamic significance of the Early Pleistocene marine succession of the 370 Sheet Guardiagrele (Central Apennines, Italy)

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Keywords: CARG Program, Early Pleistocene, open neritic to circalittoral environment.

During the realization of the Sheet 370 "Guardiagrele" of the Geological Map of Italy at 1:50,000 scale (CARG Program), multidisciplinary research including field data, biostratigraphic analyses on calcareous nannofossils and foraminifers and well-data leads to a revision of the Mutignano formation (FMT) Early Pleistocene in age, cropping out in this sector of the periadriatic belt. The formation primarily consists of siliciclastic and carbonate deposits (clays, sands, and conglomerates) that record the final infilling stages of the Pliocene-Pleistocene foredeep (Accotto Festa et al., 2014). A lot of samples collected from the FMT revealed ages ranging from the upper Gelasian to the Calabrian stage of the Early Pleistocene. Furthermore, benthic assemblages allow a large scale paleoenvironmental reconstruction from the bathyal (upper Gelasian) to the infralittoral-circalittoral (middle-late Calabrian) zones, indicating a regressive trend. Moreover, field data and sedimentological observations show that Gelasian to early Calabrian deposits of the lower succession (cropping out east of the Casoli Village) consist of prevailingly massive clays, with sporadic silty levels

sedimented at greater depths; they tend to thin out or completely disappear as they proceed towards the chain or to the Guardiagrele village area, where they show an appreciable degree of deformation. Instead, generally coarser deposits of the middle-late Calabrian sedimented at shallower depths and exhibit a greater lateral continuity and a lower degree of deformation. Therefore, biostratigraphic results, sedimentological observations, and the geometric, stratigraphic and bathymetric reconstructions imply the Pleistocene marine succession could not be considered an undifferentiated sedimentary body of alternating distinct facies (Crescenti et al., 2011). Conversely, it should be subdivided into new stratigraphic units of different age and palaeoenvironmental meaning. Besides, in addition of the Piacentian in age previously established basal member FMT 1 (membro di Canzano, Brozzetti et al., 2011), we propose the definition of two new members: a middle one (FMT 2), late Gelasian-early Calabrian in age, referrable to an open neritic marine environment and an upper one (FMT 3), Calabrian in age, of a circalittoral environment. Between the two members, the presence of a modest angular unconformity may be recognized. Finally, surveys and micropaleontological analyses revealed the presence of a condensed succession of deposits, Gelasian - Calabrian in age, never reported inside the orogen building between the Maiella Mountain and the Alloctonous Units. This is the south-westernmost ever recognized outcrop of the Mutignano formation and a crucial clue to assessing the timing of compressive tectonic deformation in this sector of the central Appennine.

Brozzetti F. et al. (2011) - Note illustrative della carta geologica d'Italia alla scala 1:50.000, Foglio 339 Teramo.
Crescenti U. et al. (2011) - Note illustrative della carta geologica d'Italia alla scala 1:50.000, Foglio 361 Chieti.
Festa A. et al. (2014) - Geology of the Aventino River Valley (eastern Majella, central Italy). Journal of Maps, 10(4), 584-599, http://dx.doi.org/10.1080/17445647.2014.899524.

Stratigraphic and structural reconstruction during the Zanclean-early Piacenzian: a case study of the Trubi unit of CARG Sheet n. 628 "Sciacca" (southwestern Sicily)

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Keywords: lithofacies analysis, synsedimentary tectonics, Pliocene.

The reflooding of the Mediterranean Sea by Atlantic waters, following the end of the Messinian Salinity Crisis, marked the return to normal sea conditions in this region (Micallef et al., 2024). Depositional dynamics radically changed in the Mediterranean (Van Couvering et al., 2000) starting from 5.33 Ma, well documented by the following deposition of the pelagic record of the Trubi.

This work aims to interpret the different lithofacies of the Trubi unit cropping out in the Sciacca area (CARG Sheet n. 628 "Sciacca"; Sulli et al., 2024), using them as a proxy to reconstruct the paleoenvironmental and physiographic evolution of southwestern Sicily during the Pliocene. Biostratigraphic analyses based on planktonic foraminiferal communities were performed to obtain a comprehensive chronostratigraphic framework of the studied successions. Additionally, lithostratigraphic, sedimentological, and facies analyses, along with structural analyses, have proven to be crucial elements in reconstructing the depositional dynamics as well as the timing and style of tectonic deformations that have affected the outermost portion of the Sicilian Fold and Thrust Belt during the Pliocene (Gasparo Morticelli et al., 2015).

The data highlighted that the pelagic sequences of the Trubi unit were deposited in different depositional settings during the early Zanclean.

Due to compressional tectonic forcing, central-western and northern portions of the study area, consisting of deformed Meso-Cenozoic carbonate successions and their Neogene covers, remained exposed during the Late Miocene, preventing the deposition of evaporitic series there. Here, in fact, the marly limestones and marls of the basal part of the Trubi unit (planktonic foraminiferal biozones MPl1/2) unconformably overlie the Miocene deposits of the "San Cipirello marls" and/or directly the underlying carbonate substrate. Subsequently, during the middle-late Zanclean (planktonic foraminiferal biozones MPl3/4a), in the northwestern sector of the M. S. Calogero structural high and south of the Caltabellotta ridge, marly-clayey facies were deposited, attesting to the development of hemipelagic sedimentation. Finally, significant amounts of carbonate megabreccias were deposited at the base of tectonically controlled scarps during the late Zanclean-early Piacenzian (planktonic foraminiferal biozone MPl4), particularly in the R. Ficuzza ridge area (northern part of the Sheet).

Conversely, in the southeastern sector of the sheet area, which is characterized by the presence of the Gela Nappe units, the marly limestones and marls of the basal portion of the Trubi unit (planktonic foraminiferal biozones MPl1/2) were unconformably deposited on top of the late Messinian clayey-gypsum deposits. Pelagic deposition persisted in this sector until the early Piacenzian (planktonic foraminiferal biozones MPl3/4), apart from the deposition of brecciated clays with resedimented deposits related to submarine gravitational flows exclusively in the easternmost portion.

Gasparo Morticelli M. et al. (2015) - Deep controls on foreland basin system evolution along the Sicilian fold and thrust belt. Bulletin de la Société Géologique de France, 186, 273-290, https://doi.org/10.2113/gssgfbull.186.4-5.273.

Micallef A. et al. (2024) - Land-to-sea indicators of the Zanclean megaflood. Communications Earth & Environment, 5(1), 794, https://doi.org/10.1038/s43247-024-01972-w.

Sulli A. et al. (2024) - Note Illustrative della Carta Geologica d'Italia alla scala 1:50.000, F. 628 Sciacca, ISPRA - Serv. Geol. d'It., Roma, https://doi.org/10.15161/oar.it/4na57-8b027.

Van Couvering J.A. et al. (2000) - The base of the Zanclean Stage and of the Pliocene Series. Episodes Journal of International Geoscience, 23(3), 179-187, https://doi.org/10.18814/epiiugs/2000/v23i3/005.

A revised Upper Jurassic stratigraphy of the Belluno Basin

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Keywords: Jurassic, Southern Alps, Rosso Ammonitico.

The Belluno Basin (eastern Southern Alps) was a narrow deep-water corridor formed in the Early Jurassic as part of the rifting of the Adria microplate, which eventually led to the opening of the Ligurian-Piedmont Ocean. It is infilled by nearly 2000 m of Jurassic and Lower Cretaceous carbonates, commonly containing chert, deposited in deep water environments. In the early stages, the basin was flanked to the West by the Trento Carbonate Platform and to the East by the Friuli Carbonate Platform. Both platforms rested on Early Jurassic structural highs and were separated from the Belluno Basin by normal faults. The Trento Platform drowned during the Middle Jurassic, while the Friuli Platform persisted until at least the Late Cretaceous.

The Late Jurassic of the Belluno Basin is represented by cherty limestones of the Fonzaso Formation overlapped by white lime-mudstone of the Maiolica fm. in late Tithonian. There have, however, been inconsistencies in how the interval has been mapped since the very beginning of the CARG project. These inconsistencies concern a nodular limestone unit, late Kimmeridgian to early Tithonian in age, either considered part of the Fonzaso Fm. (e.g., Chiari et al., 2007; Picotti & Cobianchi, 2017) or a facies of the Rosso Ammonitico Veronese fm. (Costa et al., 1992).

We have documented the Upper Jurassic facies gradient along a ca. 35 km-long platform-basin transect, extending from the Grappa Massif to the area of Vittorio Veneto. The nodular cherty limestones of the basin domain correlate to the upper member of the Rosso Ammonitico Veronese (ARV_3), but show distinctive facies that can be identified in the common mapping practice.

We suggest that the Kimmeridgian-Tithonian nodular limestones with chert of the Belluno Basin should not be associated with the units of a former platform domain, but may rather be distinct as a new member of the Fonzaso Fm. For this new lithostratigraphic unit, occurring in several sheets of the Italian Geological Map at the 1:50000 scale (e.g., Monte Grappa, Feltre, Belluno, Longarone, Vittorio Veneto, Claut), we propose the name "Revine Member of the Fonzaso Formation" (FOZ_1).

The Revine Member is the first basinal unit after the Late Jurassic rifting phase to show thicknesses comparable to those of its correlative on the Trento Platform domain. It therefore represents the leveling out of the seafloor topography. Its distinctive feature, i.e., nodularity, is likely related to this physiographic change and reflects improved water circulation and better oxygenation of the sea bottom, which fostered bioturbation.

Chiari M. et al. (2007) - Integrated stratigraphy (radiolarians and calcareous nannofossils) of the Middle to Upper Jurassic Alpine radiolarites (Lombardian Basin, Italy): Constraints to their genetic interpretation. Palaeogeography, Palaeoclimatology, Palaeoecology, 249, 233-270, https://doi.org/10.1016/j.palaeo.2007.02.001.

Costa V. et al. (1992) - Note illustrative della Carta Geologica d'Italia alla scala 1:50000, F. 63 Belluno. 74 pp., Servizio Geologico d'Italia.

Picotti V. & Cobianchi M. (2017) - Jurassic stratigraphy of the Belluno Basin and Friuli Platform: a perspective on far-field compression in the Adria passive margin. Swiss Journal of Geosciences, 110, 833-850, https://doi.org/10.1007/s00015-017-0280-5.

A New Geological Map of the Dolomites UNESCO World Heritage Site: Methodology and aplications for geoscience communication

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Keywords: Dolomites, UNESCO World Heritage, geological map.

The Dolomites, inscribed as a UNESCO World Heritage Site (WHS) in 2009, represent one of the most spectacular and scientifically significant mountain landscapes on earth. Despite their outstanding geological value, the last geological map covering the full extent of the Dolomites dates back to the one appended to the landmark monograph "Le Dolomiti: geologia dei monti tra Isarco e Piave", authored by Piero Leonardi and published in 1968 at a scale of 1:150,000. Over half a century later, significant advances in geological knowledge and scientific communication demand a thoroughly updated and purpose-designed cartographic resource.

This contribution presents the new geological map of the Dolomites UNESCO WHS, developed within the framework of the science dissemination activities promoted by the Fondazione Dolomiti UNESCO. It provides both general audiences and geoscience professionals with an innovative, accessible, and scientifically rigorous visual tool. Conceived for use at the 1:125,000 scale, the map synthesises the geological substrate into 26 cartographic units, grouped and colour-coded according to their temporal attribution and depositional environment. This approach allows users to visualize the geology of the Dolomites — from Basement to Cenozoic molasse — in an intuitive and visually compelling manner.

The map was constructed through a multi-source integration methodology. The data sources include the geological sheets of the CARG project (the Italian national geological mapping programme), the geological hazard map of the Autonomous Province of Trento, published scientific literature, and previously unpublished field surveys partly conducted specifically for this project. The heterogeneous nature of the available cartographic coverage across the study area posed a significant methodological challenge: existing datasets differ in scale, stratigraphic nomenclature, and structural representation. A substantial harmonisation and simplification effort was therefore undertaken to ensure internal consistency across the entire map, both for the substrate units and for the structural elements.

To the understanding of the three-dimensional geological architecture of the Dolomites, two interpretive geological cross-sections have been constructed, illustrating the main tectonic structures, including the regionally significant thrust systems and associated folds.

The new geological map of the Dolomites UNESCO WHS will be released in both ready-to-print and digital formats, ensuring broad accessibility for a diverse range of users — from hikers and geotourists following the Geotrail itineraries to students, educators, and earth scientists. This work represents a significant step forward in the geological documentation and public communication of one of the world's most celebrated mountain regions, and it is hoped that it will serve as a lasting resource for both scientific inquiry and heritage appreciation for decades to come.

Reconstruction of geological models in southwestern Sicily using a multidisciplinary approach based on outcrops, boreholes and geophysical surveys

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Keywords: CARG, HVSR, geological models.

A multidisciplinary study was carried out in the southwestern sector of Sicily in the framework of the activities associated with the preparation of the geological sheet n. 618 "Castelvetrano" at the 1:50.000 scale for the Italian National Geological Mapping Programme (CARG) (https://progetto-carg.isprambiente.it/).

The study area is located in the outer sector of the Sicilian thrust and fold belt chain and hosts a sedimentary succession that ranges from the Lower Jurassic to the Pleistocene in age (Vitale, 1997). This research focused mainly on reconstructing the subsurface features of selected areas characterized by relevant differences in lithologies and mechanical behaviour. The aim was to determine geological models in which the depth and extent of the stratigraphic horizons separating between different stratigraphic deposits is described.

These geological models were performed by analysing geological, palaeontological and geophysical data, integrating existing heterogeneous datasets with new geological and geophysical surveys. The workflow was subdivided in several steps. Firstly, stratigraphic logs were collected from multiple databases and critically analysed to filter reliable information. A list of lithological codes was created to associate each lithostratigraphic identified in the logs to a specific lithostratigraphic unit. During this phase, the depth of the top of each stratigraphic unit were recorded and digitized to insert them into geological models then.

A second phase involved the logs re-evaluation with imprecise, misleading contradicting information, to assign a univocal formation name to each stratigraphic unit. To resolve these issues, detailed geological field surveys were carried out in areas with ambiguous stratigraphic data. Ad hoc sedimentological and paleontological investigations performed on outcrops and trenches, helped to provide accurate stratigraphic definition and this refine the stratigraphic assignment to each unit.

In the third phase, existing microtremor recordings, processed through the Horizontal to Vertical Spectral Ratio technique (HVSR) (Nakamura, 1979) were qualitatively analysed alongside new passive seismic surveys. The analysis of the HVSR curves enabled a correlation between stratigraphic and geophysical data, particularly where these geophysical surveys have been performed near stratigraphic logs. Models derived from HVSR inversion, constrained by geological and existing geophysical data, were developed. The seismic units were subsequently linked to the main lithological boundaries (Canzoneri et al., 2025), defining the depths of the top of these interfaces. Finally, by merging all punctual information, the main lithological horizons have been reconstructed.

This workflow advances the knowledge of this sector of Sicily and provides a framework for reconstructing the geological evolution of the area.

Canzoneri A. et al. (2025) - Reconstruction of a 3D bedrock model in an urban area using well stratigraphy and geophysical data: a case study of the city of Palermo. Geosciences, 15(5), 174, https://doi.org/10.3390/geosciences15050174.

Nakamura Y. (1989) - A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface. Railw. Tech. Res. Inst. Q. Rep., 30, 25-33, http://worldcat.org/oclc/3127232.

Vitale F.P. (1997) - The Belice and the Menfi Basins: sequence stratigraphy and evolution during the Pliocene and the Early Pleistocene. Time scales and basin dynamics. Sicily, the adjacent Mediterranean and other natural laboratories. Western Sicily Field Guidebook, Palermo, 48-58.

Decoding a "Monotonous" Basement: New insigthts on the Northern Dora-Maira Massif from the CARG "172 Pinerolo" Sheet

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Keywords: CARG Project, Dora-Maira, crystalline basement.

Understanding the geology of Italy is essential for reconstructing its geodynamic evolution and for supporting geological hazard assessment and natural resource management. In this context, geological mapping represents a fundamental tool, providing the basis for further analyses and interpretations.

Within this framework, the ongoing geological mapping of the "172 - Pinerolo" Sheet, part of the Italian CARG (Geological Cartography) Project, focuses on a sector of the Western Alps comprising the Dora-Maira Massif (DMM) (Sandrone et al., 1993), tectonically overlain by oceanic-derived units. This is a key area for investigating continental subduction and exhumation in collisional orogens. Although ultra-high-pressure (UHP) metamorphism was first documented in the southern DMM Brossasco-Isasca Unit (Chopin, 1984), the northern DMM has long been considered a relatively "monotonous" basement, consisting of an upper polycyclic and a lower monocyclic basement unit affected by Alpine eclogite- and blueschist-facies metamorphism, respectively.

However, investigations carried out during the project reveal a far more complex architecture. An integrated multidisciplinary approach was adopted for the study, combining digital geological mapping, structural and microstructural analysis, petrology, thermodynamic modelling, geochemistry, U-Pb zircon and Ar^{40}/Ar^{39} petrochronology and palynology. Fieldwork was conducted using tablet-based digital mapping integrated with georeferenced databases in a QGIS environment.

This approach produced several important new results and a re-organization of the tectonic units of the DMM. U-Pb zircon dating identified previously unrecognised Lower Cambrian-to-Permian magmatic suites, providing new constraints on the pre-Alpine evolution of the crystalline basement (Dana et al., 2025). Petrological investigations and thermodynamic modelling constrained high- to ultra-high-pressure (HP/UHP) metamorphic conditions across the different units, whereas structural analyses revealed a polyphase Alpine tectonic evolution and clarified the relationships between continental basement and oceanic-derived units. Particularly noteworthy is the discovery of Paleozoic and Mesozoic fossil palynofloras preserved within UHP metamorphic rocks (Carosi et al., 2025), demonstrating that palynological analysis can represent a rapid and cost-effective tool for deciphering the internal architecture of crystalline basements.

Overall, the new data offers new insights on the geological framework of the northern Dora-Maira Massif, highlighting a previously unrecognised complexity and confirming the crucial role of integrated geological mapping in reconstructing the evolution of deeply subducted continental crust.

Carosi R. et al. (2025) - Buried, not erased: palynofloras in ultra-high-pressure metamorphic rocks. Sci. Rep., 15(1), 35865, https://doi.org/10.1038/s41598-025-23551-5.

Chopin C. (1984) - Coesite and pure pyrope in high-grade blueschists of the Western Alps: a first record and some consequences. Contrib. Mineral. Petrol.86(2), 107-118, https://doi.org/10.1007/BF00381838.

Dana D. et al. (2025) - The Lower Paleozoic to Permian evolution of the Dora-Maira Massif basement (Western Alps) revealed by zircon geochronology. Geol. Mag., 162, e45, https://doi.org/10.1017/S0016756825100332.

Sandrone R. et al. (1993) - The dora-maira massif. In Pre-Mesozoic geology in the Alps, 317-325, https://doi.org/10.1007/978-3-642-84640-3_18.

Accessible and interactive multiscale geo-structural data visualization: An example of WebGIS integration within the CARG Project (Sheet 602 “Motta San Giovanni”)

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Keywords: WebGIS, multiscale, geo-structural data.

Modern geological mapping increasingly requires the integration of heterogeneous datasets collected across multiple spatial and observational scales. Within the framework of the ISPRA CARG project, this challenge is particularly evident in structurally complex metamorphic contexts, where field observations, topographic data, and microstructural analyses need to be integrated to reconstruct geological evolution and produce reliable cartographic outputs.

This contribution presents a WebGIS-based approach designed to extend traditional geological mapping into an interactive, multiscale knowledge system. The proposed framework enables the integration of geo-structural data ranging from regional to outcrop scale measurements, up to thin-section analyses. By structuring these datasets within a unified web environment, the approach supports seamless navigation across scales and facilitates the direct comparison of observations that are typically fragmented across different platforms and formats.

The methodology is applied to the CARG Sheet 602 “Motta San Giovanni”, focusing on a mylonitic shear zone outcrop (Fazio, 2019) where field surveys and petrographic investigations have been conducted. This case study demonstrates how a properly structured web platform can enhance the interpretation of multiscale geodata, helping the transition to a more dynamic representation by means of dedicated and interactive web tools. This, in turn, improves data accessibility, supports interdisciplinary integration, and potentially allows a more comprehensive understanding of complex geological systems.

Fazio E. (2019) - Chapter 10 - Recognition of Structures in Mid-crustal Shear Zones and How to Discern Between Them, in: Billi, A., Fagereng, Å. (Eds.), Problems and Solutions in Structural Geology and Tectonics, Developments in Structural Geology and Tectonics. Elsevier, 119-128, https://doi.org/10.1016/B978-0-12-814048-2.00010-7.

The Monte Bianco and Gran San Bernardo sheets of the Carta Geologica d'Italia: a full traverse of the Europe-vergent tectonic domains of the Alps

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Keywords: Monte Bianco, Gran San Bernardo, CARG Project, geological mapping.

Here we present the new Monte Bianco and Gran San Bernardo sheets of the Carta Geologica d'Italia. These sheets are notable in that they encompass all the tectonic domains of the Europe-vergent belt of the Alps, from the Helvetic-Dauphinois, through the Penninic, to the Austroalpine. In total they document almost 20 tectonic units, listed below from top to bottom and from SE to NW. In the Austroalpine, the Valpelline and Arolla units of the Dent Blanche Nappe are present, along with minor outcrops of the Roisan-Cignana Shear Zone. Above the Penninic units, we find the Combin Unit, part of the Piedmont ophiolitic nappes. This is in contact, through the Pleureur continental cover unit, with the Grand Saint Bernard Middle Penninic nappe system, represented by the Mont Fort, Siviez-Mischabel and Ruitor (mainly) basement nappes, and by the Houillère and Costa Serena (mainly) cover units. These in turn are in contact, at the Briançonnais frontal thrust, with the External Penninic Pierre Avoi, Tarantasia, Pyramides Calcaires, and Ferret units. Across the Penninic Frontal Thrust, underlined by heterogeneous slices of cover and mafic rocks, a thick — probably tectonically thickened — sequence of the Helvetic cover is present, with basement slices represented by the Testa Bernarda and Mont Chetif units, and finally the continuous basement of the Mont Blanc massif.

Metamorphic conditions within these units range from pre-alpine high-grade (Valpelline) to alpine blueschist (Grand Saint Bernard), low-T greenschist (External Penninic), and anchizone (Helvetic). Deformation is polyphase, including phases of nappe stacking and exhumation under extensional or oblique strike-slip regimes.

The Quaternary succession includes glacial, fluvial, gravitational, and periglacial deposits, spanning from the Last Glacial cycle (~30-11.5 ka BP) to the Present. These deposits reflect the geomorphological evolution of medium- to high-elevation valleys shaped by glacier advance and retreat, debris flow, slope instability, and permafrost-related activity. Glacial deposits from the Last Glacial Maximum (LGM) and Late-Glacial phases are locally preserved, whereas the more prominent moraines are mainly associated with Holocene expansions, particularly the Little Ice Age (LIA). Gravitational and periglacial deposits, including talus, debris-flow accumulations, landslides, and rock glaciers, are widespread at all elevations.

New insight of the Gardetta-Viozene Zone (GVZ) from the Cuneo-Colle di Tenda (sheets 226 and 243) CARG mapping project

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Keywords: Cuneo-Colle di Tenda, deformation zone.

The southern termination of the Western Alps in the Maritime and southern Cottian Alps is characterized by the juxtaposition of different geological domains in a complex transpressive tectonic system developed along the Pennidic thrust zone between the Briançonnais and the Provençal-Dauphinois domains. This region consists of an assemblage of juxtaposed tectonic units aligned along a WNW-ESE direction, corresponding to a regional deformation zone (Limone-Viozene Zone, d'Atri et al., 2016; Gardetta-Viozene Zone, GVZ, Piana et al., 2021).

The detailed geological mapping of the sheets "226 Cuneo" and "243 Colle di Tenda" allowed to characterize a NW-SE striking sector of the GVZ developed between the Gesso and Stura valleys. This sector, named as Andonno Zone, includes tectonic slices of the Briançonnais domain as well as the Eocene to lower Oligocene Alpine Foreland Basin succession, composing a complex deformation zone characterized by tectonic disruption of the primary stratigraphic succession and a low-grade metamorphism. Tectonic slices are composed of Middle and Upper Jurassic marbles, Cretaceous hemipelagic metasediments, cargneules and minor Middle Triassic dolomitic meta-breccias. Metamorphosed limestones and sandstones, referable to the Alpine Foreland Basin succession, also occur. These bodies are strongly deformed and stretched along an oblique lineation, and often show a well-developed mylonitic fabric indicating a top-to-WNW vergence.

The study area shows three main deformation phases (D1-D3). D1 corresponds to SW-verging thrusting leading to stacking of Briançonnais, Provençal, and Dauphinois domains, associated to a metamorphism decreasing towards the external sectors. During this phase, the Andonno Zone was developed as a thick tectonic boundary juxtaposing the Briançonnais domain over the Provençal domain. D2 and D3 phases reflect retrovergent folding and transpressional deformation during the progressive exhumation and Alpine back-thrusting, which characterized the Oligocene and Early Miocene evolution of SW Alps.

The detailed studies carried out in the frame of the geological mapping of the sheets "226 Cuneo" and "243 Colle di Tenda" allow to better understand the frontal zone of the Alpine belt (Pennidic thrust zone), to which the study area belong to, both in terms of metamorphism, age of deformation, and structural setting.

d'Atri A. et al. (2016) - Geological setting of the southern termination of Western Alps. International Journal of Earth Sciences, 105(6), 1831-1858.

Piana F. et al. (2021) - The Alps-Apennines Interference Zone: A Perspective from the Maritime and Western Ligurian Alps. Geosciences, 11(5), 185.

From the Early Pleistocene to the Lateglacial: A polyphase glacial record in the Pellice Valley, NW Italy

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Keywords: cartography, glacigenic successions, Pellice Valley.

Research and fieldwork conducted within the framework of the ongoing CARG Project (Geological Map of Italy, Pinerolo Sheet N. 172) have provided new insights into the glacial evolution of the Pellice Valley, a major 30-km-long catchment in the inner Western Alps. The area preserves key evidence of repeated Alpine glacial expansions spanning from the Early to Middle Pleistocene to the Lateglacial. During the Last Glacial Maximum (LGM), the Pellice paleoglacier reached a length of ~19 km, terminating near the village of Villar Pellice. Deposits and forms related to the last glacial cycle, grouped within the Cognetti synthem, include subglacial sediments (lodgement and submarginal tills) and terminal moraines near Teynaud. A subsequent glacial stillstand is documented around the Cognetti settlement by several lateral-frontal morainic ridges. The occurrence of marker lithologies such as Monviso Massif metabasites and serpentinites within glacial deposits suggests that some tributary glaciers (eg., Comba Carbonieri) coalesced with the main glacier during the LGM, whereas others (Comba Luissa and Subiaschi) did not. Smaller, heavily remodelled morainic ridges upstream of Bobbio Pellice and near Ferrera are attributed to the early Lateglacial, while younger Lateglacial stadials are widespread within tributary valleys and along the main valley floor at progressively higher elevations. Downstream of the LGM terminus, pre-LGM glacigenic deposits have been grouped into three distinct units based on pedostratigraphic and morphostratigraphic evidence: the Purracira synthem, the Budro supersynthem, and the Saret supersynthem, related to the MIS 6, MIS 12-10, and MIS 22-20 glaciations, respectively. The Purracira synthem comprises poorly weathered submarginal and ice-marginal glaciolacustrine deposits (soil hues up to 7.5YR) perched above the LGM margin. The Budro supersynthem consists of lodgement, submarginal, ice-marginal, and glaciolacustrine sediments, exhibiting stronger weathering (up to 5YR soil hues). The oldest unit, cropping out at the valley outlet between Luserna San Giovanni and Bricherasio, is the Saret supersynthem. It consists of lodgement, sub-marginal, and deformation tills, weathered erratic boulders (eclogites, orthogneisses, and metagabbros), and a terraced proglacial fluvial unit with up to 2.5YR soil hues. These deposits record a maximum glacier expansion attributable to MIS 22-20, based on the occurrence of unexposed lacustrine bottomset deposits from a palaeo-lake between Torre Pellice and Luserna San Giovanni, recovered from boreholes. These subsurface sediments were previously interpreted as the infill of an Early Pleistocene tectonic basin (Val Pellice lacustrine complex; Collo, 1996) but are here reinterpreted as the infill of a late Early Pleistocene proglacial lake. Their age is assigned by correlation with analogous lacustrine deposits showing reversed palaeomagnetic polarity, exposed in the nearby lower Chisone Valley (Bernard supersynthem).

Collo G. (1996) - I depositi lacustri delle valli Chisone e Pellice (Alpi occidentali, Provincia di Torino). Alpine and Mediterranean Quaternary, 9(1), 123-136.

Towards sustainable territorial planning: The hydrogeological Sheet No. 464 'Ischia Island

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Keywords: hydrogeological map, volcanic aquifer, Ischia Island.

Identifying and implementing effective development strategies in small volcanic islands remains a major challenge due to the complex interaction among environmental, geological, and socio-economic factors. Sustainable and resilient management approaches require the integration of scientific and technological knowledge related to environmental resources, natural hazards, and socio-economic dynamics. In this perspective, territorial planning should adopt a holistic and interdisciplinary approach, prioritizing geological and hydrogeological frameworks over fragmented sector-based policies. Geothematic cartography, particularly hydrogeological mapping, represents a fundamental tool for territorial governance, fostering cross-disciplinary and intersectoral decision-making processes.

This contribution presents the ongoing activities related to the preparation of the Hydrogeological Sheet No. 464 "Ischia Island" within the C.A.R.G. Project.

Ischia Island is characterized by intense and long-lasting hydrothermal activity documented since the 16th century, with the first studies on therapeutic use of thermal waters dating back to Iasolino (1588). Over time, numerous geological maps, including detailed surveys at a 1:10,000 scale, have considerably improved the understanding of the island's volcanic and structural evolution, highlighting the close relationship between hydrothermal circulation and volcano-tectonic processes.

Reconstructing the hydrothermal system is therefore crucial for territorial planning, not only for water and geothermal resource management, but also for volcanic hazard prevention and mitigation. Geological data collected during the realization of Geological Sheet No. 464 enabled a comprehensive analysis of the island's hydrogeological setting and the production of the Geohydrological Units Map of Ischia Island at a scale of 1:10,000 (Fabbrocino et al., 2022; 2024).

Further developments of this cartographic framework are essential, particularly regarding the hydrogeological characterization of marine sectors, still poorly investigated despite the widespread occurrence of coastal groundwater springs, and the improvement of quantitative and qualitative datasets related to springs and fumaroles. The research adopts a strongly interdisciplinary approach aimed at integrating geological, volcanological, hydrogeological, and geochemical information into a comprehensive database. This framework is intended to identify critical issues, define an operational model of the island's hydro-geo-thermal system, and improve hydrogeological, geochemical, and volcanic monitoring activities, ultimately contributing to natural hazard mitigation.

Finally, the hydrogeological map of Ischia Island and its unique environmental and volcanic features provide a valuable basis for future research activities with direct operational implications for active volcanic areas and local communities.

Fabbrocino S. et al. (2022) - A GIS-Based Hydrogeological Approach to the Assessment of the Groundwater Circulation in the Ischia Volcanic Island (Italy). Front. Earth Sci., 10, 883719, https://doi.org/10.3389/feart.2022.883719.

Fabbrocino S. et al. (2024) - Geohydrologic units of Ischia Island (Southern Tyrrhenian Sea, Italy). Journal of Maps, 20(1), 2317142, https://doi.org/10.1080/17445647.2024.2317142.

Modelling of the Monte Agnello carbonate platform and its response to the Middle Triassic Tectono-Magmatic Event

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Keywords: carbonate platforms, modeling, Dolomites.

Well-exposed and well-preserved carbonate platform successions represent valuable natural analogues for improving the characterization and understanding of carbonate reservoirs, both for hydrocarbon exploitation and subsurface storage. High-resolution geological mapping and georeferenced data collection enable the construction of accurate 3D digital models, which provide powerful tools for visualizing platform architecture, geometry, and facies distribution.This study focuses on the Monte Agnello area, where an exceptionally complete sedimentary succession is exposed. The succession ranges from the Lower Triassic mixed terrigenous-carbonate ramp deposits of the Werfen Formation to the Anisian Richthofen Conglomerate, followed by the establishment of a low-relief carbonate platform (Contrin Formation) and the subsequent nucleation and growth of a high-relief, flat-topped microbial carbonate platform (Sciliar Formation). The sedimentary succession is capped by volcaniclastic deposits recording the onset of central-vent effusive volcanic activity, which buried the carbonate platform during the Late Ladinian.The Monte Agnello area is located close to Predazzo, where the emplacement of a major volcanic complex is documented by abundant magmatic rocks, including volcanic products and intrusive bodies emplaced at different crustal levels. The carbonate platform is crosscut by numerous volcanic dykes and locally affected by block faulting related to synvolcanic tectonics, with collapsed platform blocks subsequently buried by volcanic deposits, mainly lava flows. The uppermost platform interior is characterized by the transition from karstified surfaces with paleosols and plant trace fossils to basal breccias, tuffs, and subaerial lava flows, documenting widespread subaerial volcanism associated with intrusive activity.The Anisian-Ladinian Monte Agnello platform preserves a continuous record of all stages of platform evolution, from nucleation to aggradation, subsequent progradation, and finally platform demise related to magmatic activity. In contrast, these evolutionary stages are partly obscured in the nearby and better-known Latemar platform by erosion and synsedimentary tectonics associated with magmatic activity.To build the threedimensional carbonate platform model, extensive georeferred geolgical surveys has been performed. The primary focus was on the identification of platform facies and its distribution in order to display the most accurate zonation and platform architecture. Structural framework identification and reconstruction has salso been crucial to build the digital model. By the software Petrel all identified contacts and limits have then been digitalized as surfaces, faults orientation, timing and kinematism have been specified as well. As a result the model achieved shows Monte Agnello carbonate platform's different ghrowth stages and zonation. It also allowed to reconstruct main contact surfaces between magmatica and vulcanic bodies, and the carbonate platform itself. The geo- referred geological surveys, rock sampling and following three dimensional modeling of different event surfaces, allowed the reconstruction of a carbonate platform evolution model in response to a complex tectonic framework and a close intrusive event.

Thrust-top sedimentation and nappe stacking in the central-southern Apennines: new insights from the Guardiagrele area

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Keywords: central-southern Apennines, allochthonous nappe, thrust-top deposits.

As part of the survey of Sheet 370 "Guardiagrele" of the Geological Map of Italy at 1:50,000 scale (CARG Program), carried out between 2021 and 2025, we present new data from the northernmost outcrop of the shale-dominated allochthonous nappe overlying the Maiella Tectonic Unit. The study area lies in the southern Abruzzo Region (central-southern Apennines), east of the Maiella ridge, within the Aventino River basin.

Within the complex fold-and-thrust architecture of the allochthonous nappe, we distinguish two main tectonic units: the Molisana and the Aventino tectonic units, together emplaced above the Maiella Unit. Their differentiation, in terms of tectono-sedimentary evolution, is based on the lithostratigraphic framework of the successions and on the age and characteristics of foredeep and thrust-top deposits, integrated with structural data including geometrical relationships, deformation styles, and the lithology of disarticulated tectonic slices.

The allochthonous tectonic stack is sealed by upper Messinian-Zanclean thrust-top deposits resting in angular unconformity on previously deformed units. These deposits, in turn, were involved in subsequent phases of thrusting, providing key constraints on the timing of deformation. Biostratigraphic analyses (foraminifers and calcareous nannofossils) and detailed mapping leading to the chronostratigraphic and the paleoenvironmental reconstruction allowing the recognition of three main depositional cycles within the thrust-top succession: (i) upper Messinian evaporites of the Vena del Gesso Formation (VGS), linked to the Mediterranean salinity crisis; (ii) post-evaporitic pelitic deposits with conglomeratic intercalations, attributed to the Roccascalegna Formation (RLS); and (iii) Zanclean turbiditic pelitic-arenaceous deposits referred to the Coste Mulino Formation (INO). The VGS is restricted to the Aventino Unit, whereas the RLS and INO formations seal the entire allochthonous tectonic stack.

These results improve the definition of stratigraphic and structural relationships between the Molisana and Aventino units and their contact with the Maiella Unit. The integration of stratigraphic and chronological data from thrust-top deposits provides new constraints on the timing and kinematics of deformation, contributing to the reconstruction of the final structural architecture of this sector of the central-southern Apennines.

Geological mapping of the Plio-Quaternary succession in the southern Apennine foredeep, Italy: insights from the CARG Project - Sheet 420 "Troia"

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Keywords: CARG Project, geological mapping, foredeep marine and continental Quaternary deposits.

The Sheet 420 "Troia" of the Geological Map of Italy at 1:50,000 scale (CARG Project) straddles the boundary between the Apulia and Campania regions, at the transition between the southern Apennine chain (Daunia Apennines) and the northern Bradanic foredeep (Tavoliere di Puglia plain). The investigated area mainly corresponds to the northeastern sector of the sheet, where the upper part of the Plio-Quaternary foredeep succession crops out over a low-relief landscape of approximately 100 km².

Since the Pliocene, this sector was affected by tectonic subsidence, mainly recorded by the silty-clayey hemipelagites of the Argille Subappennine Formation (Azzaroli et al., 1968). Starting from the Middle Pleistocene, regional uplift promoted the progressive emersion of the chainward sector of the foredeep, favouring continental sedimentation in the emerged areas, while marine sedimentation progressively shifted toward more external sectors (Moretti et al., 2010).

The ongoing geological survey integrates stratigraphic, sedimentological, and geomorphological analyses of outcropping Quaternary deposits with borehole and ViDEPI seismic data, within a GIS-based workflow following CARG Project standards. In addition, paleontological, petrographic, and chronostratigraphic analyses are currently underway to further constrain the timing of the mapped deposits and the Quaternary geological and geomorphological evolution of the Tavoliere di Puglia plain.

In the investigated sector, the Argille Subappennine Formation widely crops out along the main fluvial valleys and represents the main substrate of the Quaternary terraced deposits, with a prevailing monoclinal structural attitude. These marine deposits are unconformably overlain by terraced, thin tabular sedimentary bodies, mainly composed of gravel and sandy gravel, deposited in alluvial plain environments and characterized by relatively homogeneous sedimentary features. The terraced succession was subdivided according to the criteria of Unconformity-Bounded Stratigraphic Units (UBSUs) and referred to the Tavoliere di Puglia Supersynthem, a higher-rank unit including synthems and subsynthems already established in neighbouring CARG sheets (e.g., Servizio Geologico d'Italia, 2010a, b). The basal surfaces of the alluvial deposits show a general E-NE dip, with progressively decreasing gradients from the oldest to the youngest units at comparable distances from the chain. This morphostratigraphic architecture reflects the combined control of regional uplift and the structural setting of the foredeep.

This contribution highlights how modern geological mapping within the CARG multidisciplinary framework provides robust constraints for reconstructing the Quaternary tectono-sedimentary and geomorphological evolution of the southern Apennine foredeep system. Such an approach also supports territorial planning and geo-hazard assessment, including flood risk, slope instability, soil erosion, and desertification processes.

Azzaroli A. et al. (1968) - Note illustrative della Carta geologica d'Italia. Foglio 188 "Gravina di Puglia". Servizio Geologico d'Italia, 57 pp.

Moretti M. et al. (2010) - Evoluzione geologica del settore settentrionale del Tavoliere di Puglia (Italia meridionale) nel Pleistocene medio e superiore. Alpine and Mediterranean Quaternary, 23(2), 181-198.

Servizio Geologico d'Italia (2010a) - Carta Geologica d'Italia alla scala 1:50.000, F. 407 S. Bartolomeo in Galdo. ISPRA, https://doi.org/10.15161/oar.it/212351.

Servizio Geologico d'Italia (2010b) - Carta Geologica d'Italia alla scala 1:50.000, F. 408 Foggia. ISPRA, https://doi.org/10.15161/oar.it/212355.

Quantitative assessment of Coastal Geodiversity through integraded UAV survey and Artificial intelligence: A Case Study from Isola delle Correnti, Sicily

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Keywords: deep learning, geodiversity, UAV survey.

The assessment of geodiversity is fundamental for land management and conservation, as it support the preservation of geological heritage and the identification of areas characterized by high environmental variability. In recent years, deep learning techniques, particularly Convolutional Neural Networks (CNNs), have been widely applied to semantic segmentation tasks in geospatial and biomedical imaging (Ronnenberger et al., 2015). In this work, we investigate the geodiversity variability of the coastal area of Isola delle Correnti (south-eastern Sicily) through the integration of UAV multisensor data and U-net CNN image analysis.

A multisensor UAV survey was carried out using DJI MATRICE 400 drone equipped with a P1 photogrammetric sensor and a L2 LIDAR sensor, producing high resolution orthophotos and the Digital Elevation model (DEM). Following Fernandéz et al. (2020) approach, the study area was divided into a regular grid of 10 x 10 m cells, within which lithological, geomorphological, and geomorphometric variability was quantified. Lithological and Morphological indices where extracted through semantic segmentation of orthophotos and DEM-derived products using a 2D U-Net architecture based on convolutional layers with 3 x 3 kernels, producing pixel wise classified maps of the study area. The geomorphometric index was instead obtained from DEM-based raster layer, including slope, roughness and Topographic Position Index (TPI).

The final geodiversity map, obtained by aggregating the defined lithological, morphological, and geomorphometric indices, highlights coastal sectors characterized by high geodiversity variability. These areas may represent priority targets for environmental conservation and geological heritage protection.

Fernández A. et al. (2020) - Assessment of Geodiversity in the Southern Part of the Central Iberian Zone (Jaén Province): Usefulness for Delimiting and Managing Natural Protected Areas. Geoheritage, 12, Article 20, https://doi.org/10.1007/s12371-020-00447-6.

Ronneberger O. et al. (2015) - U-Net: Convolutional Networks for Biomedical Image Segmentation. In Medical Image Computing and Computer-Assisted Intervention - MICCAI 2015, LNCS 9351, 234-241, https://doi.org/10.1007/978-3-319-24574-4_28.

AI-Assisted Digitalization of Stratigraphic Logs for Geological Mapping: A Case Study of the CARG Sheet 263 - Prato (Italy)

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Keywords: AI-assisted geognostic data digitization, multimodal vision-language models (LMMs), stratigraphic log reconstruction.

The management and integration of legacy geognostic archives into structured digital databases represent a major challenge in modern geological mapping. Traditional OCR-based approaches have proven insufficient for extracting structured information from borehole logs due to their complex graphical layouts and mixed symbolic content (Rapid Method for Information Extraction from Borehole Logs, 2020). More advanced AI-based pipelines have therefore been proposed, combining text recognition with higher-level semantic interpretation (Sanchez-Pinedo et al., 2024). This study presents the methodology and results of the systematic digitization of stratigraphic logs for the CARG Sheet 263 (Prato), based on an AI-assisted multimodal interpretation approach. The workflow was developed from a heterogeneous dataset of scanned PDFs lacking a native text layer and integrates geological-stratigraphic expertise with vision-language techniques to enable both the metric reconstruction of stratigraphic intervals and the semantic normalization of lithological descriptions. Recent developments in Large Multimodal Models (LMMs) have demonstrated strong capabilities in extracting structured information from unstructured geological data (Ghorbanfekr et al., 2024) and in automating complex geoscientific digitization tasks (DIGMAPPER, 2025). A comparative analysis was conducted between a Local AI Workflow based on OCR (Tesseract, Poppler) and an Online AI Workflow leveraging LMMs. Results indicate that vision-language reasoning significantly improves the consistency of vertical metric reconstruction. The methodology was applied to over 1,300 boreholes, achieving an average processing time of approximately 5 minutes per file, corresponding to a time reduction exceeding 70% compared to manual digitization. Reliability analysis shows a lithological classification accuracy between 95% and 98%, with an average vertical reconstruction error of approximately 0.10-0.15 cm. These results highlight the effectiveness of AI-assisted approaches in translating visual information into structured geological data, although a comprehensive evaluation of total error, including geological interpretation uncertainty, remains subject to further validation.

Sanchez-Pinedo G et al. (2024) - AI-based digitization of geotechnical ground data: Integrating OCR and semantic interpretation. Scipedia.

Ghorbanfekr M. et al. (2024) - Classification of geological borehole descriptions using a domain adapted large language model. Applied Computing and Geosciences, 25, 100229, https://arxiv.org/abs/2407.10991.

Smith, J., Brown, T., & USGS Data Science Team. (2025). *DIGMAPPER:* A modular deep learning framework for automated geologic map digitization. arXiv preprint arXiv:2506.16006, https://arxiv.org/abs/2506.16006.

Geological mapping of submerged areas within the CARG project: insights from the 414 "Terracina" sheet (Southern Lazio, Italy)

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Keywords: submarine mapping, sediment distribution, morpho-bathymetry.

The submerged sectors of the 414 Sheet of the CARG Project (1:50,000 scale) encompass part of the inner continental shelf of southern Latium, extending offshore from the Circeo-Terracina coast to depths ranging 80-100 m. The southern Latium margin shows a wide continental shelf, in general subsidence, that belongs to the southern Tyrrhenian back-arc basin. A separate inset includes part of the insular shelf surrounding Ventotene and Santo Stefano (eastern Pontine Archipelago), down to the maximum depth of 200 m. At about 50 km from the mainland and beyond the continental shelf edge, the islands represent the emergent portion of a large Ventotene volcanic edifice rising from depths of ~700 m inside the Ventotene intraslope basin. Within this geological framework and under the guidelines of the CARG project, an integrated marine geological approach combining morpho-bathymetric analysis, seismic stratigraphy, and seafloor sediment characterization was applied to support the geological mapping of the submerged areas. The continental shelf is characterized by limited sediment supply, as the presence of marshy areas inland (Pontine and Fondi coastal plains) acted as sediment traps during the post-glacial transgression and the present highstand phase. Siliciclastic sands are accumulated along the coastline forming littoral wedges, with a main depocenter in correspondence of the Circeo Promontory, with implications on nearshore sediment transport patterns. The presence of artificial coastal barriers further modifies littoral dynamics, with significant effects on both beach erosion processes and coastal protection. Sediment mobility, together with the occurrence of rocky outcrops, plays a key role in controlling the distribution and development of Posidonia meadows. Palimpsest deposits are widespread throughout the remaining study area due to the limited supply of recent sediments and consist of heterogeneous accumulations formed during lower sea-level stages and later reworked under present highstand conditions. The deepest sectors of the continental study area are characterized by the deposition of the finest-grained sediments. Instead, and despite its smaller extent, the islands inset displays higher morphological and sedimentological variability across the submarine domain. Sandy beaches are almost absent and the nearshore is therefore dominated by rocky outcrops, commonly colonized by Posidonia meadows. Differently, deeper outcrops are associated with bioherms. The remaining insular shelf shows multiple submarine depositional terraces at variable depths. They formed by waves sediment reworking during different sea-level fluctuations and are also preserved inside the volcanic caldera to the northwest. Seafloor sediments are predominantly biogenic, consisting of calcareous encrustation and shell fragments locally reworked by bottom currents, whereas palimpsest deposits were mapped within and west of the submerged caldera.

Revealing Hidden Quaternary Fault Systems through Integrated Geological Cartography: Insights from the Southern Alps

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Keywords: Southern Alps, neotectonics, active faults.

This contribution illustrates how integrated Quaternary geological mapping can effectively reveal active tectonic structures concealed beneath complex sedimentary successions, with direct implications for geohazard assessment and territorial knowledge. The study focuses on two active fault systems within the fold-and-thrust belt of the European Southern Alps, in western Lombardy (northern Italy), an area characterized by limited surface expression of deformation.

Within the conceptual and methodological framework promoted by the CARG project, we combine detailed geological and structural field mapping with subsurface information derived from commercial seismic reflection data, borehole stratigraphy, aeromagnetic data, and near-surface geophysical surveys, including electrical resistivity tomography and seismic tomography. This multidisciplinary approach allows reconstruction of fault geometry, cumulative displacement, and timing of activity during the Quaternary.

The tectonic evolution is discussed in relation to the stratigraphic and geomorphic development of the Alpine foreland, starting from the Pliocene reflooding of the Mediterranean Basin after the Messinian salinity crisis, when deeply incised canyons and fjord-like valleys were inundated. These inherited landforms were later reshaped and largely infilled during Early-Middle Pleistocene glaciations, which deposited thick alluvial successions, locally referred to as "Ceppo".

Our results show that post-depositional tectonic phases displaced the entire Quaternary sedimentary succession, providing quantitative evidence for fault activity despite scarce or absent surface indicators. The integration of stratigraphic architecture, sedimentary infill, and fault-controlled deformation demonstrates that Quaternary deposits constitute a key archive for identifying active structures otherwise invisible in conventional mapping.

The study highlights the added value of subsurface-constrained Quaternary mapping for CARG-scale geological cartography, emphasizing its role as a gateway to improved understanding of active tectonics, landscape evolution, and geohazard potential in the Southern Alpine foreland.

Tectonic evolution of the southern-western Alps: a reappraisal of the Ligurian knot from new Carg survey

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Keywords: Alps, Mediterranean tectonics, geological survey.

The Carg project has facilitated a significant advancement in the completion of the geological mapping of the Ligurian Alps, which are the southernmost sector of the Alpine chain. In recent years, two new maps - 244-Ormea, 245-Albenga - have been finalized, while others are currently in progress. These additions complement the maps produced over the past two decades, enabling the creation of an updated cartographic database for the region. This contribution aims to provide an overview of the newly integrated data within the existing framework, offering a re-evaluated tectono-stratigraphic evolution of this sector of the Alps across the pre-Alpine, Alpine, and post-collisional Apennine-driven phases. The new data encompass both submarine and emerged areas, investigated through geophysical surveys and fieldwork, with extensive use of Unmanned Aerial Vehicles (UAVs) to derive structural information. The geological complexity of the Ligurian Alps is underscored by its diverse rock suite, including: i) Paleozoic to Eocene metaintrusive, metavolcanic, and metasedimentary sequences, which underwent pre-Alpine and/or Alpine orogenic deformation and metamorphism; ii) Oligocene to Pliocene post-orogenic sediments and a significant Quaternary mixed marine-alluvial fan. A key novelty concerns the structural setting of the Ligurian Alps and the Ligurian Sea margin, where previously underestimated or overlooked kilometer-scale strike-slip fault systems have been identified. These structures exhibit significant persistence and continuity, displacing earlier folding and thrusting features. Stratigraphic-structural analyses suggest ongoing activity from the Oligocene to Pliocene, influencing both the past and present-day seismo-tectonic setting. New findings highlight the critical role of geological mapping in refining tectonic models and provide insights into the post-Oligocene tectono-stratigraphic evolution of the Ligurian Alps and the Ligurian Sea margin within the broader central Mediterranean context.

QGis and QField data entry form for geological structure associations

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Keywords: structures, data, association.

Geological mapping concerns the interpretation of different data types, regarding, e.g., lithostratigraphic units and lithotectonic units, as well as macroscale and mesoscale tectonic features and interpretation of regional tectonic phases. During fieldwork, it is thus necessary to recognize and record mesoscale elements (in outcrops) but also to infer their relation with the main structural associations, and with the main macroscale/map-scale tectonic features represented in the map, as well as the information about the related tectonic phases.

For this reason, we created a dedicated database, together with an operative tool for fieldwork ("Measurement Point Data Entry Form" for QField), to store structural data, meant both to collect the measurements (foliations, faults, fold geometric features, shear zones, vein and fracture systems) and also to relate them to each other and/or to the main macroscale tectonic features of the map.

The data entry form allows to achieve this task through a dedicated organization of its fields (properties and relations) thought to describe not only the rough data but also the relation between them.

For example, in the Cuneo - Colle di Tenda sheets of the CARG project we deal with a complex geological context: there are several geologic units pertaining to different paleogeographic domains, separated by tectonic contacts. The whole outcropping succession was involved in the Alpine orogenesis, and it recorded (in different ways based on rock characteristics and tectonic path) up to five main deformation phases (d'Atri et al., 2016; Piana et al., 2021). The evidences of these deformative stages are foliations, folds, fracture sets, faults and shear zones, mutually interconnected and often reactivated. These data can be collected, by filling the data entry form, since the beginning of the fieldwork, in order to support the interpretation of the geological setting to be represented on the map and the understanding the geological history of the area.

In order to deal with geological mapping procedures of the CARG project framework, we designed the "Measurement Point Data Entry Form" harmonizing the data format to the CARG database (strata 19), allowing the further migration of the data.

d'Atri A. et al. (2016) - Geological setting of the southern termination of Western Alps. Int. J. Earth Sci., 105, 1831-1858.

Piana F. et al. (2021) - The Alps-Apennines Interference Zone: A Perspective from the Maritime and Wester Ligurian Alps. Geosciences, 11, 185, https://doi.org/10.3390/geosciences11050185.

The effects of the Plio-Quaternary crustal pop-up of the Venetian belt on the Borgo Valsugana area

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Keywords: Valsugana fault system, eastern Southalpine domain, crustal uplift.

The Borgo Valsugana, n. 61 Sheet of the 1:50,000 Geological Maps of Italy, is located in the Brenta River catchment, between the Dolomites, the Volcanic Athesian Group (GA) and the Altopiano dei Sette Comuni, and behind the Neoalpine Venetian belt. The survey was carried out through a multidisciplinary approach effective in handling the variety of geological domains that include the Southalpine basement intruded by the Lower Permian Cima d'Asta Magmatic Complex and related volcanic successions, the Upper Permian-Cenozoic sedimentary sequence and the Quaternary Cover. The area

The territory is divided into two parts by the Valsugana fault system: the Southalpine basement and the volcanic GA area to the NW and the sedimentary sequences to the SE. Beside the SE vergent Valsugana master fault, this tectonic system includes other high-angle strike slip and reverse faults, as well as thrusts sharing the same vergence and orientation of the master fault. These faults deform the entire sedimentary sequences up to Mid Miocene at the footwall of the Valsugana master fault, up to the southern side of Mt. Civerone and Mt. Lefre along the left bank of the Brenta River. Asymmetric folds such as the Borgo syncline belong to the Valsugana tectonic system.

The Plio-Quaternary crustal uplift of the Venetian Belt, caused the uplift of the Altopiano dei Sette Comuni, transporting its crystalline basement and sedimentary sequences north-northwestwards, over the Upper Cenozoic succession of Val di Sella. This uplift was also responsible for the north-northwestward movement of M. Civerone and M. Lefre over the Val di Sella thrust fault. in addition NW-SE and N-S Pliocene-Quaternary faults developed throughout the area of the Borgo Valsugana sheet reactivating Permian lineaments associated to the GA volcanic emplacement (e.g., the Redebus line LRE) as north-vergent thrusts, and the north-south Jurassic faults of the Altopiano dei Sette Comuni (e.g., the Val Bronzale LVB and Grigno-Val Tolvà LGT faults) as strike slip and tear faults.

Semi-automatic karst landforms analysis and regional multiscale mapping: Insights from the Central Apennines

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Keywords: karst landforms, geomorphometric-spatial analyses, Central Apennines.

In recent decades, advances in GIS and remote sensing have greatly improved multiscale landforms mapping in karst geomorphology. However, updated systematic regional-scale studies remain scarce in several carbonate karst massif (e.g. the Central Apennines), particularly depending on the lack of high-resolution topographic data. To address this gap, a systematic multiscale and semi-automatic mapping with quantitative analysis of karst landforms was developed and applied to the Abruzzo region (Central Apennines).

The approach incorporated: 1) identification of carbonate karst morpho-units (≤ 1:100,000 scale) defined by morphostructural and hydrogeological boundaries; 2) mapping and classification of karst areas integrating existing data with manual delineation (1:50,000); 3) semi-automatic detection and mapping of karst landforms (≥ 1:25,000). All steps relied on multiresolution DEMs (1-10 m) and other remote sensing data. Landforms mapping was performed through a supervised, semi-automatic workflow on DEM-data, and field calibration: 1) small closed depressions (i.e. dolines) were extracted using calibrated fill-sinks tool; 2) open depressions with raster stacking; 3) large depressions (i.e. poljes) by automatic and manual delineation; 4) karst valleys by hydrological analysis of drainage network. This allowed to map over 53,000 features, including 4371 dolines for which geomorphometric and spatial analyses were conducted.

Results show high variability with strongly left-skewed distributions, partly reflecting poor sensitivity of the mapping to small features. Doline areas range from 104 m^2 to 0.28 km^2 (median 0.0021 km^2), depths ^{2}, with pitting index 90 to 720, indicating strong spatial variability in karstification intensity. Kernel and Grid-based density reach peaks of 22-26 d/km^2 highlighting major hotspots. Most dolines occur between 1,000-1,600 m a.s.l. on low-steep slopes (This study provides an updated regional framework for epigean carbonate karst analysis, showing that robust and consistent results can be achieved even using medium-resolution DEMs in the lack of more detailed data. The integration of classical geomorphological interpretation with GIS-based approach is valid in other karst regions, while the future availability of higher-resolution data is expected to further improve detection accuracy and reliability.

Multiscale mapping of carbonate karst landforms in Abruzzo (Central Apennines, Italy): Semi-automatic approach and quantitative analysis

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Keywords: Central Apennines, epigean karst mapping, landforms classification.

The Central Apennines represent a key area for karst studies in Italy. However, while hypogene karst and spring systems have been extensively investigated, region-wide, high-resolution mapping of epigean karst features using modern GIS-based approaches is still lacking. This study addresses this gap by producing a new comprehensive, multiscale investigation, classification, and mapping of karst landforms and features in Central Italy (Abruzzo region).

Carbonate terrains, mainly Jurassic-Cretaceous limestones, cover about 70% of the mountain sector of the region and are organized into morpho-structural units bounded by active normal faults, which have fragmented ancient karst surfaces and strongly influenced the development of endoreic basins and fluvio-karst drainage patterns. To manage this complexity, the research workflow combined classical geomorphological interpretation with semi-automatic detection techniques applied to multiresolution DEMs (10 m and 5 m), locally supported by 1 m LiDAR-based data and integrated with other available remote sensing data.

The mapping approach was structured across three scale ranges: 1) small scale (≤ 1:100,000) for the definition of carbonate karst morpho-units (CKMUs); 2) intermediate scale (1:50,000) for the delineation of the main karst areas within CKMUs; and 3) large scale (≥ 1:25,000) for detailed mapping and classification of individual landforms. At the lower scale ranges, mapping relied on manual remote interpretation of major features (including the major poljes) followed by quantitative morphometric measurement; whereas at large scale semi-automatic procedures were applied. These included fill-sinks algorithms for closed depressions (dolines, uvala and minor poljes), raster stacking of DEM-derived parameters for open depressions, and supervised filtering of karst valleys from the regional drainage network. All outputs were validated through remote checks and field surveys in selected representative test areas. The dataset was the base for further geomorphometric and spatial analysis.

The workflow resulted in the identification of: 1)12 CKMUs at regional scale; 2) 347 main karst areas at intermediate scale, classified into six types based on landforms clustering; and 3) 53,887 individual landforms at large scale. The latter include 4,371 closed depressions, 30,247 open depressions, 130 karst plains, 14 poljes, and 19,125 karst valleys. Classification thresholds for depressions were based on surface area (0.04 km² between dolines and minor poljes; 2 km² between minor and major poljes), with limited manual adjustments. The resulting dataset was compiled into a regional karst landforms map (represented at 1:50,000 scale) and a geospatial archive.

This integrated approach demonstrates the effectiveness of combining classical and GIS-based techniques for regional-scale karst mapping and provides a replicable framework supporting hydrogeological modelling, hazard assessment, and geodiversity management.

Mapping the nappe-like structure of the crystalline basement of the Aspromonte Massif: a journey ranging from Variscan vs. Alpine metamorphic processes to the Pliocene-Pleistocene Apennine thin-skinned orogenesis (CARG Project Sheet No. 602, Motta S. Giovanni)

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Keywords: Western Mediterranean geodynamics, mylonites, crustal-scale shear zone.

Geological Sheet no. 602 fully embodies the etymological essence of the term "Aspromonte" (Asper and Mons).

The entire area, covering approximately 640 km², lies within the most remote and inaccessible part of the southernmost physiographic corner of the continental Apennine range, here interrupted by the Strait of Messina and continuing beyond it in northern Sicily with the Peloritani mountain range.

This is the southernmost sector of the Calabria-Peloritani Orogen (CPO), a strongly arcuated ribbon-like orogenic segment very different from the rest of the Apennine-Maghrebian chain since it is mostly composed of relics of Variscan and pre-Variscan basement rocks, locally involved into a weak to strong Alpine multistage reworking, testifying a very complex geodynamic evolution still not completely unravelled.

This evolution has been related to the dismembering of the southern European Variscan belt realm, followed by the development of the Alpine orogeny, within the microplate framework of the Western Mediterranean geodynamics (e.g., Cirrincione et al., 2015; Malusà et al., 2015). In this geological framework, the study of the present-day distribution of peri-Mediterranean Variscan basement relics, their transport directions, and their detailed P-T evolution is crucial for a reliable palinspastic relocation of the original CPO basement units before the closure of the southern Alpine Tethys.

According to Fazio et al. (2015) and Ortolano et al. (2015), the present-day geological structure of this southernmost sector of the CPO can be interpreted as a unique nappe-like system formerly structured during the Middle- to Late-Oligocene deep-seated exhumation, which developed thick mylonitic horizons followed by a continuous Africa-verging thrust-dominated tectonics linked to the later stages of Alpine geodynamics (i.e., the Apennine stage) before being involved into the still active gravitational collapse associated with a strongly seismogenic normal faulting system (Cirrincione et al., 2015).

The CARG sheet no. 602 is inserted in this geological framework, where Pliocene-Pleistocene brittle-dominated southeast-verging thrust sheet tectonics led to the stacking of the two uppermost tectonic slices of the present-day nappe edifice (i.e., the Stilo Unit—SU and Aspromonte Unit—AU). These two units are both characterized by low-greenschist to upper-amphibolite-facies multi-stage Variscan metamorphism, whereas locally involving, only in the deeper AU, a pervasive meso-Alpine mylonitic evolution. The latter produced a thick late-Oligocene mylonitic horizon, with a very well-preserved northeastern tectonic transport, observed also into the deepest upper-greenschist facies metapelites of the basal Madonna di Polsi Unit (MPU), exclusively registering a complete Alpine metamorphic cycle.

Cirrincione R. et al. (2015) - The Calabria-Peloritani Orogen, a composite terrane in Central Mediterranean; its overall architecture and geodynamic significance for a pre-Alpine scenario around the Tethyan basin. Period. Mineral., 84, 701-749, https://doi.org/10.2451/2015PM0446.

Fazio E. et al. (2015) - Tectono-metamorphic map of the south-western flank of the Aspromonte Massif (southern Calabria -Italy). Journal of Maps, 11, 85-100, https://doi.org/10.1080/17445647.2014.962634.

Malusà M.G. et al. (2015) - Contrasting styles of (U)HP rock exhumation along the Cenozoic Adria-Europe plate boundary (Western Alps, Calabria, Corsica). Geochem. Geophys. Geosystems, 16, 1786-1824, https://doi.org/10.1002/2015GC005767.

Ortolano G. et al. (2015) - Petro-structural geology of the Eastern Aspromonte Massif crystalline basement (southern Italy-Calabria): an example of interoperable geo-data management from thin section - to field scale. Journal of Maps, https://doi.org/10.1080/17445647.2014.948939.

Stratigraphic architecture and bio-chronostratigraphic refinement of the Cretaceous-Miocene succession from the CARG Geological Sheet 313 "Camerino"

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Keywords: stratigraphy, Central Apennines, CARG project.

The Umbria-Marche-Sabina (UMS) domain is crucial for deciphering Mediterranean geological history, preserving exceptionally continuous pelagic successions that record the Meso-Cenozoic tectonic and paleoenvironmental evolution of the Apennine system. This study presents high-resolution litho-, bio-, and chronostratigraphic data spanning the Lower Cretaceous to Lower Miocene interval within the Geological Sheet 313 "Camerino" (CARG, 1:50,000 scale). We integrated detailed field measurements from multiple successions, most notably the outstanding 870-m-thick Fiastra Lake section. Exceptional exposure along the northern shores of the reservoir, exposed during water-level lowering, allowed systematic sampling from the Maiolica to the Bisciaro formations, facilitating robust basin-scale correlations. High-resolution lithofacies and microfossil analyses identified key paleoceanographic and ecological events, including:

- the Barremian Faraoni Event and Aptian OAE 1a (Selli Event), marked by nannoconid crises and planktonic foraminiferal radiations;
- Albian anoxic events linked to productivity peaks;
- the end-Cenomanian/Turonian OAE 2 (Bonarelli level), characterized by bottom-water anoxia and the extinction of rotaliporids;
- the poorly documented Cenomanian-Turonian "Filaments Event";
- the major Santonian faunal turnover, marking the definitive transition to globotruncanid-dominated assemblages;
- Campanian-Maastrichtian calciturbidites triggered by synsedimentary extensional tectonics and platform-margin collapse;
- the Cretaceous-Paleogene (K-Pg) mass extinction; and
- the Paleocene-Eocene Thermal Maximum (PETM), marked by global warming and the rise of eutrophic-adapted foraminifera.

Litho-biostratigraphic correlations between the several stratigraphic sections measured within the Sheet Camerino reveal significant facies and thickness variations in key intervals, pointing to a strong paleotectonic and paleotopographic control on pelagic deposition mainly during the late Mesozoic. Despite challenges in identifying biozone boundaries (lack of specific markers, poor preservation/small size of fossils, and lithology limiting study to thin sections), the resulting bio-chronostratigraphic sequence aligns well with recent coeval records across the UMS basin (e.g., Coccioni & Premoli Silva, 2015; Galeotti et al., 2015; Coccioni et al., 2016; Petrizzo et al., 2025). Consequently, the Camerino area stands out as a pivotal reference section and a fundamental benchmark for classic central and northern Apennines successions.

Coccioni R. & Premoli Silva I. (2015) - Revised Upper Albian-Maastrichtian planktonic foraminiferal biostratigraphy and magnetostratigraphy of the classical Tethyan Gubbio section (Italy). Newsletters on Stratigraphy, 48(1), 47-90.

Coccioni R. et al. (2016) - Integrated magnetostratigraphy, biostratigraphy, and chronostratigraphy of the Paleogene pelagic succession at Gubbio (central Italy). Geological Society of America Special Papers, 524, p-SPE524.

Galeotti S. et al. (2015) - The Bottaccione section at Gubbio, central Italy: a classical Paleocene Tethyan setting revisited. Newsletters on Stratigraphy, 48(3), 325-339.

Petrizzo M.R. et al. (2024) - Planktonic foraminifera in biostratigraphy and biochronology. Newsletters on Stratigraphy, 59(1-2), 117-174.

Geology and structural setting of Asinara Island (NW Sardinia, Italy): insights from integrated onshore-offshore mapping

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Keywords: geological map, Variscan basement, CARG Project.

The Asinara Island (NW Sardinia) represents an area where it is possible to investigate the medium- to high-grade metamorphic basement that formed the inner part of the Variscan orogen, as well as the Posada-Asinara shear zone (i.e., a km-scale transpressive shear zone; Carosi R. & Oggiano G., 2002) that drove the exhumation of the metamorphic core of the belt. Although Asinara Island offers good exposure of the main tectonic units that make up the Sardinian Variscan belt, for many years, a detailed geological map of the island was lacking due to former access limitations.

The island is located within the area covered by geological Sheet n. 424 "Isola Asinara" of the CARG Project. This sheet is currently under production and is based on existing data integrated with a new, detailed survey. This provides an opportunity to test the modern approach and standards for mapping crystalline basement, as outlined in the new normative project from the Italian Geological Survey (Simonetti et al., 2024). In this contribution, we present the new 1:10,000 scale geological-structural map of the entire Asinara Island, including the marine area, which is useful for better understanding this key sector of the Variscan belt in Sardinia. The basement is characterized by two tectono-metamorphic units (i.e., the Medium- and High-Grade Metamorphic Complex) and five intrusive units (i.e., Pedra Bianca alkali feldspar granite, Castellaccio and Punta Sabina monzogranites, felsic aplite-pegmatite dyke, mafic porphyry dyke).

Four ductile deformation phases can be identified: (i) D_1 is locally preserved, and S_1 is visible in D_2 hinges; (ii) D_2 is the most prevalent deformation phase, and S_2 is the primary foliation, which gradually transforms into a mylonitic foliation towards the Posada-Asinara shear zone; (iii) D_3 is weak and produces upright folds, primarily in the central and northern regions of the island; (iv) D_4 is associated with a sub-horizontal crenulation cleavage. Finally, brittle deformation is represented by a complex network of faults that, in most cases, show a transcurrent kinematics.

Carosi R. & Oggiano G. (2002) - Transpressional deformation in northwestern Sardinia (Italy): Insights on the tectonic evolution of the Variscan belt. C. R. Geosci., 334(4), 287-294,

Simonetti M. et al. (2024) - A review of criteria, methods, and standards for mapping crystalline terrains: Integrating field geology and analytical data. Ital. J. Geosci., 143, 426-454.

Sinkholes in gypsarenites embedded within siliciclastic successions: the Belforte del Chienti example (Macerata, Italy) from CARG Sheet 313 "Camerino"

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Keywords: sinkhole, gypsarenites, Marche.

Previously undocumented sinkholes were identified during geological field mapping for Sheet 313 "Camerino" (1:50,000 scale, CARG) within Messinian gypsarenite layers embedded in a dominantly siliciclastic succession at Belforte del Chienti (MC, central Italy). In the study area, where arenaceous and clayey lithotypes of the Laga Basin prevail, sinkholes are extremely rare, as also reflected by their scarce representation in national databases and the scientific literature. Geological field data, integrated with borehole stratigraphies, allowed the construction of a preliminary geological model of the area, which was further refined using InSAR data from the surrounding areas. The latter revealed localized ground deformations over the satellite observation period that may be associated with, or influenced by, the presence of the studied sinkholes. These subsidence structures have significantly altered the surface and subsurface hydrological flow, perturbing the pre-existing equilibrium of slopes already affected by landsliding. In addition, the high susceptibility to erosion of the investigated gypsarenite horizons may be enhanced by water losses from pressurized distribution networks and by irrigation practices. Satellite data analysis highlights ground movements potentially linked to the presence or activity of sinkholes. This case study is scientifically relevant due to its uniqueness within this lithostratigraphic and structural context and its implications for hazard assessment. The risk of further collapses, or the evolution of existing cavities, is particularly critical given the proximity of infrastructures, including roads and buildings, which increases exposure of human and material assets. Targeted geophysical and hydrogeological investigations could help identify collapse-prone cavities in extensive areas (potentially several square kilometers) that share similar lithostratigraphic and structural features. The aim of this study is to analyze and classify these sinkholes and to evaluate the potential hazards affecting the nearby residential area.

The Mt. Semprevisa stratigraphic section (Central Apennines): new insights from geological mapping of Sheet 401 Sezze (CARG Project)

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Keywords: carbonate platform, Apennines, geological mapping.

Within the framework of the geological mapping carried out for the CARG Project (Sheet 401 Sezze), a >2 km-thick stratigraphic section was measured and sampled, representing the most continuous and stratigraphically complete section of the Lepini Mountains' Mesozoic succession. Previous studies were limited to local intervals mainly for biostratigraphic purposes (e.g., Chiocchini et al., 2008) and a more complete reference section was necessary to provide a robust framework for the realization of the geological sheet. The Lepini Mountains ridge exhibits a general NW-SE trend and can be subdivided into two sectors by the Montelanico-Carpineto line (Parotto & Tallini, 2013). The measured section is located in the southwestern sector that includes the Monte Semprevisa (1536 m a.s.l.), which is the highest peak of the Lepini Mountains and the entire Volsci Range. The Mesozoic carbonate platform succession of Mt. Semprevisa belongs to the Latium-Abruzzi Domain, which remained in shallow water conditions after the Early Jurassic Tethyan rifting. This stratigraphic succession consists predominantly of alternating limestones and dolostones and ranges from the Middle Jurassic, exposed on the southwestern flank, to the Upper Cretaceous on the northeastern side. The succession is nearly continuous, with only minor gaps related to small faults. During fieldwork, several cherty horizons were identified, including both nodular and laterally continuous chert layers, as well as accumulations of isolated quartz grains parallel to bedding. These horizons occur within the Upper Jurassic interval, often associated with the occurrence of *Campbelliella striata*, and within the uppermost Lower Cretaceous, the latter consistent with previous observations by Carbone & Catenacci (1978). The origin and significance of these cherty horizons are currently under investigation.

Carbone F. & Catenacci V. (1978) - Facies analysis and relationship in Upper Cretaceous carbonate beach sequence (Lepini Mts., Latium). Geologica Romana, 17, 191-231.

Chiocchini M. et al. (2008) - Ricerche micropaleontologiche e biostratigrafiche sul Mesozoico della piattaforma carbonatica laziale-abruzzese (Italia centrale). Memorie Descrittive Carta Geologica d'Italia, 84, 5-170.

Parotto M. & Tallini M. (2013) - Geometry and kinematics of the Montelanico-Carpineto Backthrust (Lepini Mts., Latium) in the hangingwall of the early Messinian thrust front of the central Apennines: implications for the Apennine chain building. Ital. J. Geosci., 132(2), 274-289.

Evidence of Messinian activity on the Caramanico Terme fault (PE) in the cartography of CARG sheet 370 "Guardiagrele", Central Apennines (Italy)

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Keywords: Maiella fault system, Messinian, synsedimentary activity.

The survey of Sheet 370 "Guardiagrele" of the Geological Map of Italy at 1:50,000 scale (CARG Program), completed between 2021 and 2025, has yelded new data regarding the Messinian activity of the Maiella Fault System (hereinafter simply MFS; Caramanico Fault Auct.) which extends over 20 km from Caramanico Terme to the north, to Guado di Coccia to the south. MFS borders the eastern side of the so-called *Fossa di Caramanico* and delimits the western slope of the Maiella ridge, which rises for over 1500 meters above the Orta Valley. At the MFS hangingwall, the messinian *Turborotalita multiloba marls* (tr) and evaporitic cycle of the *Vena del GessoFormation* (VGS) and the *Colle Castellano formation* (TLL) (see *Congeria marls* in Patacca & Scandone, 2021), conformably cover the Oligo-Miocene carbonate ramp deposits of the *Bolognano formation* ($BOL_{1,2,3}$). Above these deposits the succession continous with the messinian terrigenous deposits of the *Porrara formation* (FMP), and the Zanclean *San Valentino conglomerates* (CSV), *Taranta Peligna clays* (TAP) and siliciclastic turbidites of the *Cellino formation* (CEN). Detailed mapping and samples analyses have provided previously unknown information regarding the Messinian synsedimentary activity of the MFS. Geological survey among San Nicolao - C.le della Tenda, Caramanico Terme, and Decontra - C.le Bianco areas, at the hangingwall of the MFS, has revealed a complete succession of deposits from the Messinian upper part of BOL(BOL_3 and tr) and the late Messinian evaporitic cycle. Instead at MFS footwall the same deposits crop out in a reduced and condensed succession. However at the top and bottom of MFS deposits referred to CSV are continuous and do not show significant thickness variations according to a synsedimentary messinian activity of the fault system, as already indicated by Scisciani et al. (2002).

Furthermore, inside the succession between the upper part of BOL_2, BOL_3, tr and the VGS, at the C.le della Tenda are present submarine landslides composed by part of pre-VGS substrate succession. These are localy interpretable as synsedimentary mass detachments originating from the bedrock, exhumed along the fault scarp in the overlying area. Based on stratimetric considerations, a MFS messinian offset in these areas of approximately 250-280 m could be calculated, i.e. equal to the sum of the thicknesses of BOL_3 + tr + VGS + TLL, which corresponds to the maximum width of the stratigraphic gap found at the footwall. This value could be much greater proceeding to the south, due to the increase of the MFS offset.

Patacca E. & Scandone P. (2021) - Geological Map of the Majella Mountain. ISPRA - Servizio Geologico d'Italia, scala 1:25.000, D.R.E.A.M, Italia.

Scisciani V. et al. (2002) - Pre-thrusting normal faults within syn-orogenic basins of the Outer Central Apennines, Italy: implications for Apennine tectonics. Boll. Soc. Geol. It., Volume spec. 2022/1, 295-304.

Mapping-Driven OSL chronological framework for mixed-sediment marine terraces in Southwestern Sicily

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Keywords: marine terraces, luminescence dating, Southwestern Sicily.

Southwestern Sicily preserves one of the most complete Middle to Late Pleistocene marine-terrace staircases in the central Mediterranean, yet chronological control remains uneven relative to the spatial complexity of mapped terraces and deformation patterns (Ferranti et al., 2021). Here, we develop a mapping-driven luminescence framework for the southwestern Sicily coastal sector, integrating mapped terrace morphology with a denser optically stimulated luminescence (OSL) dataset than previously available for this region. TerraceM-3, a MATLAB toolbox for shoreline-angle and inner-margin mapping, combined with geomorphic interpretation aided by red relief image maps (RRIM; available as a QGIS toolbox at http://www.terracem.com), is used to define tentative terrace levels and guide sample selection, linking each luminescence age to terrace geometry, elevation, sedimentary fabric, and geomorphic confidence (Jara-Muñoz et al., 2026).

The coastal sediment succession is carbonate-rich and includes marine, aeolian, fluvial, and potentially reworked components. We therefore treat OSL ages as context-dependent chronological constraints rather than direct terrace labels. Our dataset comprises 20 luminescence records, including measurements on quartz and the polymineral fraction. To unify dose-rate and age-assessment our workflow involves carbonate-aware correction using RCarb/DRAC-style inputs, inspection of equivalent-dose distributions, and population-sensitive D_e modeling, including finite-mixture approaches where multiple signal populations are present (Durcan et al., 2015; Kreutzer et al., 2019).

This framework is designed to produce robust ages for complex carbonate-platform terrace deposits, where sediment mixing and partial resetting can obscure simple age interpretation. The resulting chronology will support probabilistic MIS assignment and uplift-rate modelling, allowing us to test whether regional uplift patterns inferred from published terrace records are locally modified by fold growth and thrust-front deformation.

Durcan J.A. et al. (2015) - DRAC: Dose Rate and Age Calculator for trapped charge dating. Quaternary Geochronology, 28, 54-61, https://doi.org/10.1016/j.quageo.2015.03.012.

Ferranti L. et al. (2021) - Late Quaternary coastal uplift of southwestern Sicily, central Mediterranean sea. Quaternary Science Reviews, 255, 106812, https://doi.org/10.1016/j.quascirev.2021.106812.

Jara-Muñoz J. et al. (2026) - TerraceM-3: Integrating machine learning and ICESat-2 altimetry to estimate deformation rates from wave-abrasion terraces. Earth Surface Dynamics, 14(2), 291-311, https://doi.org/10.5194/esurf-14-291-2026.

Kreutzer, S., Mauz, B., Martin, L., & Mercier, N. (2019). 'RCarb': Dose Rate Modelling of Carbonate-Rich Samples - an Implementation of Carb in R. Ancient TL, 37(2), 1-8, https://doi.org/10.26034/la.atl.2019.533.

Higher-order increments in geomorphometry for surface texture analysis: simple tools, deep insights

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Keywords: surface roughness, surface texture, DEM.

Surface roughness/texture analysis is fundamental in geomorphometry, providing key diagnostic features for terrain fingerprinting and for characterizing a wide range of surface processes (Pike, 2000; Trevisani & Guth, 2025). Analogously, in image analysis texture underpins pattern recognition approaches and provides rich predictive features for supervised learning. In both domains, the patterns under investigation—whether terrestrial or extraterrestrial—are often spatially complex: they exhibit nonstationarity, anisotropy, curvilinear structures, multiscale organization, spatial discontinuities, and in some cases, multifractal behavior. These characteristics demand analytical tools capable of capturing the multifaceted nature of topographic variability.

A simple and effective solution is to adapt and generalize well-known geostatistical tools based on higher-order increments (Herzfeld, 2002; Trevisani et al., 2023). By deploying these tools within a multiscale framework, it is possible to derive informative and interpretable indices that significantly amplify the capabilities of geomorphometric analysis. We illustrate this approach using applications on real and synthetic surfaces, further exploring the relationship between these geomorphometric indices and key physically-based geomorphometric derivatives.

Herzfeld U.C.(2002) - Vario functions of higher order - Definition and application to characterization of snow surface roughness. Computers and Geosciences, 28(5), 641-660.

Pike R.J. (2000) - Geomorphometry - diversity in quantitative surface analysis. Progress in Physical Geography 24, 1-20. https://doi.org/10.1191/030913300674449511.

Trevisani S. & Guth P.L. (2025) - Surface Roughness in Geomorphometry: From Basic Metrics Toward a Coherent Framework. Remote Sensing, 17, https://doi.org/10.3390/rs17233864.

Trevisani S. et al. (2023) - A simplified geostatistical approach for characterizing key aspects of short-range roughness. CATENA, 223, https://doi.org/10.1016/j.catena.2023.106927.

S39.

From geological data to knowledge: data-driven workflows for geological interpretation

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Geo-IT3D: Web-Based visualization and standardized dissemination of Italian 3D geological models

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Keywords: 3D geological models, Geo-IT3D.

Three-dimensional geological models are increasingly recognized as fundamental tools for geoscientific interpretation, subsurface characterization, natural hazard assessment, and territorial planning. Within this framework, the Italian CARG Programme promotes the systematic development of 3D geological models associated with the official geological mapping of Italy, extending traditional two-dimensional geological representation into an integrated digital subsurface framework.

To support the accessibility and dissemination of these datasets, ISPRA developed Geo-IT3D (https://geo-it3d.isprambiente.it), a web-based platform designed for the interactive visualization, exploration, and sharing of Italian 3D geological models. The system provides direct browser-based access to complex geological datasets without requiring dedicated desktop applications, enabling users to interactively explore geological units, stratigraphic horizons, faults, and associated attributes through intuitive 2D and 3D environments.

A key aspect of Geo-IT3D is the implementation of interoperable and standardized geological data structures compliant with INSPIRE and GeoSciML specifications. The platform adopts semantically controlled vocabularies developed within the GeoSciences IR project (https://hub.geosciences-ir.it/Vocabolari.html) and harmonized with INSPIRE and GeoSciML standards. These vocabularies are based on the terminology and formal definitions provided by the CARG 3.0 Glossary (https://progetto-carg.isprambiente.it/glossario/index.html), the official reference glossary of the Geological Survey of Italy for the national geological mapping program. Controlled vocabularies provide standardized terminology for lithology, geological age, depositional environments, structural elements, and 3D geological objects, ensuring semantic consistency and interoperability among models produced by different institutions and research groups.

The underlying data architecture supports both surface-based and volumetric geological representations using standardized geometries and metadata structures. Automatic validation procedures specifically developed for the Italian national database of 3D geological models, enables automated verification of geometries, attributes, metadata completeness, and vocabulary compliance. This approach contributes to improving data quality, reproducibility, and long-term accessibility according to FAIR principles.

The platform has been tested on geological models characterized by different scales and geological complexity, including regional sedimentary basins, fold-and-thrust systems, and urban geology applications. These case studies demonstrate the capability of Geo-IT3D to efficiently manage heterogeneous geological datasets while preserving interoperability and facilitating multidisciplinary data integration.

By combining open web technologies, standardized geological schemas, and interoperable services, Geo-IT3D represents a significant step toward the creation of a national digital infrastructure for 3D geological knowledge, supporting both scientific research and applied decision-making processes.

Pre-exploration workflow for natural hydrogen prospectivity quantification

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Keywords: natural hydrogen, georesource, prospectivity maps.

Natural hydrogen (H_2) is emerging as a promising low-carbon resource for energy storage and for the decarbonization of hard-to-abate sectors. Recent accidental discoveries of subsurface H_2 accumulations in different geological settings such as Mali, Albania, and Australia demonstrate that H_2 can be generated and preserved in economically significant concentrations. These examples highlight the need for systematic, geology-based, high-confidence exploration strategies to identify the most prospective regions and accelerate natural H_2 exploration.

Within the EU-funded NHEAT —Natural Hydrogen for Energy trAnsiTion— project, this study developed a novel semi-quantitative workflow for national-scale assessment of natural H_2 prospectivity that consists of a four-step procedure:

- GIS-based integration of geological, structural, geophysical, and geochemical data in thematic maps;
- identification of potential H_2-generating mechanisms according to regional tectonic, geological, and magmatic contexts;
- identification of the evidence and conditions associated with each mechanism;
- weighted scoring of H_2 prospectivity to rank and prioritize exploration targets.

The workflow was tested in Italy, where H_2 generation may be related to serpentinization of ultramafic rocks, hydrothermal alteration of Fe-rich igneous rocks, and thermogenic degradation of organic matter. The results identify the Tuscan geothermal region as the highest-priority target, where H_2 may be generated by hydrothermal alteration of granitoids. The Voltri Massif shows moderate potential linked to active serpentinization, whereas the Northern Apennines may preserve H_2 generated from fossil serpentinization events. The Po Basin may also sustain H_2 production related to organic matter degradation.

This national-scale synthesis transforms complex geological constraints into decision-ready insights, reducing uncertainty in early exploration decisions and supporting the allocation of resource and field efforts. Because it is based on a reproducible and editable matrix approach, this semi-quantitative workflow is transferable to other case studies, contributing to the global energy transition by integrating natural hydrogen into broader decarbonization strategies alongside existing geothermal and gas infrastructures.

The Geological database on the CARG-gate portal: Data development and sharing

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Keywords: CARG Program, geological data, database, CARG-gate.

The CARG Program - the Geological Map of Italy at 1:50,000 scale, developed by the Geological Survey of Italy - has so far produced 301 geological sheets out of a total of 634, achieving coverage of 47% of the national territory. All CARG products are published and available for consultation on the ISPRA website.

The geological information, acquired at 1:25,000 scale and derived from surface and subsurface surveys of both the emerged and submerged areas of Italy, is organised within a comprehensive geological database (BDG) that has evolved since the 1990s to comply with modern technological standards.

The conceptual model relating to the specific knowledge domains of geology is of the Entity-Relationship-Domain type; it has a stable architecture that can be implemented at all levels and can be continuously updated with new content.

The information layers, which constitute the physical structure of the BDG entities, are a type of file in which the connection between the graphic elements (geometric primitives: points, lines and polygons) and the descriptive elements is guaranteed; the latter are managed in the form of alphanumeric tables within a relational database management system.

The databases for each geological sheet are processed using systems that check for constraints, domains, and geometric and topological consistency, employing automated Python procedures and manual on-screen checks to ensure compliance with the CARG guidelines (Battaglini et al., 2009).

In order to improve the usability, accessibility and interoperability of this vast amount of geological data, it was necessary to convert the databases into the open-source GeoPackage format, which was implemented with seven layers relating to geology, geomorphology, resources and prospecting, This was achieved using specially designed scripts which, following a preparatory phase of reviewing and reorganising the items, enabled the transcoding of codes to clarify the information contained in the original databases, including the implementation of the text for the geological map legends.

The new CARG-gate platform, dedicated to products linked to the CARG Program, allows users to access and download databases in Geopackage format, which have been created for each individual sheet, previously indexed by assigning a Digital Object Identifier (DOI).

This website also allows users to browse an interactive map that displays the progress of BDG publication and to consult the layers relating to geology, geomorphology and resources and prospecting. The features of each layer are displayed using conventional symbols, created in accordance with the standards of the Italian Geological Survey.

Access to and usability of CARG geological data are of fundamental importance, as geological knowledge forms the basis of all land-use planning and environmental protection activities, and is strategic for the identification of natural, extractive and mineral resources.

Battaglini L., Carta R., D'Angelo S., Delogu D., Falcetti S., Pantaloni M., Papasodaro F. & Tacchia D. (2009) - Carta Geologica d'Italia - 1:50.000 - Progetto CARG: modifiche ed integrazioni ai Quaderni n. 2/1996 e n. 6/1997.Quaderni del Servizio Geologico d'Italia, serie III, 12(I), 166 pp.

CARGmap - exploring geology with your smartphone

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Keywords: CARG Program, apps, geological data.

The Geological Database of the CARG National Program contains geological information, acquired at 1:25,000 scale, derived from surface and subsurface surveys of both emerged and submerged areas of Italy, which were carried out for the purpose of producing the Geological Map of Italy at 1:50,000 scale. Currently, geological survey coverage has reached 47% of the national territory with 301 sheets completed and will reach 63% with the 93 sheets currently in progress.

Geological data are organized into a complex series of information layers and topological rules, including spatial data (20 layers) and alphanumeric data (14 related tables), ruled by logical and spatial relationships and constraints, as well as field code domains, according with the relevant standards established by the CARG guidelines (Battaglini et al., 2009).

In order to improve the traceability, accessibility, interoperability, and reusability of this vast amount of geological data, in line with the FAIR principles and INSPIRE standards, a complex process of transcoding and standardization of CARG data has been initiated.

The information contained in the databases of each Geological Map is summarized in the following seven layers, presenting the decoded content in plain text for visualisation: three layers relate to geological units, tectonic features, and bedding; three layers relate to geomorphological information (points, lines, and polygons); and finally, one layer relates to resources and prospecting.

CARGmap is a multi-device application developed as part of the PNRR Geosciences IR Project, designed to make this processed geological data accessible. Through this app, optimized for Android and iOS, users can view geological maps and access the information contained in the corresponding databases. Information is accessed by tapping on the map, which opens a pop-up or an information panel containing a description of the selected feature. Geological data is uploaded via the back-end platform by authorized ISPRA staff.

Users can geolocate and submit feedback regarding the data they have observed. In addition, the app offers functionality for downloading data for offline navigation, as well as the user's registration of georeferenced content such as itineraries, points of interest, and geolocated photos. This content can be saved locally or sent anonymously to ISPRA for review and analysis.

CARGmap is the official tool of the Italian Geological Survey for free access to all geological maps of the Geological Map of the CARG Program and makes a significant contribution to the accessibility and dissemination of data, as well as serving as a highly valuable national prototype in the geological field.

Battaglini L. et al. (2009) - Carta Geologica d'Italia - 1:50.000 - Progetto CARG: modifiche ed integrazioni ai Quaderni n. 2/1996 e n. 6/1997. Quaderni del Servizio Geologico d'Italia, serie III, 12(I), 166 pp.

Integration and harmonisation of multi-source borehole data from the Brindisi Plain (CARG Puglia Project, sheet n. 476-477 "Brindisi", southern Italy)

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Keywords: stratigraphic data harmonization, CARG project, Brindisi Plain.

The Brindisi Plain (southern Italy) is being investigated within the framework of the CARG Project, sheet n. 476-477 "Brindisi". This flat area represents a challenging for geological mapping due to its high degree of urbanisation and the widespread presence of agricultural land. Mesozoic limestones, cropping out in the north-western corner of the area, represent the relatively deep bedrock in the plain. These limestones are covered by Pleistocene deposits, first formed during the subsidence phase of the Bradanic Trough (the south Apennines foredeep) and subsequently, at least from the Middle Pleistocene, during the Foreland uplift (i.e., the Murge region, in the Brindisi area). The subsidence related deposits correspond to the Calcarenite di Gravina Fm. (Early Pleistocene coarse-grained biocalcarenites) followed by the Argille subapennine Fm. (Early Pleistocene grey-blue silty clays). These units are covered in paraconformity by marine terraced deposits, Middle-Late Pleistocene in age and mainly bioclastic in origin. Locally, alluvial and coastal Holocene deposits unconformably lie on the previous units.

In this context, subsurface data are essential for constraining stratigraphic framework of the investigated area. A significant amount of borehole data is available from multiple sources, such as public institutions (e.g. Ente Irrigazione, Genio Civile, ISPRA), private companies and bibliographic references. These legacy datasets are heterogeneous, having been collected for different purposes and according to non-uniform standards, resulting in inconsistencies in format, terminology and stratigraphic attribution. This study presents an approach to data-driven workflow designed to uniform these multi-source geognostic datasets into a coherent and interoperable database. The workflow includes data collection, quality control, standardisation and harmonisation, to ensure reproducibility and enabling future integration into the Geological Database at 1:25,000 scale, according to ISPRA guidelines.

Attention is given to the harmonisation of the main stratigraphic markers, including the top of the lithostratigraphic units, which are key for regional correlation. The final dataset is expected to support stratigraphic interpretation and provide a basis for planning targeted borehole campaigns within the CARG Project, as well as for the preliminary development of 2D/3D geological models using dedicated software (e.g. Petrel, Move).

Integrating AI tool for the extraction of geological knowledge from heterogeneous historical data

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Keywords: GeoAI, natural language processing (NLP), critical raw materials (CRM).

Within the framework of the URBES project, funded under the Italian National Recovery and Resilience Plan (PNRR), an intelligent platform has been developed to support the identification and valorisation of Critical Raw Materials (CRM) and Strategic Raw Materials (SRM) derived from anthropogenic deposits, including abandoned mining sites and urban environments. To address the challenges associated with heterogeneous and historically fragmented datasets, advanced Artificial Intelligence (AI) techniques have been integrated for large-scale information retrieval and structuring. In particular, GeoAI and Natural Language Processing (NLP) methodologies are embedded into high-performance automated pipelines executed on GPU-based computational infrastructures, enabling efficient extraction, semantic organisation, and integration of complex data sources. The GeoAI component relies on deep learning models based on the U-Net architecture (Ronneberger et al., 2015), specifically designed for semantic image segmentation. This encoder-decoder framework effectively captures multi-scale spatial features, making it well-suited for the interpretation of historical maps and geological raster data, often affected by noise and incompleteness. Within URBES, the model is trained in a supervised manner using expert-annotated datasets to identify relevant cartographic elements, such as mining areas, extraction waste deposits, and other indicators of anthropogenic resources. The output consists of semantically segmented maps from which georeferenced features are extracted and subsequently integrated into a geospatial database. This approach significantly enhances the accessibility of legacy information while maintaining high accuracy through expert-driven validation. In parallel, the NLP pipeline is designed to systematically process unstructured textual data, particularly PDF documents containing technical reports, environmental assessments, and historical mining archives. The system automatically distinguishes between two processing modes depending on document type. For digitally native PDFs with selectable text, advanced NLP techniques based on Transformer architectures are employed for named entity recognition and relation extraction. Relevant information - such as deposit names, raw materials, concentrations, geographic references, and CRM-associated minerals - is parsed into structured data units and indexed accordingly. For scanned or image-based PDFs, an initial digitisation phase is performed using advanced Optical Character Recognition (OCR) techniques enhanced by deep neural networks capable of handling complex layouts and variable scan quality. The extracted text is then processed through the same NLP pipeline, ensuring methodological consistency and uniform data structuring, in line with established approaches in automated information extraction (Jurafsky & Martin, 2025). In both workflows, the extracted information is stored in a semantic database designed to support advanced querying and linkage with georeferenced entities within a WebGIS infrastructure. This integrated approach not only enables efficient information retrieval but also supports the progressive construction of a scalable and interoperable knowledge base. The synergy between GeoAI and NLP thus facilitates a comprehensive data valorisation process, transforming heterogeneous sources into structured knowledge to support spatial analyses and decision-making processes in the domain of critical raw materials.

Jurafsky D. & Martin J.H. (2025) - Speech and Language Processing: An Introduction to Natural Language Processing, Computational Linguistics, and Speech Recognition with Language Models. 3rd edition, Prentice Hall PTR.

Ronneberger O. et al. (2015) - U-Net: Convolutional Networks for Biomedical Image Segmentation. In: Navab N., Hornegger J., Wells W., Frangi A. (eds.), Medical Image Computing and Computer-Assisted Intervention - MICCAI 2015. MICCAI 2015. Lecture Notes in Computer Science, Springer, 9351, 234-241, https://doi.org/10.1007/978-3-319-24574-4_28.

GIS-based workflow for 3D-modeling-oriented geological mapping: Current applications and future AI perspectives

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Keywords: GIS, 3D-modeling, geological mapping.

This work examines the current state of geological cartography and its digital transition, with particular attention to the three-dimensional representation and analysis of geological field data. Although a geological map is conventionally presented as a two-dimensional projection of outcropping features, it is inherently a three-dimensional document linking surface observations to the subsurface geological framework. However, the widespread use of Geographic Information Systems (GIS) has often reduced this complexity to a two-dimensional representation, limiting the potential of geological maps as inputs for three-dimensional.

Building upon the experience of implicit modeling (Lajaunie et al., 1997; Calcagno et al., 2008) and GemPy (de la Varga et al., 2019), here we propose a workflow for building three-dimensional geological models directly from geological maps within QGIS. The approach combines GemPy's implicit interpolation algorithms for reconstructing geological surfaces and volumes with the ability to perform the entire modelling sequence inside the open-source QGIS environment. In doing so, QGIS is effectively reconfigured into a "geological GIS", capable of managing spatial data, supporting geological interpretation through structured inputs, and generating subsurface models within a single integrated platform.

Applications to different Italian cartographic scenarios, including datasets from the CARG Project, have been performed to test the proposed workflow across heterogeneous geological contexts. A key issue concerns the standardization of field data acquisition so that geological observations can be effectively processed by computational systems. To address this, the work introduces the concept of structural sampling interval (Miao & Wang, 2026), defined as the spacing of strike-dip measurements in relation to map scale and the structural characteristics of the study area.

The generated 3D outputs were then used as a preliminary training dataset for AI-driven 3D geological model prediction. This early use of AI is conceived as a first step towards progressively improving the reliability of computer-aided reconstructions of geological bodies and automating geological interpretation, by reducing dependence on operator-driven manual subsurface reconstruction and widening access to geological map consultation and analysis for all stakeholders involved in land-use planning. The preliminary outcomes presented here, together with their associated uncertainty, represent a proof of concept, while the next step will consist in progressively expanding the available geological map datasets to improve model robustness and generalizability.

Within such a data-centred workflow, artificial intelligence may play a transformative role by formalizing and reproducing the interpretive rules traditionally applied by geologists, provided that these rules are explicitly defined, consistently encoded, and shared within the geoscientific community.

Calcagno P. et al. (2008) - Geological modelling from field data and geological knowledge: Part I. Modelling method coupling 3D potential-field interpolation and geological rules. Physics of the Earth and Planetary Interiors, 171, Issues(1-4), 147-157, https://doi.org/10.1016/j.pepi.2008.06.013.

de la Varga M. et al. (2019) - GemPy 1.0: open-source stochastic geological modeling and inversion. Geoscientific Model Development, 12(1), 1-32, https://doi.org/10.5194/gmd-12-1-2019.

Lajaunie C. et al. (1997) - Foliation fields and 3D cartography in geology: principles of a method based on potential interpolation. Mathematical geology, 29(4), 571-584, https://doi.org/10.1007/BF02775087.

Miao C. & Wang Y. (2026) - Multivariate Gaussian process regression for characterization of geo-data spatial variability from limited and non-co-located measurements. Engineering Geology, 364, 108611, https://doi.org/10.1016/j.enggeo.2026.108611.

X-Min Learn: An open-source software for developing custom machine learning models for mineral classification from thin section X-ray maps

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Keywords: machine learning, mineral identification, python.

We present X-Min Learn, an open-source software that implements a user-friendly, data-driven workflow for developing custom machine learning (ML) models specialized in pixel-wise mineral classification from X-ray elemental maps of rocks thin sections, collected with SEM-EDS or EPMA-WDS instrumentations. The proposed methodology addresses the full transformation chain from raw image data to mineralogical interpretation, with particular emphasis on ground-truth dataset structuring, ML model development, automated mineral identification, and post-processing classification refinement.

Custom models can be trained on user-provided ground-truth data (i.e., examples of fully classified thin sections), reducing potential biases introduced by traditional classification routines based on manual region-of-interest (ROI) selection. This is achieved through an interactive, no-code environment (i.e., the "Developer's Toolkit"), which simplifies ground-truth dataset compilation, class balancing, model parameter tuning, and performance evaluation, ensuring consistent data handling while extending accessibility to users with limited coding experience. The resulting models are reusable and sample-independent, reducing classification time while maintaining classification accuracies comparable to those achieved by established tools like XMapTools (Lanari et al., 2014) and Q-XRMA (Ortolano et al., 2018).

In addition to custom models, X-Min Learn also includes traditional ROI-based supervised and unsupervised classifiers, supporting different analytical requirements and providing alternatives when ground-truth data is unavailable. Results obtained from these approaches, once carefully validated, can be employed to generate new ground-truth datasets. In this view, the integrated morphological image processing algorithms provide powerful but accessible functionalities for post-classification refinement.

These features make X-Min Learn a versatile and autonomous tool for developing custom ML models from mineral X-ray maps data, encouraging standardized datasets organization and sharing, thereby promoting collaborative model development within the community. Furthermore, its modular architecture enables the integration of multi-source data, potentially opening perspectives for correlative microscopy workflows that combine multiple analytical techniques to enhance mineralogical interpretation.

Lanari P. et al. (2019) - Quantitative compositional mapping of mineral phases by electron probe micro-analyser. Geological Society, London, Special Publications, 478(1), 39-63, https://doi.org/10.1144/SP478.4.

Ortolano G. et al. (2018) - Quantitative X-ray Map Analyser (Q-XRMA): A new GIS-based statistical approach to Mineral Image Analysis. Computers & Geosciences, 115, 56-65, https://doi.org/10.1016/j.cageo.2018.03.001.

IsoBorDat repository: A global compilation of Boron isotope data in natural waters

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Keywords: Boron isotopes, IsoBorDat repository, statistical analyses.

Over the past decades, the use of stable boron isotopes ($^{11}B/^{10}B$), expressed as $\delta^{11}B$ relative to the NBS SRM 951 standard (Catanzaro et al., 1970), has increased substantially in Earth Sciences. In hydrological research, $\delta^{11}B$ has been widely applied as an effective tracer of geochemical processes and of sources of boron in waters (geogenic *vs* anthropogenic). Here, we present "IsoBorDat", a global, open-access repository that compiles boron isotope ratios and boron concentrations from hydrological systems worldwide (Pennisi et al., 2026). IsoBorDat organizes data published in scientific literature into five main categories based on the type of sampled reservoir: meteoric waters (rain and snow), rivers, lakes, groundwaters, and contaminants. The contaminant category includes both solid and liquid anthropogenic sources, as well as waters explicitly affected by human activities, such as fertilizer-impacted waters, sewage, landfill leachates, oilfield produced waters, and industrial by-products. This structure allows direct comparison between natural hydrological reservoirs and potential anthropogenic boron inputs, supporting source identification across different environmental scales.

We perform qualitative and quantitative exploratory statistics to examine how boron concentrations and $\delta^{11}B$ values are distributed within and among the main water types.Our analysis shows that: (1) rivers and groundwaters display pronounced multimodal and multifractal behaviour, reflecting the superposition of multiple geochemical processes acting at different spatial and temporal scales, including water-rock interactions, adsorption-desorption processes, mixing of contrasting water sources, and variable flow regimes; (2) lakes exhibit wide variability related to residence time and hydrological balance; (3) meteoric waters are characterized by generally low boron concentrations but highly variable isotopic signatures, controlled by geographic and atmospheric factors. In contrast, (4) contaminated waters tend to show more linear and homogeneous distribution patterns, consistent with the predominance of point-source anthropogenic inputs.

Overall, these results highlight the importance of accounting for non-linear and non-equilibrium dynamics when interpreting boron isotope data in hydrological systems. IsoBorDat represents a valuable tool for investigating boron behaviour across diverse environments and supports the integrated use of boron isotopes in environmental studies, contamination assessment, and monitoring applications within the ISOTOPE Virtual Research Environment. We conclude with a call for contributions of boron and $\delta^{11}B$ data in hydrological research, inviting scientists to submit their datasets using the provided template, which will be incorporated into IsoBorDat.

Catanzaro E.J. et al. (1970) - Boric acid, isotopic, and assay standard reference materials. US Nat. Bur. Stand., Spec. Publ. 260, 17

Pennisi M. et al. (2026) - Boron and $\delta^{11}B$ in hydrological studies: A comprehensive overview based on the IsoBorDat repository. Applied Geochem., 201, 106756, https://doi.org/10.1016/j.apgeochem.2026.106756.

Using the Urban Geo-climate Footprint (UGF) to categorize Italian urban centers by geological and climatic factors

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Keywords: urban geology, urban subsurface, geological hazards.

Modern cities are increasingly threatened by the complex interplay of geological, climatic, and human-induced factors, necessitating structured assessment tools like the Urban Geo-climate Footprint (UGF) developed by Lentini et al. (2024). This study applies the UGF methodology to Italy's 21 regional capitals, capturing the nation's diverse topographical and climatic range from the Alpine regions to the southern volcanic provinces. The approach fits into a data-driven workflow designed to transform heterogeneous geological and environmental datasets into actionable knowledge for urban management.

The index synthesizes five primary drivers: Deep Geological Processes (DEE) involving seismic and volcanic activity; Superficial Processes (SUP) like subsidence and landslides; Exogenous Processes (EXO) including climate-related sea-level changes and extreme weather; Geological Complexity (GEO) regarding stratigraphy and stability; and Anthropogenic Pressures (SAP) such as soil sealing and pollution. By integrating multi-source digital archives, including historical records, geognostic data, and remotely sensed products, the UGF methodology harmonizes diverse data types into a standardized framework.

The resulting framework illustrates a varied landscape where cities like Trento and Campobasso (UGF-1) experience relatively low environmental strain, whereas Naples and Genoa (UGF-4) face high-intensity pressures from the convergence of seismic, volcanic, and human stressors. Mid-range cities like Milan, Bologna, and Venice fall into the UGF-2 or UGF-3 categories, characterized by more moderate interactions. Spatial observations show a general southward escalation in geo-climatic pressure, influenced by Mediterranean climate extremes and Apennine seismicity. While coastal centers are largely affected by erosion and storm surges (SUP and EXO), major metropolitan areas exhibit higher human-induced instability (SAP). Interestingly, geological complexity (GEO) remains relatively uniform across the peninsula, reflecting Italy's inherent natural diversity.

It is important to note that these UGF classifications are intended to pinpoint specific environmental pressures for planning purposes rather than to serve as a definitive ranking of risk or vulnerability. In this context, the UGF acts as a tool for visual analytics, supporting geological interpretation and evidence-based decision-making across different scales. Furthermore, a qualitative assessment of "geo-benefits" reveals that many cities, including Rome, Palermo, and Trieste, derive notable environmental advantages from their unique settings. In summary, the UGF approach provides a clear synthesis of urban stressors, offering a nuanced perspective for evidence-based planning and resilience by treating the subsurface as a critical and indispensable piece of urban infrastructure. This study demonstrates how structured data manipulation and synthesis can effectively bridge the gap between complex geological data and sustainable urban planning.

Lentini A. et al. (2024) - The Urban Geo-climate Footprint approach: Enhancing urban resilience through improved geological conceptualization. Cities, 145, 105287, https://doi.org/10.1016/j.cities.2024.105287.

EMODnet Geology: An example of data collection, standardization and harmonization

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Keywords: EMODnet, INSPIRE, database.

The European Marine Observation and Data network (EMODnet) is a long-term marine data initiative funded by the European Union through the DG-MARE. It provides easy and free access to existing data from seas surrounding European countries subdivided into thematic Lots: bathymetry, geology, physics, chemistry, biology, seabed habitats and human activities. The Project Portal includes metadata, data products and webservices and allows to freely browse through digital maps, standardized and harmonized at European scale, and download the underlying databases.

EMODnet Geology provides maps at a 1:100,000 scale or finer, but also at coarser scales (1:250,000 and 1:1,000,000) to ensure maximum areal coverage. It includes sea-bed substrate, sediment accumulation, erosion rates, Quaternary and pre-Quaternary lithology and age, geomorphological features, coastal behaviour, geological events and probabilities, minerals and submerged landscapes, which are managed within dedicated work packages. Each work package is coordinated by a Partner of the Consortium carrying out the Project; Coordinators provide Guidelines for the compilation of the layers included in their work packages. Data are represented by shapefiles/geodatabases complemented by detailed attribute tables and by metadata organized according to the INSPIRE Directive.

Basically, two approaches have been applied: terms to fill in the attribute tables are organized in domains derived from the INSPIRE Code List or a preliminary semantic transformation of the original definitions into INSPIRE Code List is performed before compiling the attribute table. The first option allows a hierarchical organization and more flexibility, whereas the second option has not got a hierarchy (as INSPIRE) and fulfills more strictly INSPIRE requirements.

All Partners of the Consortium are requested to gather national data, elaborate them according to the Guidelines and deliver their shapefiles to the Coordinators. Coordinators compile Europe wide layers, verify attributes and their correspondence to the Guidelines, harmonize data according to the standards established and across boundaries, submit final products to Partners for their validation and provide validated layers to the Portal management for publication. Metadata in INSPIRE format are compiled through the EGDI Metadata Portal and harvested periodically by the EMODnet Central Portal to include intervening updates.

The geological Survey of Italy - ISPRA is Partner of the EMODnet Geology Consortium and coordinates the “Geological events and probabilities” work package, which includes submarine landslides, volcanoes, earthquakes, tsunamis, fluid emissions and Quaternary tectonics.

Data stored in different work packages might provide useful information concerning potential impacts on human activities. The EMODnet Geology database constitutes a solid base for further studies aimed at multiple applications such as geological hazard assessment and land management.

Integrated geophysical characterization of heterogeneous limestone terrains for engineering applications: The LIMESAFE framework in Malta

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Keywords: engineering geophysics, rock-mass integrity, Malta.

Limestone terrains in the Maltese Islands present significant challenges for engineering site investigation because rock-mass conditions may vary sharply over short distances as a result of fracturing, karstification, weathering, and anthropogenic disturbance. Conventional investigations based mainly on sparse boreholes provide essential ground-truth information, but they may fail to resolve critical lateral variability between control points. This limitation can increase uncertainty during excavation, foundation design, and preliminary ground-risk assessment.

This contribution presents the LIMESAFE framework, a multi-method approach designed to improve non-invasive characterization of heterogeneous carbonate settings. The workflow integrates passive seismic techniques, surface-wave analysis, Electrical Resistivity Tomography (ERT), Ground Penetrating Radar (GPR), and geomatic observations to obtain spatially continuous information on near-surface rock conditions. The objective is not to replace conventional geotechnical investigation, but to complement it by identifying zones of contrasting stiffness, disturbed or weathered material, possible discontinuities, and other subsurface heterogeneities that may require targeted verification.

A central component of the framework is calibrating the geophysical responses against observable rock-mass conditions in accessible limestone outcrops and available geotechnical information. This "rock-to-signal" strategy aims to reduce interpretative ambiguity by linking geophysical anomalies to engineering-relevant indicators, such as fracturing intensity, weathering grade, and relative rock mass quality. Particular attention is given to the combined interpretation of seismic, electrical, radar, and geological constraints, since single-method interpretations in carbonate terrains can be non-unique.

The expected outcome is a practical and transferable workflow for preliminary subsurface screening in limestone-dominated urban and peri-urban environments. By translating integrated geophysical observations into standardized subsurface-integrity classes, the approach aims to support more informed engineering interpretation, optimize intrusive investigation campaigns, and reduce uncertainty in areas with strong geological variability that affect construction and infrastructure planning. Although developed in Malta, the framework is relevant to other Mediterranean carbonate regions facing similar near-surface engineering challenges.

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A compositional approach in the identification of the provenance and anthropogenic impacts on stream sediments in the Ombrone Grossetano River Basin (Southern Tuscany, Italy)

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Keywords: isometric log-ratio transformation, sequential binary partitions, stream sediments.

River ecosystems are facing an increased pressure from pollution, land use modifications and climate change, hence the growing necessity for surveys dedicated to environmental assessments. In a river ecosystem, the geochemical and mineralogical characteristics of stream sediments represent the overall composition of a drainage basin, reflecting both bedrock lithology and anthropogenic inputs and thus provide a valuable matrix for environmental surveys.

Geochemical datasets from stream sediments are compositional data, as their parts are positive and constrained to a constant sum (Aitchison, 1986) and pertain to the *simplex* sample space (Pawlowsky-Glahn & Egozcue, 2001), requiring a transformation to be appropriately analysed using classical statistical techniques. In this context, we propose the application of knowledge-driven Sequential Binary Partitions (SBPs; Egozcue & Pawlowsky-Glahn, 2005) of isometric log-ratio (ilr)-transformed data to disentangle the relationships between geochemistry and mineralogy. The approach works toward improving the understanding of natural and anthropogenic influences on sediment composition. The efficiency of this methodology is tested on a representative river basin, the Ombrone Grossetano River Basin (Southern Tuscany, Italy), which is characterized by a wide lithological variability and has been greatly impacted by past mining activities.

Geochemical data (X-ray fluorescence) were transformed using ilr-balances, whereas mineralogical compositions (X-ray diffraction), lithological information, and mass-specific magnetic susceptibility (χ) measurements were used to support the identification of sediment sources. The strong correlations observed between ilr-balances and mineral phases confirm that the geochemical signals reliably reflect sediment mineralogy and the basin's lithological variability, whereas the comparison between χ and ilr-balances aids in the detection of localized anthropogenic inputs, notably Fe-enrichments linked to historical mining in a specific sub-basin (Farma-Merse). The combined use of compositional data analysis, mineralogical constraints and magnetic susceptibility provides a transferable framework to investigate sediment provenance and anthropogenic legacy in complex river systems. Beyond the case study, the results highlight the importance of considering whole-composition geochemical relationships to correctly interpret element distributions in fluvial sediments.

Aitchison J. (1986) - The statistical analysis of compositional data. Chapman and Hall.

Egozcue J.J. & Pawlowsky-Glahn V. (2005) - Groups of parts and their balances in compositional data analysis. Math. Geol., 37(7), 795-828, https://doi.org/10.1007/s11004-005-7381-9.

Pawlowsky-Glahn V. & Egozcue J.J. (2001) - Scaling stratigraphic events using extreme occurrences. Bull. Int. Stat. Inst., 2, 473-476.

From legacy geological data to webgis-based knowledge: The pilot project of the anthropogenic sinkholes territorial database of the Metropolitan City of Naples

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Keywords: multi source data, geodatabase, WebGIS, anthropogenic sinkholes.

The integration of multi-source data represents a significant methodological challenge, particularly in urban areas, where geological, anthropogenic, infrastructural, and historical factors interact across different spatial and temporal scales. This challenge becomes especially relevant when new investigations must be integrated with historical geological data for hazard assessment purposes, as in the present case study.

This work presents the results of a pilot project carried out by the Department for the Geological Survey of Italy (ISPRA), in collaboration with the Planning Department of the Metropolitan City of Naples, aimed at standardizing and enhancing the usability of the large amount of data collected over recent decades concerning anthropogenic sinkhole phenomena. The project was motivated by the fact that many urban areas within the Metropolitan City of Naples are affected by a high susceptibility to anthropogenic sinkholes.

The main outcome of the project is the "Anthropogenic Sinkholes Territorial Database of the Metropolitan City of Naples", which integrates and organizes georeferenced information on the predisposing and triggering factors of anthropogenic sinkholes within a unified knowledge framework. The database is publicly available through the official ISPRA portal and the Metropolitan City of Naples web platform.

Project activities included the collection, digitization, and georeferencing of legacy data related to: (i) the distribution of underground cavities; (ii) surface geology; (iii) subsoil stratigraphic setting; (iv) groundwater circulation; and (v) infrastructure networks and underground utilities.

Each dataset presented specific characteristics in terms of scale, completeness, and original format (raster or vector). The final result was the development of a geodatabase whose data is served through a WebGIS system enabling the analysis of spatial relationships among the factors predisposing to anthropogenic sinkholes. By integrating heterogeneous multi-scale data, the system supports geological interpretation and the identification of areas potentially prone to sinkhole occurrence, where more detailed investigations and studies may be required.

WigglePy: A GIS-native computational workflow for the digital rescue and harmonization of legacy seismic data

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Keywords: seismic reflection, QGIS.

The transformation of legacy geological data into digital format is a primary challenge in modern geosciences. Large archives of vintage seismic reflection profiles are essential for constructing 2D-3D geological models and characterizing seismogenic structures. However, a substantial portion of this information is preserved only as scanned raster images, creating a bottleneck for data harmonization and integration into modern data-driven workflows.

This work presents WigglePy, an open-source Python-based QGIS plugin that implements a complete workflow for converting raster seismic profiles into digital SEG-Y format within a native GIS environment (Maesano et al., 2026).

WigglePy was developed to aid the activity of the SISMOLAB-3D of INGV and specifically in the frame of the RePop project aimed at using the recovered digital data to constrain the slip rates of buried compressional structures in the Po Plain and in the Adriatic offshore.

The tool addresses critical data handling strategies by integrating five interactive modules: (i) project setup and metadata management via JSON files to ensure reproducibility; (ii) timeline suppression through morphological filtering; (iii) semi-automated trace detection; (iv) GIS-native geometry assignment linking traces to Common Depth Points (CDP) ; and (v) signal conditioning.

WigglePy uses three extraction strategies—Savitzky-Golay morphological reconstruction, Fast Fourier Bandpass, and Wiener deconvolution—to restore the seismic waveform. Methodological validation using synthetic benchmarks demonstrates that these computationally lighter operators achieve reconstruction errors comparable to formal matrix-based inversion methods, while offering a three-order-of-magnitude increase in efficiency (~0.1 ms/trace), enabling real-time visual analytics.

By embedding the profile reconstruction logic into QGIS, WigglePy enables simultaneous management of spatial context and signal extraction. This workflow provides a robust solution for the scientific rescue and revitalization of vintage archives, ensuring that recovered digital data are natively consistent with existing spatial datasets supporting geological interpretation and decision-making.

Maesano F. (2026) - WigglePy: a QGIS-integrated workflow for converting raster legacy seismic profiles into SEG-Y format. Annals of Geophysics (article accepted).

The Digital Geological-Technical Map of the Umbria Region for Seismic Microzonation

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Keywords: geological-technical map, seismic microzonation, GIS based database.

This work describes the development of the digital Geological-Technical Map of the Umbria Region, designed as a technical evolution of the existing 1:10,000 scale regional geological cartography. The primary objective of the project is the transition from a descriptive chrono-stratigraphic model to a relational vector database focused on providing geotechnical and lithostratigraphic parameters for seismic risk mitigation. The implementation involved systematic data transfer and conversion from base cartography to standardized Seismic Microzonation formats. Through a process of rigorous reinterpretation and expert judgment, each formation was translated into unique lithotechnical codes (e.g., genetic environment 'Gen' and lithotechnical type 'Tipo_gt'), ensuring the homogeneity required for site effect characterization. The system enables a systematic distinction between the seismic (geological) bedrock and surficial deposits—a critical factor for defining geophysical models and assessing local seismic response.The methodology is built upon an ESRI Geodatabase architecture that integrates topology management and relationships between diverse information layers. Central to the transformation process is the semantic reclassification of geological units based on the Seismic Microzonation Standards (Version 4.2). This approach resulted in a database structured into polygonal Feature Classes, comprising over 34,000 engineering geological units and 60,000 geomorphological entities coded for stability analysis.The results highlight the effectiveness of the GIS framework in streamlining regional geological heterogeneity into 12 operational technical classes compliant with national standards. The final product, fully interoperable and INSPIRE Directive-compliant, represents an advanced decision-support tool for urban planning, capable of transforming complex regional geological history into technical data ready for engineering and seismic modeling.

Geomorphometry and surface roughness: Work in progress?

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Keywords: geomorphometry, roughness, texture.

Surface roughness, intended in the broad sense of surface texture (Hobson, 1972; Mark, 1975; Shepard et al., 2001; Trevisani & Guth, 2025), is a fundamental geomorphometric concept with a wide range of applications across the earth sciences and ecology. Since the work of Hobson (1972), it has drawn particular attention in geomorphometric literature. Yet, despite this interest, the analysis of surface roughness/texture does not constitute a well-defined subdiscipline of geomorphometry. Instead, it remains largely represented by a scattered set of geomorphometric derivatives, lacking an organic methodological and interpretative framework.

This presentation aims to highlight the key challenges characterizing this field of inquiry, including inconsistent terminology, misuse of indices, and the absence of benchmark datasets for characterizing, comparing, and validating existing and proposed morphometric indices. A further critical issue concerns the complex spatial-statistical structure of "real-world" morphologies, requiring multiscale approaches and ad-hoc indices capable of detecting specific aspects of landscape patterns.

Ultimately, there is an urgent need for a coherent geomorphometric framework for surface texture analysis, based on a balance between interpretability and information extraction capabilities. It is the author's conviction that fostering progress in this field will require community-driven initiatives, such as the creation of an atlas of surface textures.

Hobson R.D. (1972) - Surface Roughness in Topography: Quantitative Approach; ed. by Chorley, Richard J.., Methuen & CO LTD: London; Vol. 6.

Mark D.M. (1975) - Geomorphometric Parameters: A Review and Evaluation. Geografiska Annaler. Series A, Physical Geography, 57, 165-177, https://doi.org/10.2307/520612.

Shepard M.K. et al. (2001) - The Roughness of Natural Terrain: A Planetary and Remote Sensing Perspective. Journal of Geophysical Research: Planets, 106, 32777-32795, https://doi.org/10.1029/2000JE001429.

Trevisani S. & Guth P.L. (2025) - Surface Roughness in Geomorphometry: From Basic Metrics Toward a Coherent Framework. Remote Sensing, 17, https://doi.org/10.3390/rs17233864.

Investigating and documenting seismogenic faults: recommended best practices for utilizing and reporting subsurface geophysical data

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Keywords: seismogenic faults, exploration data, geological modeling workflow.

Earthquakes of engineering significance are generated by pre-existing, relatively mature geological faults. These faults generally span a length from a few to several tens or hundreds of kilometers and can break the entire Earth's crust.

Defining the three-dimensional configuration of such seismogenic faults is crucial for developing applications for earthquake hazard analyses at different spatial scales and, in turn, for providing robust information to support earthquake risk mitigation strategies. Reconstructing fault surfaces is complicated and requires integrating multiple data types and processing methods, often involving geometric simplifications based on data availability. Subsurface data is key in this respect. The mining, oil, and gas industries have collected extensive subsurface data, often classified by country regulations. Despite their abundance, there is no standardized procedure for documenting how hydrocarbon data are used to characterize seismogenic faults. This creates challenges at the interface between industry datasets and public research, with important societal implications and obstacles to the implementation of FAIR principles. To address this, we developed a workflow outlining best practices for each step followed by geologists when using hydrocarbon exploration data, from data origin (public or confidential) to the final geological model used to document the existence of a seismogenic fault and its geometry.

A key element is a dedicated tool that implements the workflow in a structured environment, allowing users to systematically organize, track, and document all steps. This approach improves data quality, traceability, and interoperability, and facilitates integration with other disciplines (e.g., seismology, geodesy, and geomorphology). The outcome is a more robust, transparent, and reusable model of seismogenic faults, with clear scientific and societal benefits. This report presents an application of the workflow to several faults included in the Database of Individual Seismogenic Sources (DISS 3.3.1 - DISS Working Group, 2025).

DISS Working Group (2025) - Database of Individual Seismogenic Sources (DISS), Version 3.3.1: A compilation of potential sources for earthquakes larger than M 5.5 in Italy and surrounding areas. Istituto Nazionale di Geofisica e Vulcanologia (INGV), https://doi.org/10.13127/diss3.3.1.

Construction of a two-dimensional model of hydraulic fracturing in carbonate caprock based on well data: A case study in the Frigento antiform (southern Apennines, Italy)

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Keywords: Apulian Platform, CARG, Mefite D'Ansanto.

We present a data-driven methodology to reconstruct the fracturing pressure of the carbonate caprock in the Apulian Platform, focusing specifically on the Frigento antiform located in the southern Apennines of Italy, where the structural top reaches its culmination. Our methodology begins with an analysis of well data, which is then integrated with a two-dimensional model derived from geological and structural analyses. This study, currently under revision, aims to investigate the processes of carbon dioxide upwelling and to determine whether the volume of gas stored in the caprock is sufficient to fracture the carbonate rock. Despite numerous recent studies in the field of CO_2 rising au to the surface, the processes of fluid upwelling through the sedimentary caprock have largely been addressed qualitatively. The various conceptual models proposed do not adequately account for subsurface geology or pressures developing within the sedimentary bodies. This oversight results in a lack of two crucial aspects needed to reliably describe the physical phenomena involved. In our research, we model hydraulic fracturing based on estimates of the buoyancy force of the gas and a data-driven reconstruction of rock fracture density, specifically for a key well in the area listed in DIPs, Italy's first database of subsurface pressures. Our data analysis shows good agreement with the shallow stratigraphy of the region, as derived from surface surveys conducted as part of the CARG project, and it is also consistent with the deep stratigraphy indicated by detailed ENI reports. To analyse the density data, we applied a piecewise linear segmentation method, which allowed us to derive linear trends in density increases and decreases relative to major stratigraphic horizons. The analysis result reveals a constant density within the Pliocene series, followed by an increase in density up to the top of the Mélange, and a significant decrease down to the carbonate sequence of the Apulian Platform. The subsequent step involved integrating the one-dimensional results into a two-dimensional geological model based on an interpreted seismic profile, recently published by some of the authors. This profile has been re-examined and refined by incorporating newly interpreted horizons within the sedimentary cover. The updated profile has enhanced the anchoring of density values at the top of the Mélange, allowing for the extrapolation of fracture density and the calculation of fracturing pressure at the top of the carbonate structure throughout the entire geological section. This achievement improves our understanding of the dynamics of carbon dioxide emissions at the Mefite D'Ansanto site and also facilitates the creation of subsurface models with more accurate stratigraphy and petrophysical property attribution, which will be beneficial for future studies.

Feriozzi F. et al. (2024) - The 3D crustal structure in the epicentral region of the 1980, Mw 6.9, Southern Apennines earthquake (southern Italy): New constraints from the integration of seismic exploration data, deep wells, and local earthquake tomography. Tectonics, 43, e2023TC008056, https://doi.org/10.1029/2023TC008056.

Vitagliano E. et al. (2025) - Database of Italian Pressures (DIPs). Istituto Nazionale di Geofisica e Vulcanologia (INGV), https://doi.org/10.13127/dips1.

S40.

Reconstructing Earths Deep Past from Sedimentary and Biotic Archives

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The Cecca Level: A Lower Barremian (Lower Cretaceous) Lithostratigraphic Marker of the Maiolica Formation in the Umbria-Marche Basin (Central Italy)

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Keywords: lithostratigraphic marker, Barremian, Umbria-Marche.

The Lower Cretaceous Maiolica Formation of the Umbria-Marche Basin (Central Italy) is characterized by white to ivory micritic limestones locally interbedded with chert and, within specific stratigraphic intervals, by discrete black shales (Sprovieri et al., 2006), which are usually challenging to correlate across different sections of the basin. In this study, we identify and characterize five different black shales-rich lithostratigraphic intervals that are recognized over widely separated sections. We have examined these intervals to determine their possible correlatability by combining lithostratigraphy, ammonite biostratigraphy, geochemistry, and stable isotope stratigraphy. With merely small local changes, the data show strikingly comparable stacking patterns suggesting a lithostratigraphic correlation. They are also distinguished by similar ammonite assemblages and consistent values of $\delta^{13}C_{carb}$, $\delta^{18}O$, $CaCO_3$, and TOC. Furthermore, ammonite biostratigraphy indicates that the examined intervals belong to the same biostratigraphic interval, spanning the *Kotetishvilia compressissima* Zone (Holcodiscus caillaudianus Subzone) and the *Moutoniceras moutonianum* Zone of the lower Barremian (Szives et al., 2023). The $\delta^{13}C_{carb}$ data further support the correlation between intervals predating the Mid Barremian Event (MBE, Coccioni et al., 2003). In honor of Fabrizio Cecca, whose research significantly improved our knowledge of the Mesozoic successions of the Umbria-Marche region, we name this basin-scale horizon the Cecca Level. In addition to being a lithostratigraphic marker, the Cecca Level also attests to the occurrence of significant fluctuations in pelagic marine primary productivity coupled with recurrent drops in bottom-water ventilation, which resulted in the development of transient oxygen-depleted conditions whose expression at a supra-basin scale required further investigation.

Coccioni R. et al. (2003) - The mid-barremian event (MBE): The prelude to the OAE1a. AGU Fall Meeting Abstracts, PP41B-0835.

Sprovieri M. et al. (2006) - Orbital tuning of a lower Cretaceous composite record (Maiolica Formation, central Italy). Paleoceanography, 21, 1-19.

Szives O. et al. (2023) - Report on the 7th International Meeting of the IUGS Lower Cretaceous Ammonite Working Group, the Kilian Group (Warsaw, Poland, 21st August 2022): State of the art on the current Standard Ammonite Zonation of the Western Tethyan Mediterranean Province. Cretac. Res., 153, 105716.

Changes in calcareous nannofossil calcification in the western Tethys during the Albian-Cenomanian: environmental drivers and biotic response

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Keywords: coccolithophores, calcite paleofluxes, Albian-Cenomanian.

We performed a high-resolution study of the late Albian-early Cenomanian interval in the Umbria-Marche Basin (central Italy) where a continuous pelagic succession records the transition from a marly to a limy sedimentary regime and the Oceanic Anoxic Event (OAE) 1d. Quantitative nannofossil data were obtained from the Piobbico Core-Monte Petrano composite section to identify nannofloral changes in diversity, abundance and calcification. In particular, the objective was to understand if nannoplankton calcification was key for the beginning of the limy sedimentation of the Scaglia Bianca. The investigated section is well constrained by high-resolution integrated biostratigraphy, chemostratigraphy and cyclostratigraphy that allowed the dating of nannofossil changes and evaluation of sedimentation rates. Total nannofossil calcite paleofluxes, normalized to 1 year, were gathered from absolute abundances in ultrathin sections (no. specimens/1 mm^2) and the mass of individual taxa.

Out of 36, only 10 genera constitute 90% of nannofossil assemblages. Higher absolute abundances were obtained below and above an upper Albian nannoconid-rich interval across the Marne a Fucoidi/Scaglia Bianca boundary. The amount of calcite produced by individual nannofossil taxa is strictly dependent on the ultrastructure and dimensions. The nannofossil calcite paleofluxes show a sharp increase at about 5 m below the base of the Scaglia Bianca where the $CaCO_3$ values stabilize >75%. The major contribution to the paleofluxes is provided by the most common genus *Watznaueria* and the heavily calcified nannoconids. Due to their ultrastructure and dimensions, the occurrence of nannoconids explains the high calcite paleofluxes reconstructed in samples with the lowest nannofossil absolute abundances. However, the drop in nannoconid absolute abundance in the core of the OAE 1d correlates with the highest values of calcite fluxes, up to three times those recorded prior to the nannoconid-rich interval.

Our results indicate that enhanced runoff (Marne a Fucoidi) correlates with higher nannofossil absolute abundances but lower calcite paleofluxes. The increase in the nannoconid abundance and paleofluxes correlates with the shift from marlstones to limestones (Scaglia Bianca), corresponding to the establishment of stable paleoceanographic conditions and a climate change to an arid regime. In the nannoconid-rich interval, the higher fertility nannofossil taxa show a decrease in abundance, suggesting oligotrophic conditions and a well-defined thermocline. Thus, nannoplankton calcification might derive from the trophic regime; however, the high paleofluxes above the nannoconid-rich interval suggest other potential factors. We speculate that nannofossil calcite paleofluxes might reflect changes in the carbonate chemistry (ocean alkalinity), possibly affecting calcification patterns at species-specific level.

Stratigraphic completeness of the Bonarelli Level (OAE 2, central Italy) constrained by high-resolution $\delta^{13}C_{org}$ records

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Keywords: Cenomanian/Turonian boundary, chemostratigraphy, western Tethys.

Oceanic Anoxic Event 2 (OAE 2; ~94 Ma) represents a major global carbon-cycle disturbance, although its stratigraphic signature shows marked variability across different depositional environments (Jenkyns, 2010). Within the Umbria-Marche Basin (central Italy), OAE 2 corresponds to the Bonarelli Level, a carbonate-depleted interval that limits the use of carbonate-based isotopic proxies as well as calcareous microfossil and nannofossil biostratigraphy. Consequently, both the duration and the stratigraphic completeness of this unit remain contentious (Tsikos et al., 2004; Voigt et al., 2007; Gambacorta et al., 2015).

In this study, we present a new high-resolution organic carbon-isotope ($\delta^{13}C_{org}$) dataset obtained from two Bonarelli Level sections, and we compare these records with coeval, well-constrained OAE 2 successions from other basins. The resulting isotope profiles indicate that the full carbon-isotope excursion characteristic of OAE 2 is preserved within the Bonarelli Level, albeit in a condensed stratigraphic interval. This interpretation differs from previous models that proposed a significant hiatus near the top of the unit.

Consistent trends in total organic carbon (TOC) and lithofacies across the studied sections indicate a basin-wide depositional signal. Altogether, our results support an updated palaeoceanographic framework in which the Tethyan Umbria-Marche Basin during OAE 2 was characterized by persistently anoxic to euxinic conditions, favouring the preservation of marine organic matter and intermittent reworking of radiolarian-derived biogenic silica.

Gambacorta G. et al. (2015) - Carbon- and oxygen-isotope records of mid-Cretaceous Tethyan pelagic sequences from the Umbria-Marche and Belluno Basins (Italy). Newsl. Stratigr., 48(3), 299-323, https://doi.org/10.1127/nos/2015/0066.

Jenkyns H.C. (2010) - Geochemistry of oceanic anoxic events. Geochem., Geophy. Geosy., 11, Q03004, https://doi.org/10.1029/2009GC002788.

Tsikos H. et al. (2004) - Carbon-isotope stratigraphy recorded by the Cenomanian-Turonian Oceanic Anoxic Event: correlation and implications based on three key localities. J. Geol. Soc., 161, 711-719, https://doi.org/10.1144/0016-764903-077.

Voigt S. et al. (2007) - Late Cenomanian to Middle Turonian high-resolution carbon isotope stratigraphy: New data from the Münsterland Cretaceous Basin, Germany. Earth Planet. Sc. Lett., 253, 196-210, https://doi.org/10.1016/j.epsl.2006.10.026.

Updated correlations of the Shallow Benthic Zones (Paleocene to Miocene) in the frame of GTS 2020

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Keywords: biostratigraphy, Cenozoic, SBZ.

Here we present two new charts of shallow-water biozonation, namely the Shallow Benthic Zones (SBZ), covering the Danian-Priabonian and Rupelian-Tortonian intervals, respectively. The SBZ are correlated with biozones based on planktonic foraminifera and calcareous nannofossils, as well as with the Orthophragminid Zones (OZ), and are referenced to the 2020 chronostratigraphic scale (Global Time Scale, GTS 2020), including magnetostratigraphic chrons. Based on a review of the recent literature, SBZ boundaries have been reassessed and revised, and new boundaries have been placed as accurately as possible. For the Paleocene, the recently proposed SBP zonation has been adopted.

This scheme is mainly based on data from the western Neo-Tethyan area and therefore does not include the Indo-Pacific Letter Stages, owing to the scarcity of data available for establishing reliable correlations.

Among the changes highlighted here, we emphasize that the Paleocene-Eocene and Eocene-Oligocene boundaries do not perfectly coincide with SBZ boundaries, which has important implications for shallow-water age determinations.

The Lagonegro Basin (Southern Apennines): A window into the Deep Past of the Western Tethys

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Keywords: Lagonegro basin, conodont and radiolarian biostratigraphy, Triassic.

The Lagonegro Basin (Southern Apennines) preserves one of the most complete deep-marine sedimentary archives of the western Tethyan realm, recording the tectono-sedimentary and paleoenvironmental evolution associated with the opening of the Ionian branch of the Neotethys Ocean from the Middle Triassic onward. Since the first studies carried out in the late 1960s, the basin has become a key reference area for Triassic stratigraphy because of its exceptionally fossiliferous pelagic successions, particularly rich in conodonts and radiolarians. These microfossils provide a robust framework for high-resolution biostratigraphy, paleoenvironmental reconstruction, and regional chronostratigraphic correlation.

The Lagonegro succession crops out extensively within the axial sector of the Southern Apennines fold-and-thrust belt and is traditionally subdivided into the Lagonegro I and Lagonegro II tectonic units, representing distal and proximal depositional domains, respectively. The basin formed between the Apennine and Apulian carbonate platforms during Early-Middle Triassic extensional phases linked to the opening of the western Tethys. The sedimentary record, ranging from the Lower Triassic to the Paleogene, is dominated by deep-water deposits, including cherty limestones, radiolarites, siliceous shales, and marls.

Particularly important are the Upper Triassic pelagic deposits of the Calcari con Selce Formation, where integrated conodont and radiolarian biostratigraphy allows detailed reconstruction of paleoenvironmental changes associated with the Carnian Pluvial Episode (CPE). In the Pignola 2 section, a characteristic “green clay-radiolaritic horizon”, composed of shales, radiolarites, cherts, and volcaniclastic layers, records a major environmental perturbation across the Julian-Tuvalian transition. Conodont assemblages document a clear faunal turnover, with typical Julian taxa replaced upward by Tuvalian forms, while radiolarian-rich intervals indicate enhanced silica productivity and changes in pelagic sedimentation.

The integration of conodont and radiolarian data provides precise age constraints for the succession and permits accurate placement of the middle-late Carnian boundary at the base of the green horizon. These micropaleontological datasets are further strengthened by magnetostratigraphic analyses and by a high-precision U-Pb age of 230.91 ± 0.33 Ma obtained from the Aglianico ash bed.

The Lagonegro Basin therefore represents a fundamental archive for investigating the interplay between tectonics, volcanism, paleoceanographic change, and biotic turnover during the Triassic evolution of the western Tethys. In particular, the exceptional preservation and abundance of conodonts and radiolarians make these successions a key reference for integrated Triassic biostratigraphy and paleoenvironmental studies in the Mediterranean region.

The response of calcareous nannofossil Eprolithus floralis to Oceanic Anoxic Event 2 (Cenomanian-Turonian, Late Cretaceous): insights from marine biotic archives of paleoenvironmental change

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Keywords: nannofossils, OAE 2, morphometry.

Oceanic Anoxic Event 2 (OAE 2; Cenomanian-Turonian) represents one of the most severe greenhouse perturbations of the Late Cretaceous, marked by elevated atmospheric CO_2, widespread marine anoxia, and major changes in ocean circulation and surface-water conditions. Marine microfossils provide key archives for reconstructing how paleoceanographic and climatic conditions evolved during this interval.

Here we investigate the response of the calcareous nannofossil *Eprolithus floralis*, a taxon associated with relatively cool surface waters, across four OAE 2 sections spanning different paleoenvironmental settings: Eastbourne (UK), Clot Chevalier (SE France), Novara di Sicilia (S Italy), and Tarfaya (Morocco). By integrating morphometric, morphological, and abundance data, we aim to distinguish global biotic signals from regional paleoceanographic variability and reconstruct how marine environments changed through the event.

All studied sections record a pronounced reduction in *E. floralis* size during OAE 2, with minimum values reached around peak B of the carbon isotope excursion, followed by a post-event recovery. Two morphotypes, spiky and rounded, occur consistently in all records, demonstrating that the morphological signal is primary rather than diagenetic. Rounded forms become dominant during OAE 2, whereas larger spiky morphotypes prevail before and after the event. Because the rounded morphotype is systematically smaller, changes in average size largely reflect shifts in morphotype dominance.

Despite this globally reproducible pattern, important regional differences emerge. At Novara di Sicilia and Tarfaya, where upwelling conditions likely persisted, *E. floralis* is more abundant and characterized by a stronger dominance of small rounded morphotypes, suggesting adaptation to unstable, nutrient-rich, or otherwise stressful environments. In contrast, higher-latitude sections record more balanced morphotype distributions and smaller morphometric offsets.

The combined global and local responses of *E. floralis* reveal how marine ecosystems tracked both large-scale climatic forcing and regional oceanographic dynamics during OAE 2. The parallel size decrease observed in *E. floralis* and other calcareous nannoplankton taxa suggests a widespread sensitivity to peak environmental stress, potentially linked to elevated CO_2 levels and changes in seawater chemistry. Our results highlight the value of calcareous nannofossils as marine biotic archives capable of capturing the interplay between climate change, paleoceanography, and ecosystem resilience during extreme greenhouse intervals.

Carbonate platform evolution across the Cenomanian/Turonian boundary (Akrabou Formation, Southeastern Morocco)

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Keywords: Cenomanian/Turonian boundary, OAE2, Morocco.

The Cenomanian-Turonian transition represents one of the major paleoenvironmental perturbations of the Cretaceous, characterized by global sea-level highstands, widespread marine transgression, and Oceanic Anoxic Event 2 (OAE2). Across North Africa, the transgression promoted the establishment of an epicontinental carbonate platform over previously continental domains, represented in southeastern Morocco by the up to 100 m thick Akrabou Formation.

The Akrabou Formation evolves from shallow-water bioclastic wackestones and packstones with abundant micrite into deeper water laminated lime mudstones with calcareous plankton, fish debris, and ammonite-bearing nodules, and then again to shallow benthic carbonate production. In the upper part, high-energy conditions are reflected by coarser cross-bedded levels, while peritidal facies at the top mark platform emersion and the re-establishment of continental siliciclastic sedimentation. Biostratigraphic data place the Cenomanian-Turonian boundary shortly after the maximum deepening phase.

Stable isotope analyses ($\delta^{13}C$ and $\delta^{18}O$) performed on bulk carbonates reveal a broad positive $\delta^{13}C$ excursion reaching +5‰ VPDB within the lower shallow-water interval, consistent with the global isotopic signature of OAE2 (Jarvis et al., 2006). This trend is followed by a rapid decrease to values around −2‰ VPDB within the laminated deeper-water interval, and by a subsequent return toward positive values up to +2‰ VPDB in the upper shallow-water deposits. Isotope data from the primary fibrous calcite of oyster shells display comparable trends, with slightly heavier values, supporting preservation of the $\delta^{13}C$ primary depositional signal.

We suggest that the laminated interval recorded a temporary retreat of shallow-water carbonate production under environmental stress likely related to rapid transgression and enhanced nutrient supply. This platform retreat postdates the peak positive carbon-isotope excursion (see also Wang et al., 2021), suggesting an environmental response not directly linked to OAE2, but rather controlled by basin-scale processes operating after the event. However, the crisis was not irreversible, as benthic carbonate communities recovered and platform sedimentation resumed.

Jarvis I. et al. (2006) - Secular variation in Late Cretaceous carbon isotopes: a new δ13C carbonate reference curve for the Cenomanian-Campanian (99.6-70.6 Ma). Geol. Mag., 143(5), 561-608, https://doi.org/10.1017/S0016756806002421.

Wang J. et al. (2021) - Controls on timing of Cenomanian-Turonian organic enrichment and relationship to the OAE2 event in Morocco, North Africa. Mar. Pet. Geol., 128, 105013, https://doi.org/10.1016/j.marpetgeo.2021.105013.

Isotopic and molecular characterization of shell organics in modern brachiopods: Implications for palaeocological reconstructions of fossil brachiopods

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Keywords: brachiopods, shell organics, trophic strategies.

Brachiopod shells are valuable biomineral archives for reconstructing environmental and climatic changes through deep time due to their widespread fossil record and the high preservation potential of their low-Mg calcite shells. Although representing only a minor component of the shell, the intracrystalline and intercrystalline organic matrix preserved within the shell structure may retain a geochemical signature of great importance for palaeoecological interpretations.

Carbon and nitrogen isotope compositions of shell organics ($\delta^{13}C_{org}$ and $\delta^{15}N_{org}$) have been proposed as proxies for reconstructing trophic strategies and symbioses in fossil marine invertebrates. Studies on the giant Mississippian brachiopod species of *Gigantoproductus* interpreted low $\delta^{13}C_{org}$ and intermediate $\delta^{15}N_{org}$ values as evidence for a mixotrophic lifestyle involving suspension feeding and photosymbiosis, allowing these marine invertebrates to attain an exceptional size and thick shell at the onset of the Late Paleozoic Ice Age (Angiolini et al., 2019; 2026). These studies also demonstrated the preservation of amino acids within the shell organic matrix through GC-MS and ^{1}H-NMR analyses. However, this interpretation mainly relies on geochemical data obtained from modern mollusks, whereas a comparable dataset for extant brachiopods is lacking.

Here, we present carbon and nitrogen isotope compositions of shell organic matrix extracted from nine extant brachiopod species collected from different geographic and environmental settings worldwide to establish a modern isotopic reference for brachiopod shell organics. The aim is to investigate trophic strategies in modern brachiopods and compare them with published data from modern mollusks and fossil brachiopods to refine palaeoecological interpretations based on shell organic matrix isotopic signatures. In addition, the molecular composition of the extracted organic matrix is being investigated through GC-MS analysis to characterize organic compounds.

The analyzed shell organic matrix of modern brachiopods, all known suspension feeders, shows $\delta^{13}C_{org}$ values ranging between −23‰ and −16‰ and $\delta^{15}N_{org}$ values between +6‰ and +11‰, closely matching the range reported for modern non-symbiotic filter-feeding mollusks. These results support the applicability of shell $\delta^{13}C_{org}$ and $\delta^{15}N_{org}$ as proxies for identifying trophic strategies and provide the first modern comparative framework focused on brachiopods.

Compared with the lower $\delta^{13}C_{org}$ and $\delta^{15}N_{org}$ values reported for fossil *Gigantoproductus* species, the modern dataset strengthens the interpretation that gigantoproductids occupied a trophic and ecological niche distinct from that of modern non-symbiotic brachiopod filter feeders. More broadly, this study provides a calibration for refining palaeoecological interpretations based on preserved fossil shell organic matrix and highlights the importance of modern analogues for reconstructing past ecosystems and ecological interactions.

Angiolini L. et al. (2019) - The giants of the phylum Brachiopoda: a matter of diet? Palaeontology, 62(6), 889-917, https://doi.org/10.1111/pala.12433.

Angiolini L. et al. (2026) - Brachiopod giants from the Mississippian (Asbian) of western Ireland: Fossil bioarchives of seasonality and symbiosis and far-field harbingers of climate change. Palaeogeogr. Palaeoclimatol. Palaeoecol., 683, 113418, ISSN 0031-0182, https://doi.org/10.1016/j.palaeo.2025.113418.

The Jurassic to Cretaceous transition in the Torre de' Busi section (Southern Alps): Integrated stratigraphy, geochemistry and microfossil changes

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Keywords: Jurassic/Cretaceous transition, Tethys Ocean, paleoceanography.

During the Late Jurassic-earliest Cretaceous, major palaeoceanographic and biotic changes affected pelagic ecosystems of the Tethys Ocean, culminating in the onset of widespread pelagic carbonate sedimentation. This study investigates the Tithonian-Berriasian interval using the fully pelagic and stratigraphically complete Torre de' Busi section (western Tethys, Lombardian Basin), tightly constrained by integrated nannofossil, calpionellid, and magnetostratigraphy. High-resolution analyses of stable carbon and oxygen isotopes, carbonate content, magnetic susceptibility, gamma-ray spectroscopy data, and quantitative microfossil assemblages provide a multiproxy reconstruction of environmental and biotic evolution across the Jurassic-Cretaceous transition.

Results document a progressive increase in carbonate content from radiolarian-rich cherts of the Radiolariti Formation to the calcilutites of the Maiolica Formation, accompanied by a marked decline in terrigenous input. This lithological transition coincides with major changes in planktonic communities, including the decline and final disappearance of *Saccocoma*, the diversification and proliferation of calpionellids, and the expansion of heavily calcified calcareous nannoplankton, particularly nannoconids. A major turnover in microfossil assemblages occurred in the middle late Tithonian (base of nannofossil Zone NJT17; base of calpionellid Subzone *Crassicollaria intermedia*), synchronous with the onset of Maiolica deposition.

Carbon isotope data show a long-term Tithonian decrease in $\delta^{13}C$ values, reflecting a reorganization of the global carbon cycle, whereas minimum $\delta^{13}C$ values do not coincide with abrupt biotic changes. The synchronous increase in pelagic carbonate production and calcifying plankton abundance indicates supra-regional controls related to seawater chemistry, climate aridity, and reduced nutrient supply, highlighting the sensitivity of Tethyan pelagic systems to climate-driven oceanographic change.

Fossils that map oceans: Conodonts and the geography of Deep Time

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Keywords: biofacies, provincialism, cosmopolitanism.

Conodonts, an extinct group of early vertebrates spanning from the late Cambrian to the earliest Jurassic, represent one of the most powerful tools for biostratigraphic and palaeoenvironmental reconstructions. Despite their widespread distribution and high stratigraphical resolution, their partly pelagic lifestyle has long complicated their use in palaeogeographical studies. Our study re-evaluates the concept of conodont biofacies, aiming to disentangle ecological signals from broader palaeogeographical patterns and to assess their potential for reconstructing the configuration and evolution of Palaeozoic marine domains.

Conodont assemblages reflect a complex interplay of environmental parameters, including temperature, water depth, and oceanic circulation. In the Late Ordovician, conodont distributions show pronounced provincialism, with distinct faunal regions (e.g., Midcontinent and Atlantic realms) and well-defined biofacies that record latitudinal gradients and climatic differentiation. These patterns provide robust constraints on palaeogeographical reconstructions, particularly along the northern Gondwanan margin, where biofacies analysis reveals faunal exchanges, transitional zones, and the influence of oceanic currents.

In contrast, the Late Devonian is characterised by widespread cosmopolitanism, reflecting more homogeneous environmental conditions across predominantly tropical settings. In this interval, conodont biofacies are more effective as indicators of local ecological gradients and depositional environments rather than large-scale palaeogeographical frameworks. The evolution of biofacies models, from simple depth-controlled schemes to more complex, multi-factorial interpretations, highlights the ecological plasticity of conodonts and the need for integrated approaches combining sedimentological, geochemical, and palaeontological data.

Overall, our study underscores the dual value of conodonts: as high-resolution chronological markers and as sensitive recorders of environmental and palaeogeographical change. When carefully filtered to separate ecological from geographic signals, conodont biofacies provide a complementary and powerful tool for tracing the dynamics of ancient oceans and refining global palaeogeographical models of the Palaeozoic Earth.

Morphometric adaptation facilitated the persistence of Morozovella crater during the Early Eocene Climatic Optimum

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Keywords: planktic foraminifera, Eocene, *Morozovella*.

Why some species go extinct and other persevere is a key question in Paleobiology. Major ecological restructuring of planktic foraminiferal assemblages during the Early Eocene Climatic Optimum (EECO; ~53-49 Ma), the warmest prolonged interval of the Cenozoic, led to the long- term decline of the symbiont-bearing genus *Morozovella*. However, the species *Morozovella crater* persisted throughout this interval, providing an opportunity to investigate species-level resilience under extreme warmth. The EECO therefore represents a key natural laboratory for investigating species-level resilience and marine biotic responses to sustained greenhouse conditions.

Here we integrate absolute abundance data, micro-computed tomography (micro-CT) morphometrics and stable isotope analyses of *M. crater* specimens from ODP sites 1209 and 1210 (Shatsky Rise, subtropical Pacific Ocean) to reconstruct the ecological and morphological response of this species across the EECO. Morphometric parameters include test volume, surface area, chamber number, and surface-area-to-volume ratios derived from 257 micro-CT scanned specimens covering intervals from 54.47 to 50.91 Ma. Our results reveal a marked reduction in test volume, surface area, and chamber number at the EECO onset, coinciding with the decline in abundance of M. crater. These changes suggest constrained growth under elevated temperature stress and limited resource availability, likely reflecting a shift in energy allocation from growth to maintenance processes. In contrast, during the core EECO, *M. crater* developed higher surface-area-to-volume ratios and more flattened test morphologies while recovering in abundances. This morphological shift may represent an adaptive strategy to improve energy acquisition and increase the area available for photosymbionts under prolonged greenhouse conditions. Consistently elevated $\delta^{13}C$ values of *M. crater* relative to benthic and deeper-dwelling taxa support the persistence of an upper mixed-layer habitat and sustained photosymbiotic activity throughout the interval. This contrasts with other morozovellid species, particularly *M. marginodentata* and *M. subbotinae*, which exhibit evidence for transient symbiont loss across the EECO onset at the Atlantic ODP Site 1051.

Together, these morphological and ecological adaptation may have allowed *M. crater* to persist despite the decline of the other taxa in the genus *Morozovella*. This study highlights how integrated marine biotic and geochemical archives can reveal adaptive strategies and resilience mechanisms during past climate perturbations, providing important insights into marine ecosystem sensitivity under long-term greenhouse conditions.

Biostratigraphy and facies analysis of Upper Cretaceous-Miocene carbonate successions: The slope-to-basin transition of the Matese-Frosolone Unit; insights from Geological Sheets n. 404 "Isernia" and n. 392 "Castel di Sangro" of the CARG Project

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Keywords: slope biofacies, Cretaceous-Miocene, central-southern Apennines.

An integrated stratigraphic study was carried on the Upper Cretaceous-Miocene carbonate slope successions belonging to the Matese-Frosolone tectonic unit exposed across the CARG Geological Sheets n. 404 "Isernia" and n. 392 "Castel di Sangro" (Central-Southern Apennines, Italy). Several sections were investigated by biofacies analysis and biostratigraphy to better characterize the slope to basin transition in different spatial sectors by moving northward, from the Matese carbonate platform to the Molise Basin. The Mastroleoni and Patalecchia were selected in the Isernia Sheet; Miranda and Mt. Cimorre in the Castel di Sangro Sheet.

The studied sections stretched from the Coste Chiavarine (CCH), the Monte Calvello (VLO), the Monaci (FMO) Formations to the Macchiagodena (GOD) and Longano Formations (LNG), recording the progressive evolution of carbonate sedimentation from slope to basin depositional systems.

The lithologies mainly consist of whitish to grey pelagic calcilutites and marly limestones rich in planktonic foraminifera, in alternation with bio-lithoclastic calcarenites and calcirudites. Conglomeratic beds with calcarenitic to marly matrices also occur. Pseudo-saccharoidal calcarenites with bed-parallel lamination, chert-bearing bio-lithoclastic calcirudites, and marly intervals with scattered silicified layers and nodules characterize at different levels these formations. Recrystallization and localized dolomitization variably affect these lithofacies often obscuring the original textures. Thin-section analysis allowed the identification and comparison of microfacies types classified on the based on the main textures, sedimentary structures as well as by microfossil assemblages, mainly benthic and planktonic foraminifera.

The comparison of the litho-biofacies belonging to the same formation, but coming from the different sectors, highlights more distal features of the carbonate slope in the Miranda and Mt. Cimorre respect to the Mastroleoni and Patalecchia sections that show more proximal depositional conditions (upper slope) progressively moving toward the margin of the Matese carbonate platform. These features are testified by coarser and poor selected litho-bioclastic material produced by risedimentation episodes linked to dismantling of the platform during a pre-thrusting tectonic phase preceding the Apenninic chain formation.

Overall, this study provides better time constraints pertaining the studied formations in the Matese-Frosolone sector during the Late Cretaceous-Miocene interval and refines the age of the progressive tectonic deformation and overlap of the Frosolone on the Molise Basin Units.

Early Cretaceous radiolarian assemblages from central Italy and southern Tibet

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Keywords: Gorgo a Cerbara, southern Tibet, radiolarians.

In this work we compare radiolarian assemblages from the Gorgo a Cerbara section in the Umbria-Marche Basin (central Italy) and from the BB1 section near Babazhadong (southern Tibet). The stratigraphic record of these sections offers a good opportunity to correlate the radiolarian assemblages between the eastern and western Tethys.

The comparison indicates similar faunas comparable to those in the *Aurisaturnalis carinatus* Zone and the *Turbocapsula costata* Zone. Several significant species, Archaeodictyomitra lacrimula (Foreman), *Archaeodictyomitra excellens* (Tan), *Dictyomitra communis* (Squinabol) and *Aurisaturnalis carinatus perforatus* Dumitrica and Dumitrica-Jud, which are common in older strata, make their last occurrences near the base of the *Turbocapsula costata* Zone in these two areas.

Comparison with the Gorgo a Cerbara section provides an accurate age constraint for the siliceous succession in southern Tibet, which contains no fossils other than radiolarians. The comparison indicates a close connection between the western and eastern Tethys during the Barremian to early Aptian. The correlation testifies that the radiolarian zonation in southern Tibet is applicable for the whole Tethys. The siliceous succession in BB1 section encompasses the early Aptian Oceanic Anoxic Event 1a (OAE1a). The early Aptian OAE1a is located in the upper part of the *Aurisaturnalis carinatus perforatus* subzone. The first occurrence biohorizon of the genus *Turbocapsula* and the evolutionary first appearance biohorizon of *Turbocapsula costatacostata* (Wu) are useful markers for constraining the OAE1a in the Tethys.

Eo-Miocene evolution of the East Pisco Basin, Peru: a micropaleontological perspective

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Keywords: Pisco Basin, sequence stratigraphy, upwelling.

The East Pisco Basin is one of the NW-SE oriented trench-parallel forearc basins that developed between the middle Eocene and the Early Pliocene along the Peruvian convergent margin. It hosts an exceptionally rich and well preserved assemblage of marine vertebrate fossils that make it a world-renowned fossil Lagerstätte.

Following a sequence-stratigraphic approach, we developed a robust chronostratigraphic framework in order to place all fossils in a chronological context. Unconformity surfaces were identified in the field and mapped over an area of ~1000 km2 (Di Celma et al., 2022). Such unconformities bound the main stratigraphic sequences named, from older to younger, the Paracas, Otuma, Chilcatay, Tunga and Pisco formations. Minor unconformities allowed identification of units within each sequence, reflecting eustatic cycles.

The chronology of each unit was obtained by integrating absolute Ar-Ar age determinations from ash layers, Sr/Sr analyses from carbonate shells and/or shark teeth and integrated biostratigraphy (Bosio et al., 2020; Malinverno et al., 2021, 2025).

Here we summarize the results from biostratigraphic analyses that allowed to characterize each stratigraphic unit and sub-unit: benthic foraminifera, calcareous nannofossils, diatoms and silicoflagellates are alternatively significant in different climatic and environmental contexts and provide key marker species useful for global and local correlation. Preliminary qualitative analysis of these taxa provided significant information on the climatic and paleoceanographic evolution of the area throughout significant intervals of the Cenozoic and defined the paleoecological framework for the vertebrate fossils recovered in the East Pisco Basin.

Bosio G. et al. (2020) - Tephrochronology and chronostratigraphy of the Miocene Chilcatay and Pisco formations (East Pisco Basin, Peru). Newsletters on Stratigraphy, 53(2), 213-247, https://doi.org/10.1127/nos/2019/0525.

Di Celma C. et al. (2022) - Towards deciphering the Cenozoic evolution of the East Pisco Basin (southern Peru), Journal of Maps, 18(2), 397-412, https://doi.org/10.1080/17445647.2022.2072780.

Malinverno E. et al. (2021) - (Bio)stratigraphic overview and paleoclimatic-paleoceanographic implications of the middle-upper Eocene deposits from the Ica River Valley (East Pisco Basin, Peru). Palaeogeography, Palaeoclimatology, Palaeoecology, 578, 110567, https://doi.org/10.1016/j.palaeo.2021.110567.

Malinverno E. et al. (2025) - The early depositional history of the Pisco formation (Middle to Upper Miocene, Peru) Newsletters on Stratigrapy, 58(1), 99-123, https://doi.org/10.1127/nos/2025/0864.

Tracking early Eocene Hyperthermals through calcareous nannofossil assemblages at the Site IODP U1443 (Ninetyeast Ridge, Indian Ocean)

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Keywords: calcareous nannofossils, hyperthermals, Paleogene.

The early Paleogene was a period of global greenhouse warmth characterized by a series of events called "hyperthermals". These were pronounced episodes of warming associated with negative carbon isotope excursions, possibly caused by rapid injections of greenhouse gases into the ocean-atmosphere systems (Zachos et al., 2008). The most prominent among them, the Paleocene-Eocene Thermal Maximum (PETM), was marked by a global temperature increase of about 5-8°C, that affected the terrestrial and marine organisms and their geographic ranges, their evolution and extinction (McIerney & Wing, 2011). To better understand these past climate changes, we investigated the calcareous nannofossil assemblages from Site IODP U1443, in the northeastern Indian Ocean. 4.5 m spanning the late Paleocene to the early Eocene (~56-53 Ma) were analyzed at an average resolution of about 10 cm. The calcareous nannofossil assemblages identified throughout the studied interval comprise approximately sixty species, indicating a diverse and well-preserved flora. Among these *Coccolithus*, *Discoaster*, *Sphenolithus* and *Toweius* represent the most abundant taxa across most sample. The obtained results allowed us to refine the biostratigraphy and improve the chronological framework of Site U1443 with respect to the original shipboard data and more recent literature (e.g., Clemens et al., 2016). Changes in nannofossil assemblages during the hyperthermals were also investigated to assess their response to warming, variations in trophic conditions, and associated paleoceanographic changes. Preliminary results indicate that the PETM was characterized by more pronounced changes in calcareous nannofossil assemblages compared to the other hyperthermal events. Variations in the relative abundance of several taxa are observed over the studied interval. Our data also support the absence of Calcareous Nannofossil Excursion Taxa (CNET) and most taxa belonging to the *Rhomboaster-Tribrachiatus* plexus, with the exception of the last representative, *Tribrachiatus orthostylus*, whose first occurrence seems consistent with previously published records from other sites and with its established first appearance close to ETM2 (Agnini et al., 2014).

Agnini C. et al. (2014) - Biozonation and biochronology of Paleogene calcareous nannofossils from low and middle latitudes. Newsl. Stratigr., 47(2), 131-181, https://doi.org/10.1127/0078-0421/2014/0042.

Clemens S.C et al. (2016) - Proceedings of the International Ocean Discovery Program, 353, https://doi.org/10.14379/iodp.proc.353.103.2016.

McInerney F.A. & Wing S.L. (2011) - The Paleocene-Eocene Thermal Maximum: A Perturbation of Carbon Cycle, Climate, and Biosphere with Implications for the Future. Annu. Rev. Earth Planet. Sci., 39, 489-516, https://doi.org/10.1146/annurev-earth-040610-133431.

Zachos J. C. et al. (2008) - An early Cenozoic perspective on greenhouse warming and carbon-cycle dynamics. Nature, 451, 279-283, https://doi.org/10.1038/nature06588.

Exploring conodont Paleoecology through stable Strontium isotopes

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Keywords: conodonts, strontium, lifestyles.

Conodonts represent the mineralized skeletal tissues of earliest marine vertebrates, from Cambrian to Early Jurassic. However, their ecological roles and lifestyle are still poorly constrained. Although their taxonomy and biostratigraphic significance have been extensively investigated, direct evidence for trophic differentiation among conodont taxa is still limited. Here we explore the potential of stable strontium isotopes ($\delta^{88}Sr$) as a proxy for trophic reconstruction in Upper Devonian conodonts (Świs et al., 2026). Six genera from the upper Famennian succession of the Kowala Quarry (Holy Cross Mountains, Poland) were analyzed using MC-ICP-MS after careful diagenetic screening, including measurements of both $\delta^{88}Sr$ and $^{87}Sr/^{88}Sr$ ratios (Świs et al., 2026). The investigated genera display distinct isotopic signatures. Palmatolepis, Bispathodus, and Pandorinellina are characterized by relatively higher $\delta^{88}Sr$ values, whereas Branmehla, Mehlina, and Idioprioniodus yield systematically lower compositions. These differences are not accompanied by significant variation in $^{87}Sr/^{88}Sr$ ratios (Letulle et al., 2025), and crystallographic analyses of the bioapatite do not support extensive post-depositional alteration, indicating that the isotopic variability is likely primary. The observed spread in $\delta^{88}Sr$ values (~0.2-0.3‰) is comparable to trophic-scale fractionation reported for modern vertebrates. When compared with conodont apparatus architecture, the isotopic distribution appears closely associated with P1 element morphology. Taxa possessing blade-like P1 elements, such as Branmehla, Mehlina, and Idioprioniodus, consistently show lower $\delta^{88}Sr$ values, whereas taxa with platform elements, icrion-bearing morphologies, or enlarged basal cavities exhibit higher values. These results suggest ecological differentiation among Upper Devonian conodonts and support the hypothesis that P1 morphology may reflect distinct feeding strategies and trophic positions (Świs et al., 2026).. More broadly, this study highlights the potential of stable Sr isotopes to investigate trophic organization in extinct marine vertebrate communities and provides a new geochemical approach for paleoecological studies of conodonts. This work was carried out within the PRIN-PNRR 2022 Project P2022K9BE8 “OCEANS”, granted to MR and AF.

Letulle T. et al. (2025) - Conodont apatite record of marine Sr isotopic composition in the advent of the Hangenberg Event (Late Devonian). Chem. Geol., 692, 122981, https://doi.org/10.1016/j.chemgeo.2025.122981.

Świś P. et al. (2026) - Stable strontium isotopes of Late Devonian conodonts from Kowala (Poland) reveal genus-level signatures. Palaeogeogr. Palaeoclimatol. Palaeoecol., 692, 113755, https://doi.org/10.1016/j.palaeo.2026.113755.

Facies changes in shallow-water carbonates on the rifted Adria margin: Non-skeletal facies as tectonic and environmental markers on the Lower Jurassic Trento Platform (Southern Alps)

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Keywords: ooidal facies, environmental changes, lower Jurassic.

Carbonate platforms represent excellent archives for understanding changes in biological evolution and in climatic and paleoceanographic conditions, which are expressed by abrupt facies and carbonate production changes. In the Early - Middle Jurassic interval, the shallow-water tropical carbonate systems of the western Tethys experienced discrete and diverse stepwise changes, marked by major shifts in carbonate factories and depositional systems or drowning events. On the resilient Trento Platform (Southern Alps), two regionally extensive lithostratigraphic units (Loppio Oolitic Limestone in the mid-late Sinemurian and San Vigilio Oolite in the mid Toarcian) record major depositional phases dominated by ooid and non-skeletal production.

Facies analysis was carried out across the stratigraphic boundaries marking the onset of dominant ooidal facies to investigate the controlling factors. Facies changes from the upper subtidal unit of Monte Zugna Formation (facies association FA1) to the Loppio Oolitic Limestone (FA2) are characterized by sharp transition between peloidal-micritic and almost exclusive ooidal sedimentation. FA1 comprises very shallow (restricted) inner platform facies dominated by strongly bioturbated mudstone and thin peloidal-oncoidal packstone and grainstone, possibly arranged within a complex facies mosaic. FA2 represents an extensive high-energy, shallow (passing from below to above FWWB) and subtidal shoal complex (strand-plain), dominated by micritized ooids, rarely displaying relict radial structures. Facies changes across the upper Rotzo Formation (FA3) and the San Vigilio Oolite (FA4) are marked by a transitional lithozone, made up of micrites with low-diversity biota and clay layers. FA3 includes mostly low-energy shallow lagoonal facies, represented by bioclastic (bivalves, large benthic foraminifers and algae) packstone and wackestone, associated with oncoidal packstone. FA4 represents a high-energy, shallow (above FWWB) and subtidal shoal complex, constituted by dominant (radial) ooidal grainstone and abundant crinoidal grainstone, both with very common micrite-coated grains, passing laterally to lower energy sponge-bearing facies, deposited in back-shoals settings.

The onset of Sinemurian and Toarcian non-skeletal carbonate production is indicative of rapid regional environmental changes, able to hinder skeletal and microbial productions. These changes may be controlled by the interplay between climatic oscillations (short-lasting cooler-warmer and humid-dry intervals) and the isolated physiography of the Trento Platform, exposing the platform-top to high-energy current circulation and open-marine conditions during tectonic quiescence. Although similar evolutions are reported from other Tethyan platforms, controlling factors are still debated: the ooidal limestones of the Trento Platform may represent key marker facies for understanding the dynamic environmental conditions in the Lower Jurassic western Tethys.

Early marine cementation in two ooid-rich facies (Lower Jurassic Trento Platform, Southern Alps): Integrated fluorescence and cathodoluminescence analysis

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Keywords: early marine cementation, carbonate diagenesis, ooidal limestone.

Porosity and permeability represent the most important petrophysical properties influencing the possibility of storing mineral, hydrocarbon or water resources. In sedimentary rocks, sediment composition and depositional processes control primary porosity and permeability, which may be later modified (either increasing or decreasing) significantly during diagenetic stages. As diagenetic processes occur from near-surface to deep burial settings, paragenetic sequences in carbonates result in complex histories, due to superimposed processes (e.g., cementation, dissolution, dolomitization). A particular contribution to the diagenetic evolution of porosity and permeability properties is given by type and abundance of early marine cements, which may prevent mechanical and chemical compaction during burial. Here we present petrographic data on the diagenesis of two ooidal limestones, covering the entire shallow-water Trento Platform (Early Jurassic, Southern Alps): the Loppio Oolitic Limestone and the San Vigilio Oolite. Whilst the former comprises essentially fine and poorly to well-sorted ooidal grainstone, the latter includes well-sorted crinoidal and coated grains grainstone, associated with variably sorted ooidal grainstone, showing frequently fitted fabrics and mechanical and chemical compaction features (e.g., ooid breakage, concavo-convex to sutured grain contacts and stylolites). An integrated petrographic approach has been carried out using transmitted light (TL), cathodoluminescence (CL) and fluorescence (FL), to identify and characterize different generations of cements. Grainstone from the Loppio Oolitic Limestone are commonly characterized by very thin (5-10μm) isopachous fibrous early marine cement fringing grains, non-fluorescent and non-luminescent, predating precipitation of bladed prismatic cement overgrowths, dull green to slightly reddish in FL and dull brown in CL. Integrating TL-CL-FL petrography proved essential for distinguishing between fibrous and bladed prismatic cements. Porosity is completely occluded by later equant calcite, dull to patchy bright green in FL and dull brown to patchy bright yellow in CL. Grainstone of the San Vigilio Oolite rarely display thin (10-15μm) isopachous fibrous early marine cement, non-fluorescent and non-luminescent, which is present in poorly compacted samples. Fitted-fabric grainstone are instead characterized by discontinuous scalenohedral and syntaxial calcite (dull green in FL and zoned dull red to bright yellow in CL). The results indicate that integrated TL-CL-FL analysis is fundamental to resolve thin diagenetic phases and to provide insights into early marine cementation, which in this case is more efficient in the Loppio Oolitic Limestone. The role of early marine cements is double: reducing primary porosity and permeability during early diagenesis and decreasing compaction of partly-cemented sediments during burial.

Nitrogen-cycle dynamics and planktic foraminiferal ecological strategies across the Middle Eocene Climatic Optimum (MECO ~ 40 Ma) from Atlantic Ocean

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Keywords: MECO, foraminifera-bound nitrogen isotopes, upper-ocean oxygenation.

The Middle Eocene Climatic Optimum (MECO; ~40 Ma) was a prolonged greenhouse warming (~500-600 kyr) event that affected oceanographic conditions, biogeochemical cycling and marine ecosystems. Sedimentary successions recording this interval provide valuable archives for assessing how ecosystems responded to sustained climate perturbation. We integrated stable carbon and oxygen isotopes, $\delta^{13}C$ and $\delta^{18}O$, with foraminifera-bound nitrogen isotopes, FB-$\delta^{15}N$, from two Ocean Drilling Program (ODP) sites located at contrasting latitudes: subtropical ODP Site 1051 and subantarctic ODP Site 702. This multi-proxy approach allows us to reconstruct changes in upper-ocean thermal structure, nitrogen-cycle dynamics and ecological strategies among planktic foraminiferal taxa. The $\delta^{13}C$ and $\delta^{18}O$ records indicate persistent vertical habitat partitioning among planktic foraminifera throughout the studied interval. However, partial convergence of $\delta^{18}O$ values during peak MECO warming suggests temporary upper-ocean thermal homogenization and compression of ecological niches. In parallel, FB-$\delta^{15}N$ values show systematic offsets among taxa, with lower values in *Acarinina* and *Globigerinatheka* relative to *Subbotina*, supporting photosymbiotic lifestyles in the former genera. The systematic FB-$\delta^{15}N$ differences between *Acarinina* and *Globigerinatheka* suggest dinoflagellate symbionts in *Acarinina* and non-dinoflagellate algae in *Globigerinatheka.* The divergent evolutionary paths of *Acarinina* and *Globigerinatheka* during and after the MECO, recording a decline for the former and expansion for the latter, may find explanation on the recorded FB-$\delta^{15}N$ differences that imply diverse degrees of symbiont flexibility and ecological resilience under changing photic-zone conditions. At both Atlantic sites, FB-$\delta^{15}N$ records show a coherent decrease during the MECO, reaching minimum values at peak warming. This trend points to reduced water-column denitrification and suggests that sustained greenhouse warming did not lead to widespread oxygen depletion in the investigated Atlantic settings. This study underlines the value of FB-$\delta^{15}N$ proxy coupled to $\delta^{13}C$-$\delta^{18}O$ constraints, to reconstruct nitrogen-cycles, water-column oxygenation, and photosymbiotic behaviour in planktic foraminifera during sustained greenhouse warming with implications for current and future climate changes.

Bioturbation-controlled porosity, permeability and CO_2-rock interaction in shallow-water carbonates from the Apennine Carbonate Platform, Italy

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Keywords: bioturbated carbonates, petrophysical heterogeneity, geological CO_2 storage.

Bioturbated carbonate successions pose significant challenges for reservoir characterization in hydrocarbon exploration and production, as well as in geological CO_2 storage. Bioturbation can strongly influence the petrophysical properties of host rocks by generating sedimentary heterogeneities and modifying the original porosity and permeability architecture. This study investigates a 75-m-thick Upper Cenomanian-Lower Turonian bioturbated carbonate succession from the Apennine Carbonate Platform in southern Italy, characterized by *Thalassinoides* burrow networks and by a marked contrast between dolomitized burrow fills and a predominantly calcitic host matrix.

High-resolution micro-CT imaging, laboratory permeability measurements, micro-CT-based permeability modelling and a CO_2-saturated batch experiment were combined to evaluate the petrophysical and reactive behaviour of this burrow-matrix heterogeneity. Micro-CT datasets from selected miniplugs were used to segment pore networks and quantify porosity and permeability within dolomitized burrow fills. Micro-CT-derived porosity in the burrow fills ranges from 13 to 20%, whereas modelled permeability ranges from 117 to 233 mD. These permeability estimates agree with a mean laboratory permeability value of approximately 101.8 mD. By contrast, the host matrix shows generally lower porosity and permeability, confirming the strong petrophysical contrast between burrows and surrounding sediment.

CO_2-saturated batch experiments were conducted on selected samples to assess the fabric- and mineralogy-dependent behaviour of dolomitized burrow fills and calcitic matrix under CO_2-rich conditions. Dissolved Ca^{2+} and Mg^{2+} concentrations were monitored through time to track calcite and dolomite dissolution. Pre- and post-experiment micro-CT and SEM observations were compared to identify changes in pore architecture, mineral surfaces and dissolution features.

The results indicate that *Thalassinoides* bioturbation controls pore-system organization and permeability architecture by strongly enhancing vertical and lateral connectivity relative to the surrounding matrix. The batch experiment further shows that CO_2-rich fluids produce fabric- and mineralogy-dependent reactivity, with cation release and post-experiment imaging documenting localized dissolution and surface modification mainly of the calcite mineralogy. Overall, these data highlight the role of burrow-matrix heterogeneity in controlling both flow properties and CO_2-driven dissolution in shallow-water carbonates.

Calcareous nannofossil record from the southeastern Indian Ocean (IODP Site U1514, Mentelle Basin) across the early Eocene hyperthermals

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Keywords: calcareous nannofossil, early Eocene hyperthermals, Indian Ocean.

The early Eocene represents a key interval in Earth's climate history, marked by a series of transient global warming events (hyperthermals) linked to massive releases of isotopically depleted carbon into the ocean-atmosphere system. The most prominent hyperthermal is the Paleocene-Eocene Thermal Maximum (PETM; ~56 Ma), followed by smaller-magnitude events such as ETM2 and ETM3. These hyperthermals are widely considered as analogues for future climate change. However, the mechanisms driving these events and their impact on marine ecosystems and biotic communities are still not well understood (Agnini et al., 2016). This knowledge gap is particularly evident in the Indian Ocean, where continuous sedimentary records are scarce, particularly for the minor hyperthermals.

We present a high-resolution analysis of calcareous nannofossil assemblages across a ~40 m-thick marine sediment cores retrieved at International Ocean Discovery Program (IODP) Site U1514 (Mentelle Basin, offshore southwest Australia, Indian Ocean; Huber et al., 2019). The sediment record at this site provides a unique opportunity to reconstruct paleoceanographic changes across the early Eocene hyperthermals (Vahlenkamp et al., 2020). Our study focuses on the response of calcareous nannofossils, a group of marine calcifying phytoplankton widely used in biostratigraphy and paleoceanography (Agnini et al., 2014; 2016).

The investigated interval at Site U1514 spans from the late Paleocene to the early Eocene and can be subdivided into five biozones (CNP11 to CNE4; Agnini et al., 2014). Nannofossil assemblages are mainly composed of *Coccolithus*, *Toweius, Chiasmolithus, Prinsius, Discoaster, Sphenolithus, Fasciculithus* and *Zygrhablithus*. Biotic changes include the extinction of *Fasciculithus* following PETM recovery, the radiation of *Sphenolithus* at the onset of ETM2, and the evolution of *Discoaster* throughout the studied interval. The relative abundance of nannofossil genera with well-established paleoecological preferences varied across the hyperthermal events (PETM, ETM2, H2, I1, I2, J, ETM3 and L), with, warm-water and/or oligotrophic taxa, such as *Discoaster* and *Sphenolithus* showing abundance peaks, with more intense hyperthermals associated with larger changes. The increased abundances of these dissolution-resistant taxa may also reflect changes in carbonate chemistry of the water column linked to shoaing of the carbonate compensation depth (CCD) during hyperthermal episodes.

Agnini C. et al. (2014) - Biozonation and biochronology of Paleogene calcareous nannofossils from low and middle latitudes. Newsl. Stratigr., 47, 131-181, https://doi.org/10.1127/0078-0421/2014/0042.

Agnini C. et al. (2016) - Stable isotope and calcareous nannofossil assemblage record of the late Paleocene and early Eocene (Cicogna section). Clim. Past., 12, 883-909, https://doi.org/10.5194/cp-12-883-2016.

Huber B. et al. (2019) - Site U1514. In: Hobbs R.W., Huber B.T., Bogus K.A., the Expedition 369 Scientists (Eds), Proceedings of the International Ocean Discovery Program Volume 369: Australia Cretaceous Climate and Tectonics. International Ocean Discovery Program (IODP), https://doi.org/10.14379/iodp.proc.369.105.2019.

Vahlenkamp M. et al. (2020) - A lower to middle Eocene astrochronology for the Mentelle Basin (Australia) and its implications for the geologic time scale. Earth Planet. Sci. Lett., 529, 115865, https://doi.org/10.1016/j.epsl.2019.115865.

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