A Deeper Knowledge – Discovery and Exploration of the Deep Sea Frontier

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The Deep Sea

1) what's there?

Outstanding deep sea research results to date

European role in key fields of deep-sea research

2) what's underneath?

Achievements of scientific drilling

Look into the past to reliably assess the future

3) what's next?

Emerging questions and requirements

New frontiers in science and their societal benefit

4) what's the point?

Dissemination of key research demands & results

Training as an investment into a sustainable future

pt 1: what's there?

- thousands of people cross the ocean every day, look at it from an airplane, a vessel or the beach, but barely recognise it as a 3D feature
- even if they do, the deeper volume is believed to be hostile, deserted, barren

BUT ...

pt 1: what's there?

... AT THE SAME TIME:

- the ocean is the largest ecosystem
- hosts largest creatures
- comprises life at the extreme (> 400°C)
- abundant life and biomass on the seafloor
- strong impact on global cycles

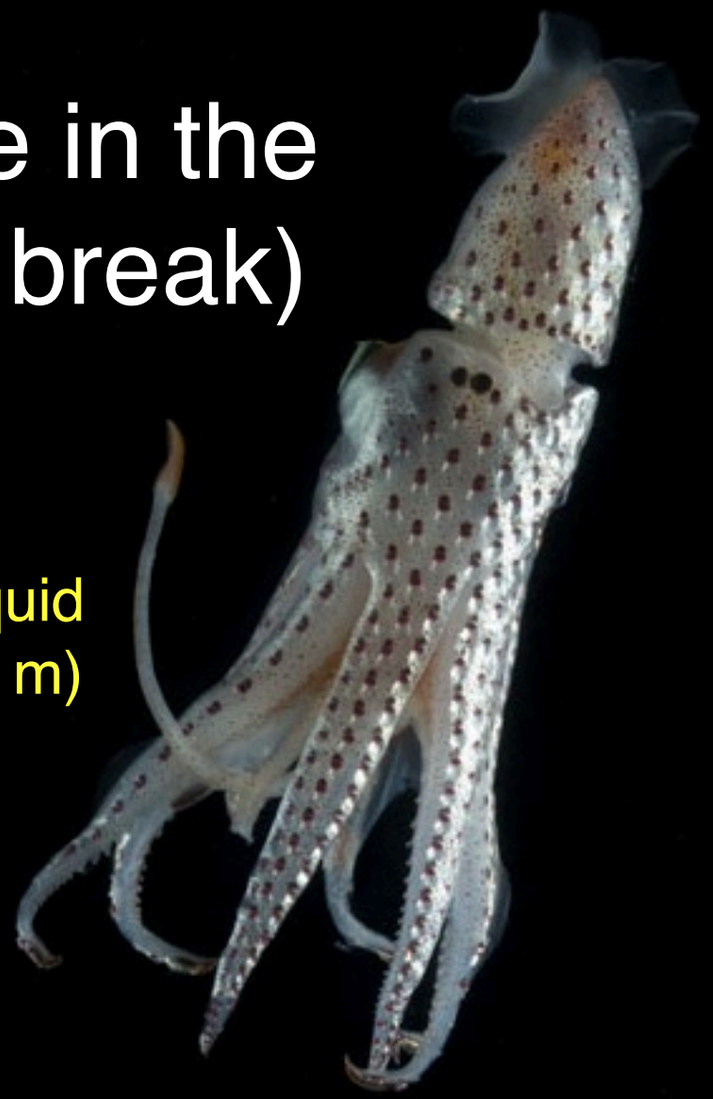
Census of Marine Life

- never learned the world above sealevel
  more about the world below sealevel
- ... we learned a lot, but still know rather little
  (i.e. a few per cent or even only per mil)

much of this marine life is taking place in the deep sea (i.e. beyond the shelf-slope break)

Vampire squid (900 m)

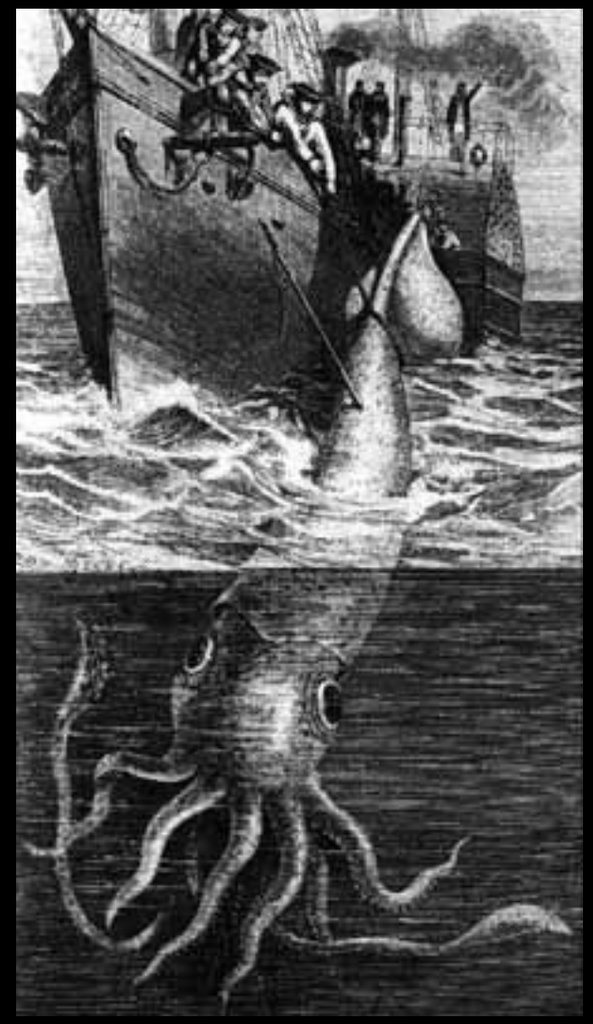
Jewelled squid
(up to 2000 m)



Trachymedusa
(more than 1000 m)

Copepod (up to 5000 m)

Life in the deep sea breaks all records known from shallow water, or on shore:



Giant calmars as large as buses,

spiders as large as dishes,

isopods larger than a football,

and living corals that are > 4000 yrs. old
(i.e. a millenium older than Moses,
or Ramses II.)

Geraldia savaglia

45 cm long, 1.7 kg

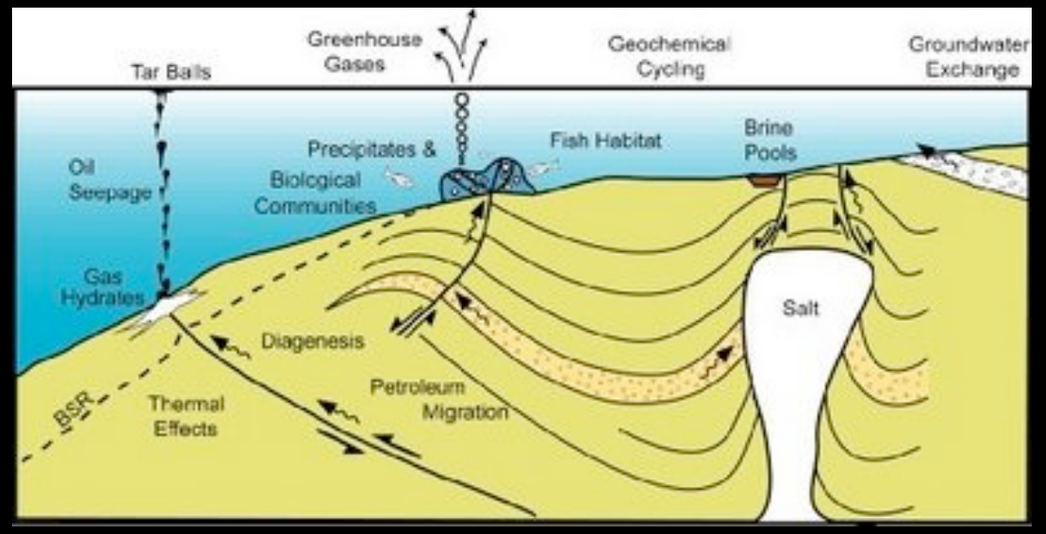
Bathynomus gigantaeus

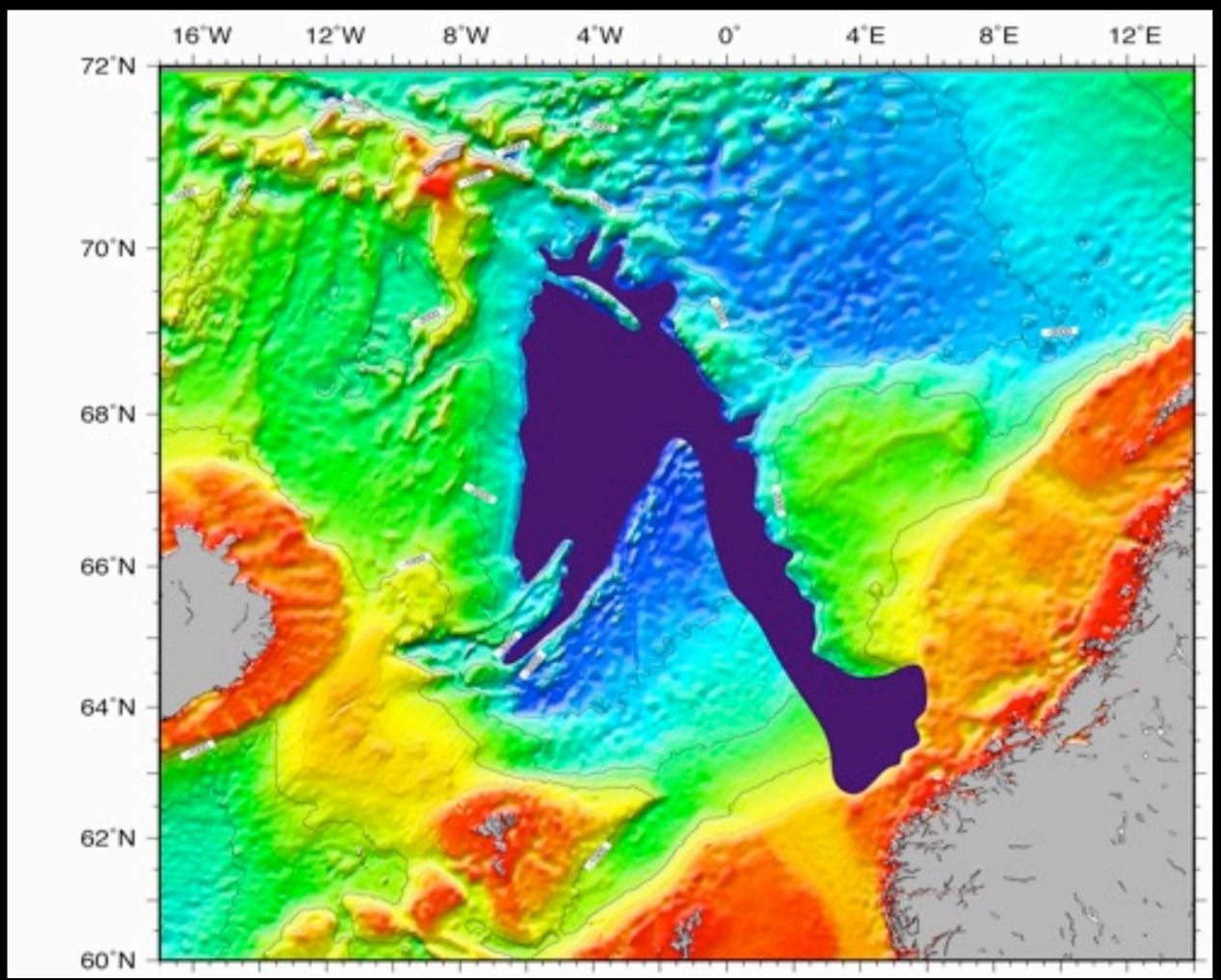
the marine **life in the dark** is fuelled by photosynthetic organic matter that rains or percolates down

- abundant in the deep sea (>1000m)
- known from Arctic to Antarctic waters
- feed from nutrients in suspension which are filtered by tentacles
- no photoautotrophic symbionts

Geofluids and gas hydrates

Fluids are crucial agents of mechanical, thermal, chemical, and biological change



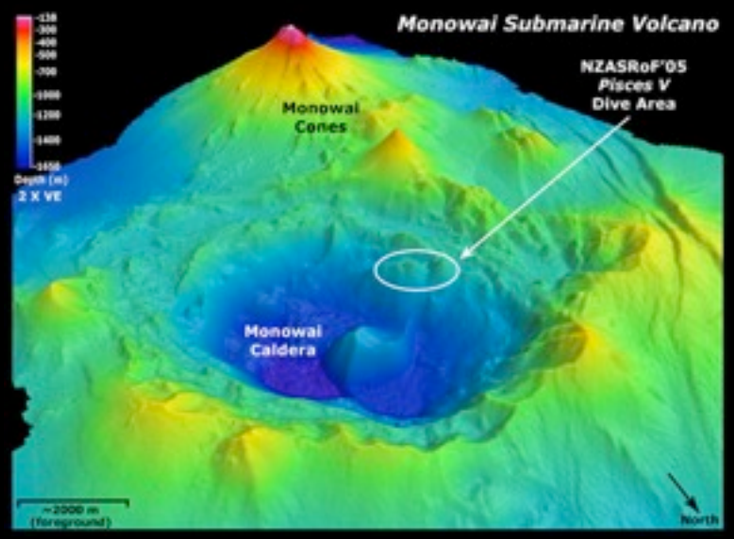


- subseafloor methane is bound at or near surface, but may originate microbially or from heat at depth

- gas hydrate not reliably quantified, but tremendous C resource

- GH dissociation bears risk of greenhouse gas release and lansliding

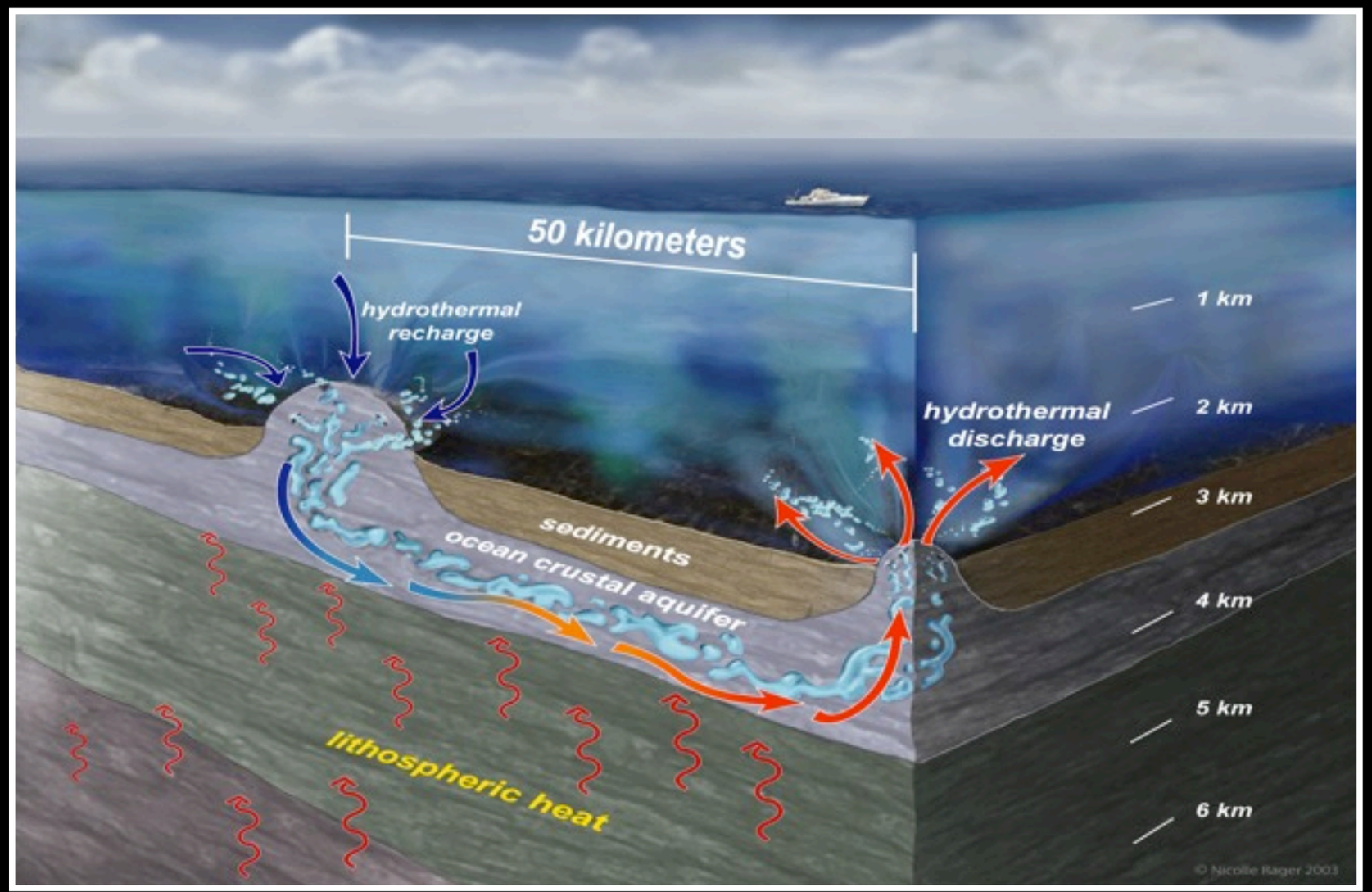
pt 1: what's there?
pt 2: what's underneath?



- thousands of volcanoes
- longest mountain belts
- massive ore deposits
- very deep trenches
- gigantic abyssal planes

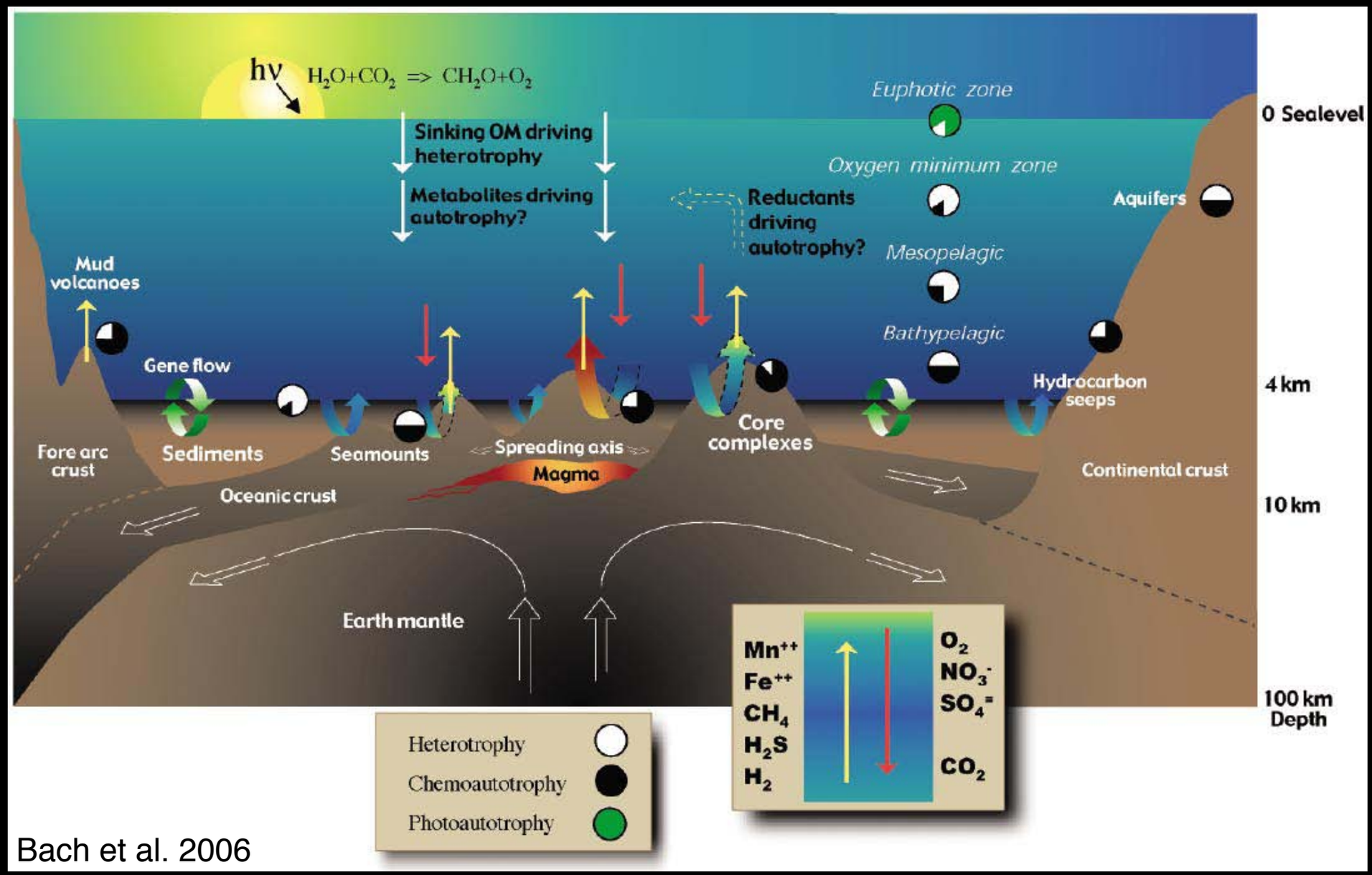
pt 2: what's underneath?

- 85% of Earth's volcanism near-infinite energy and ore supply along 60000 km of MORs
- fractured OC largest aquifer --- flux and energy provide geofuels



pt 2: what's underneath?

- one of the most thriving discoveries is carbon fixation fuelled by chemical energy (from exothermic serpentinisation of peridotitic crust), which occurs at variable T, generates massive sulfide deposits, and fluids of acidic to alkaline pH

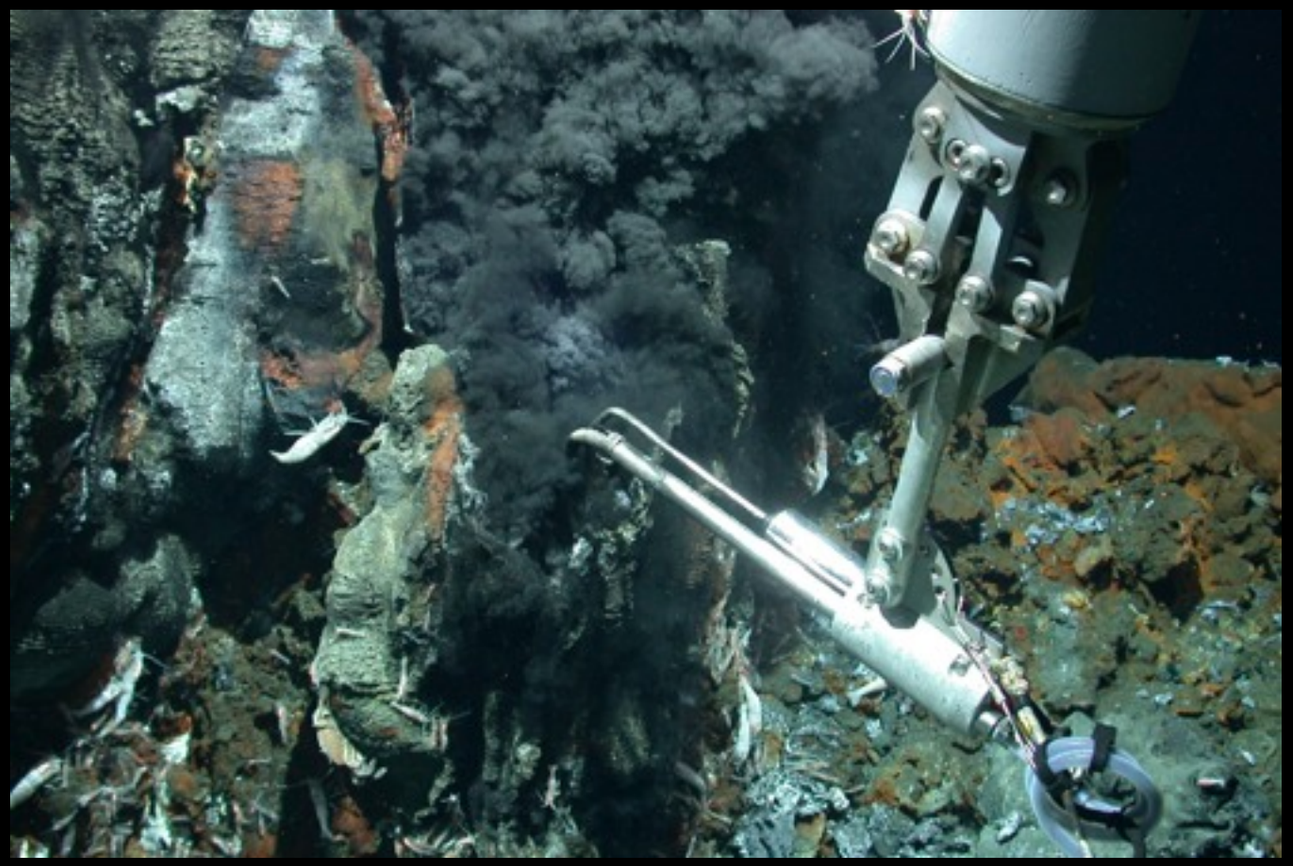


Bach et al. 2006

ecosystem ocean crust

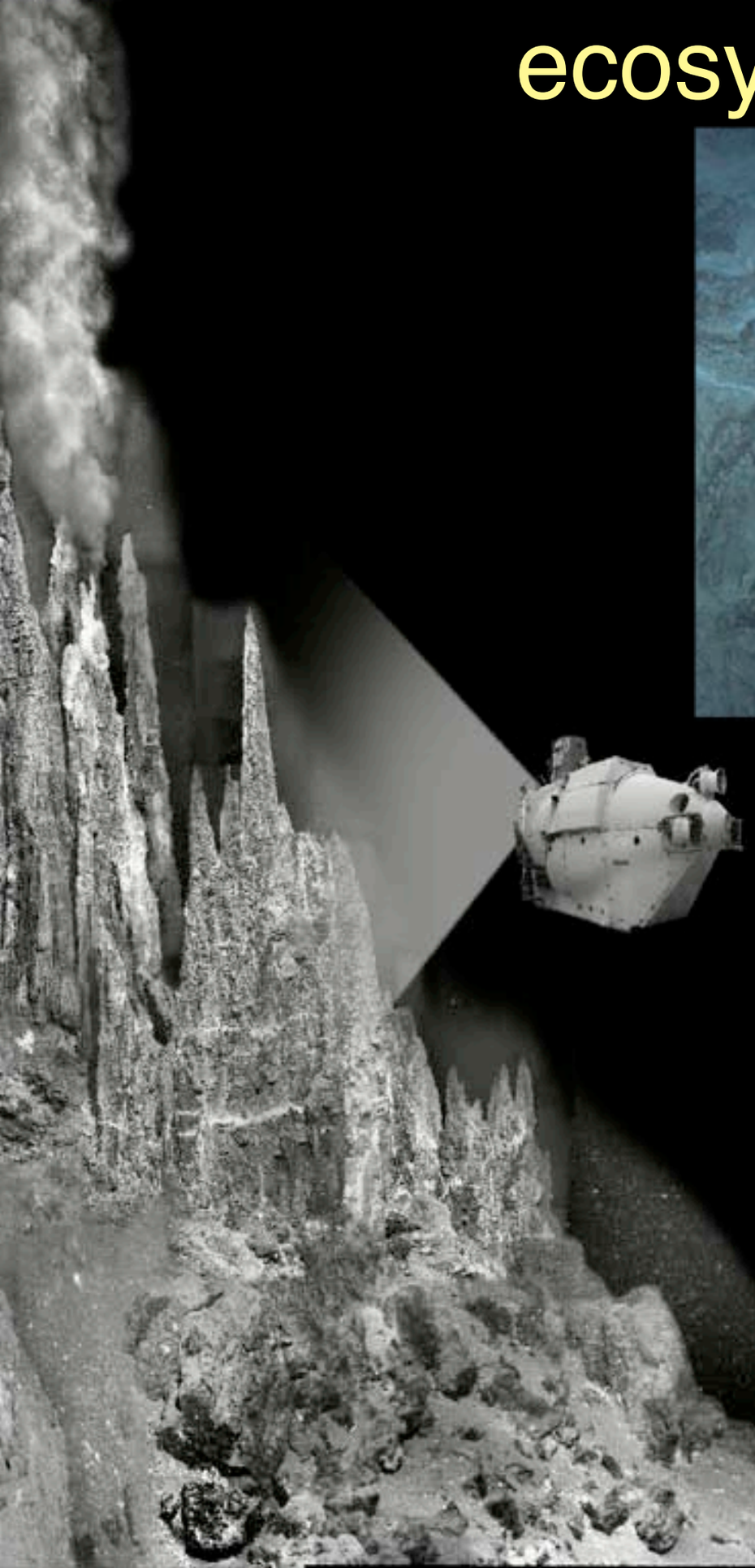
Variety of life at various scales (microrganisms, serpulids, tubeworms, bivalves, crab, etc.)

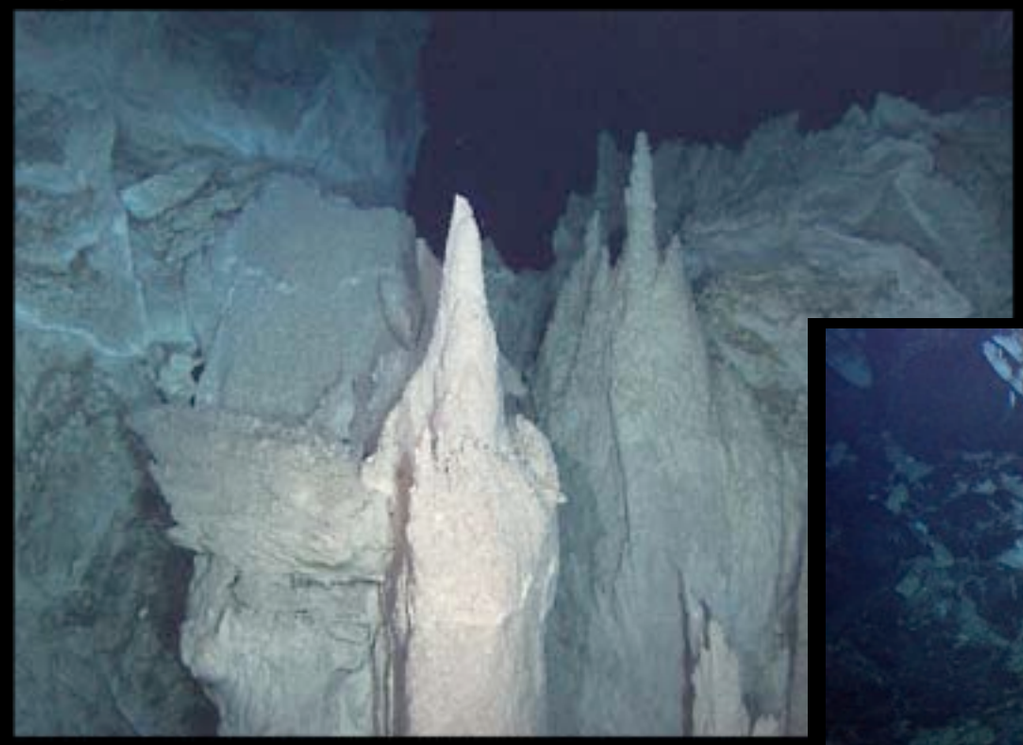
in situ T measurement by ROV:
407°C at MAR black smoker



Liquid CO2 seepage:
SCS 1200-1600 m WD

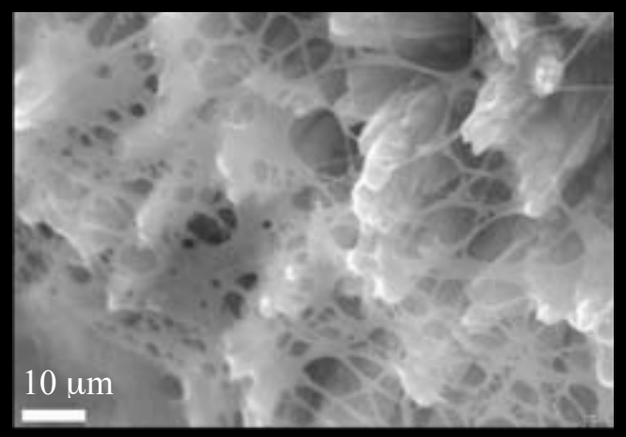
ecosystem ocean crust





Lost City, MAR

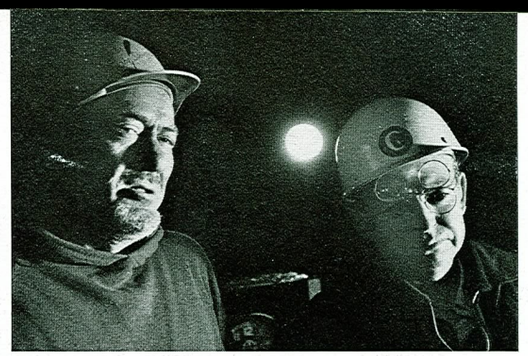
- Carbonate deposits rather than sulfide minerals
- High alkaline fluids (pH 9-11) and low temperatures (<100°C)
- μm-thin biofilms on surface
- closest analogue to early Earth or other celestial bodies (direct connection between mantle & life)



Reasons to study what lies beneath:

- past records provide clues to reliably mitigate future processes (climate change, geohazards, etc.)
- study life at the extremes (i.e. kilometres into the subbottom, high PT, evaporite bodies, etc.)
- identify and quantify portion of the global C cycle yet poorly unraveled
- boreholes offer direct coupling to the rock, and sustainable sampling and long-term instrumentation
- explore the unknown

50+ years of scientific ocean drilling



AUTHOR STEINBECK AND PHOTOGRAPHER GORO ON DECK OF THE CUSS I

High Drama of Bold Thrust through Ocean Floor

EARTH'S SECOND LAYER IS TAPPED IN PRELUDE TO MOHOLE

Last week Project Mohole (LIFE, April 7) made scientific history when its drilling barge, CUSS I (whose name is made up of the initials of oil companies who developed it: Continental, Union, Shell and Superior), pierced 601 feet into the sea floor to get core samples of the earth's never-before-penetrated second layer. On board to describe the extraordinary operation for LIFE was Novelist John Steinbeck, who is also an amateur oceanographer.

by JOHN STEINBECK

This is a short and casual log of CUSS I, the experimental drilling barge of Project Mohole. I am aboard because of a long-time interest in oceanography and some small experience in matters of the sea. I feel privileged and greatly excited.

CUSS I is a Navy barge redesigned to take sample cores from deep in the earth's surface under 12,000 feet of ocean. Our station is 44 miles east of Guadalupe and 220 miles south of San Diego. The sea bottom there is 11,700 feet beneath the surface. In a practice run we drilled a hole under 3,100 feet of water off La Jolla so we know it can be done.

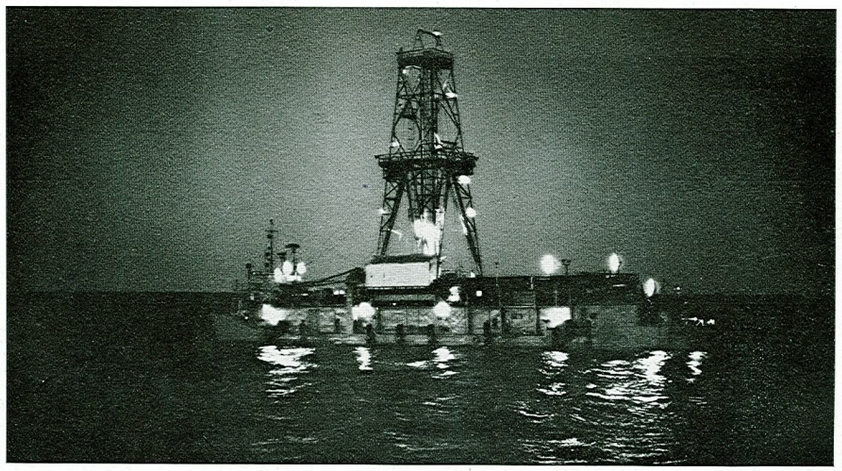
CUSS I has the sleek race lines of an outhouse standing on a garbage scow. Actually it is an oil rig, straddle-legged over a hole cut through the middle of a barge 260 feet long and 48 feet wide. In addition to drilling equipment, cores and diamond bits it is loaded with electronic equipment, much of it invented and designed for this project. But the most important and unique equipment we have is the group of men aboard, an elite and motley crew. The drilling men are the cream of a very special profession already trained in offshore oil drilling in shallow water. Then we have engineers of a dozen kinds, oceanographers, geologists, paleontologists, petrologists, geophysicists and seismologists. Our expedition should destroy the old and well loved error that doers and thinkers are different breeds—and about time too.

This is the opening move in a long-term plan of exploration of the unknown two thirds of our planet that lie under the sea. We know less about this area than we do about the moon. Therefore this log will concern itself with men and events rather than with scientific conclusions. Those will have to come later after analysis of what we find.

Thursday March 23—After five days in a San Diego shipyard refitting and taking on additional equipment, we sailed at 1:30 for our Guadalupe Station, a point in the Pacific Ocean described as 27° North latitude, 117° 30′ West longitude.

Sailed is a status word for what we did. CUSS I waddled like a duck into the channel on its four gigantic Diesel outboard motors. Come to

STEINBECK CONTINUED ON PAGE 118



←**WORKING THROUGH NIGHT,** drillers adjust "kelly" which fits over drill pipe so it can be rotated. Man on high perch (*top, center*) affixes gauge to measure strain on pipe.

AGLOW WITH LIGHTS, CUSS I lies hove to off Guadalupe Island on Easter eve—a night when its drill was busy making its unprecedented thrust into earth's second layer.

LOCATION of CUSS operation is about 150 miles off west coast of Mexico's Lower California peninsula.

Photographed for LIFE by FRITZ GORO

- vision to comprehensively understand surface processes by unraveling the deep Earth

- technology & approach adopted from industry

- basaltic nature of crust as main scientific achievement (despite <200 m core recovery)

- tremendous outreach (and momentum for successor programs)

50+ years of scientific ocean drilling

1968-1983

Verified theory of plate tectonics

Discovered that Antarctica has been ice-covered for 20 Mill yrs

Showed that the Mediterranean Sea completely dried up between 5-12 Ma (Messinian)

1985-2003

Defined the longest record of Earth's climate variability

Marine record of K/T boundary

Successfully sampled gas hydrates

Establish borehole observatories

2003-2013

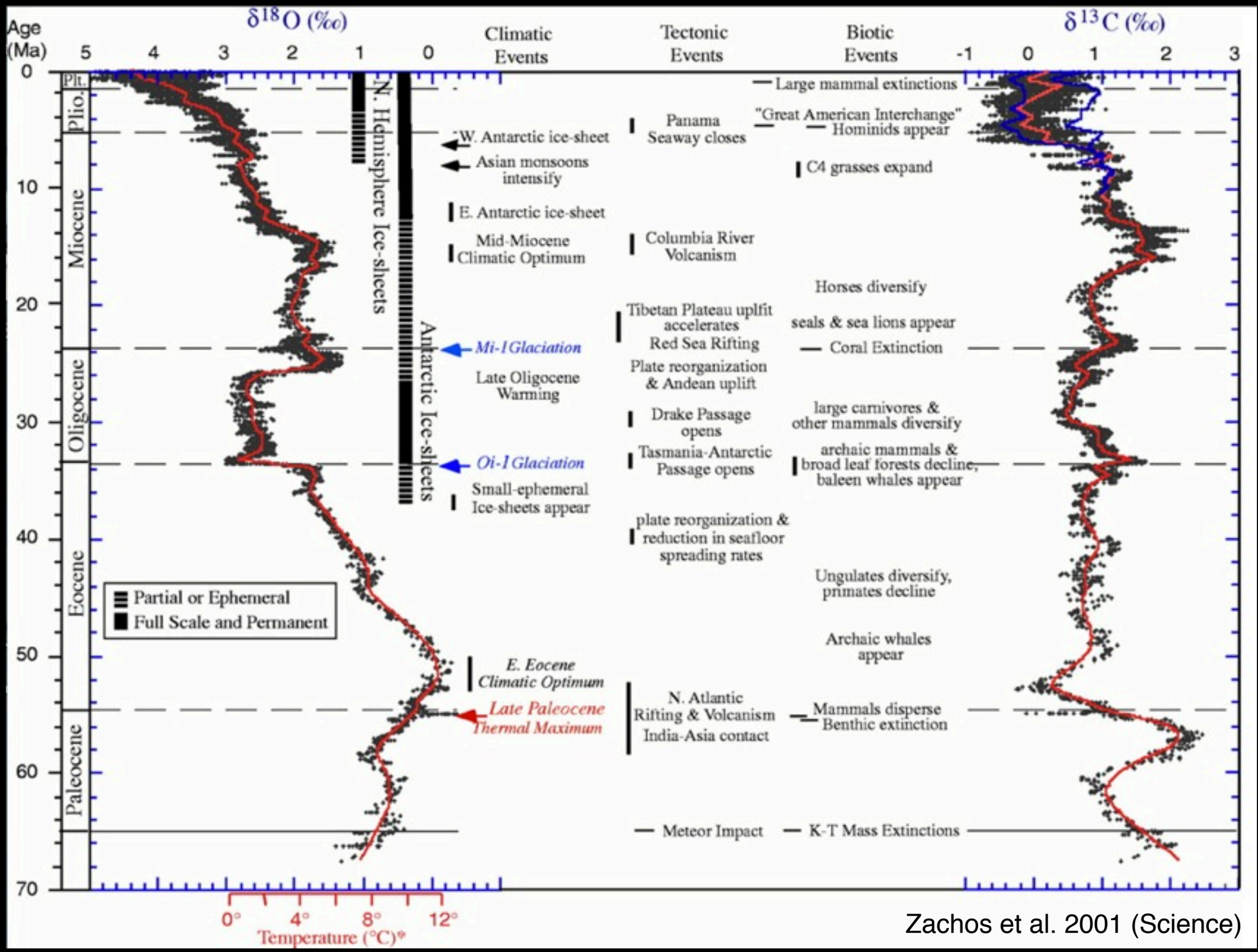
Drilling the Arctic Ocean using icebreakers

Riser drilling for earthquake zone

Reef drilling for climate reconstruction

- 24 member countries
- all fields of life and geosciences covered
- thousands of scientific publications
- valuable archives for future studies
- all data from past half century available online

Benchmark climate reconstructions using ODP core



Zachos et al. 2001 (Science)

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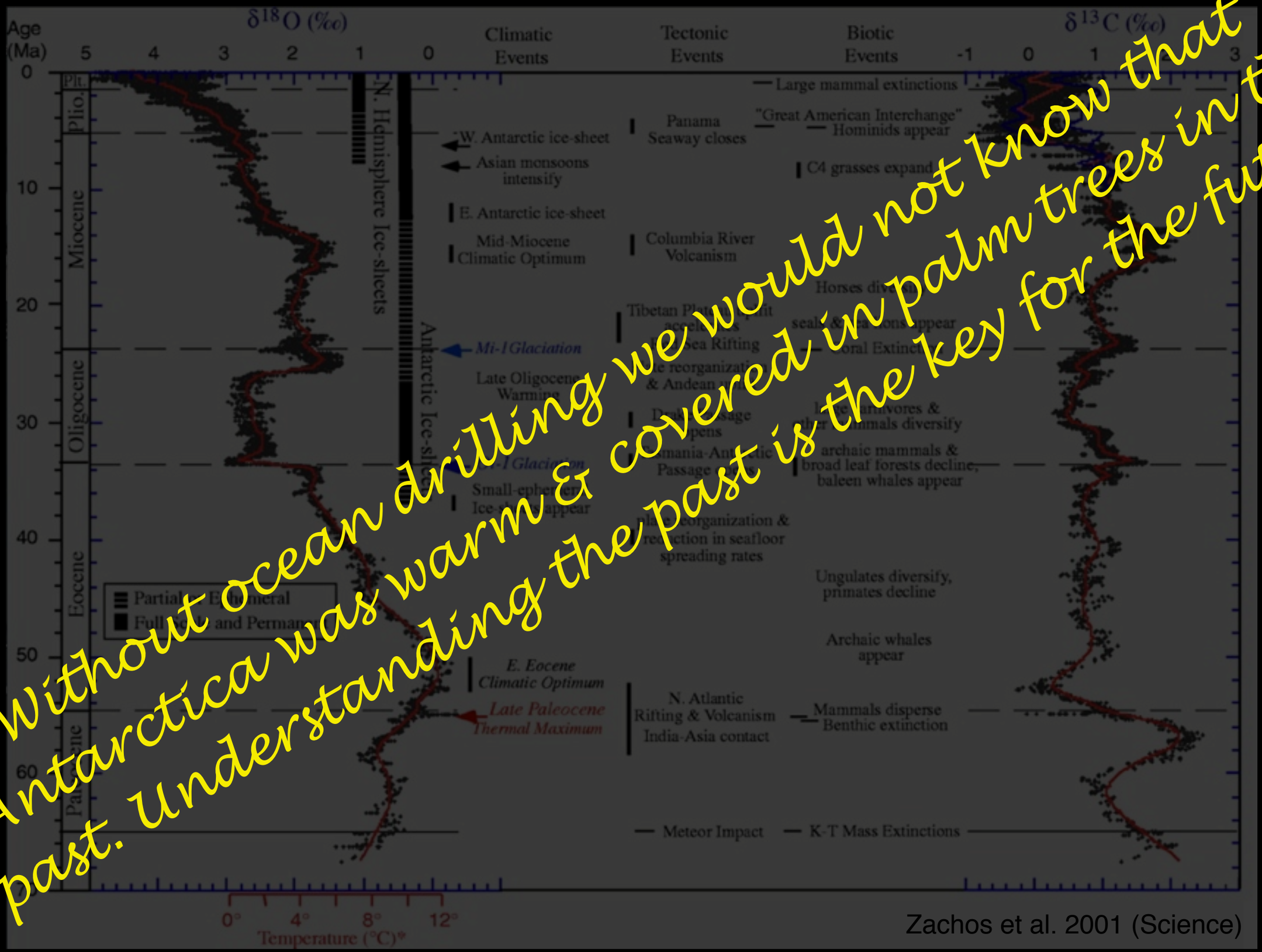
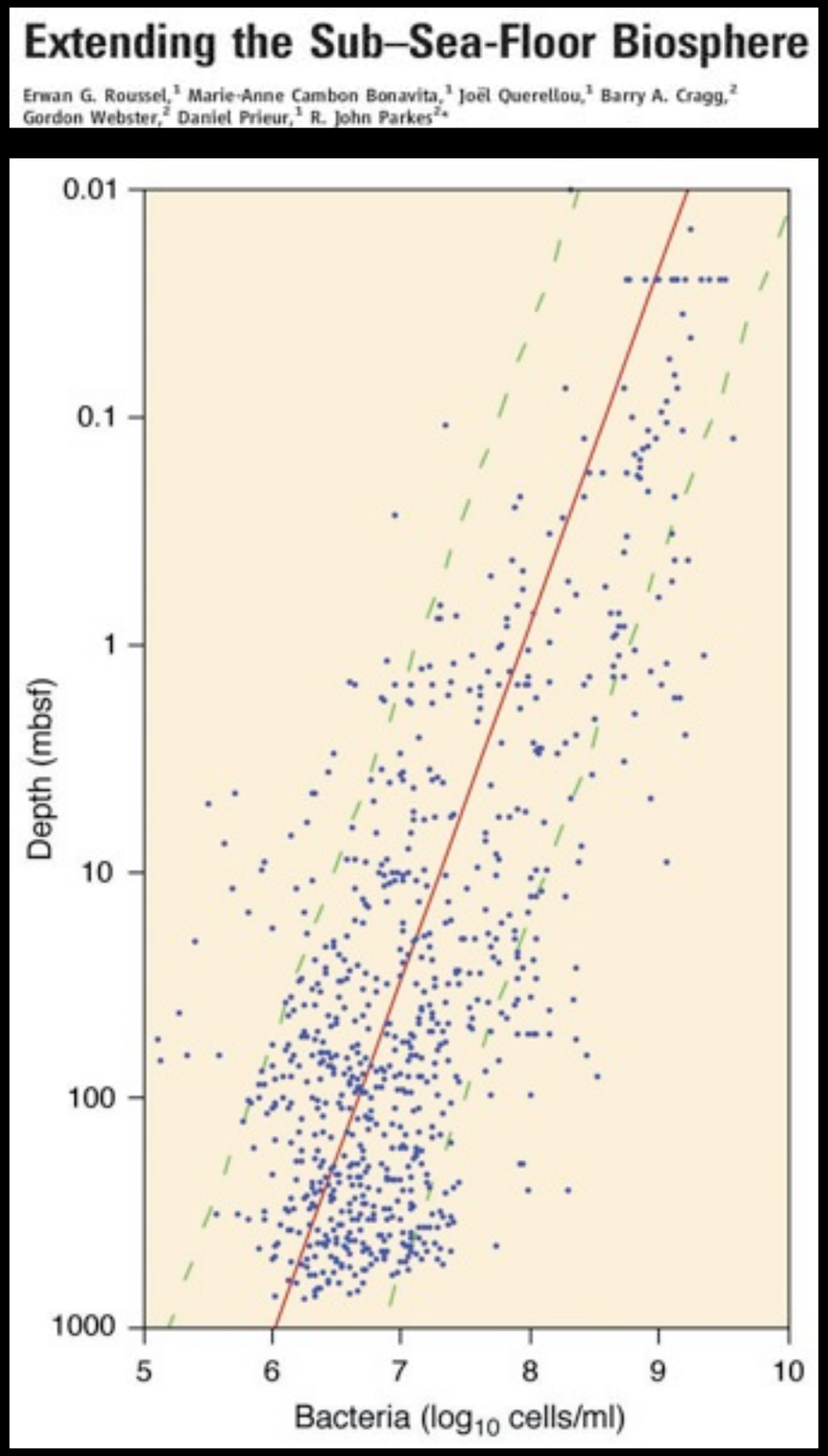


Without ocean drilling we would not know that Antarctica was warm & covered in palm trees in the past. Understanding the past is the key for the future.

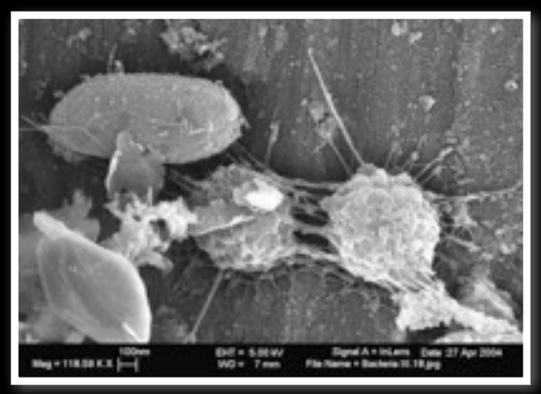
Zachos et al. 2001 (Science)

Deep biosphere



Roussel et al., 2008 (Science)

- Scientific exploration (identification, environmental limits, turnover rates, ...)
- Biomass in the subseafloor rivals that of land + oceanic ecosystems
- Impact on biogeochemical cycles
- Biotechnology applications



FLOCS
(Flow-through osmo colonisation system)

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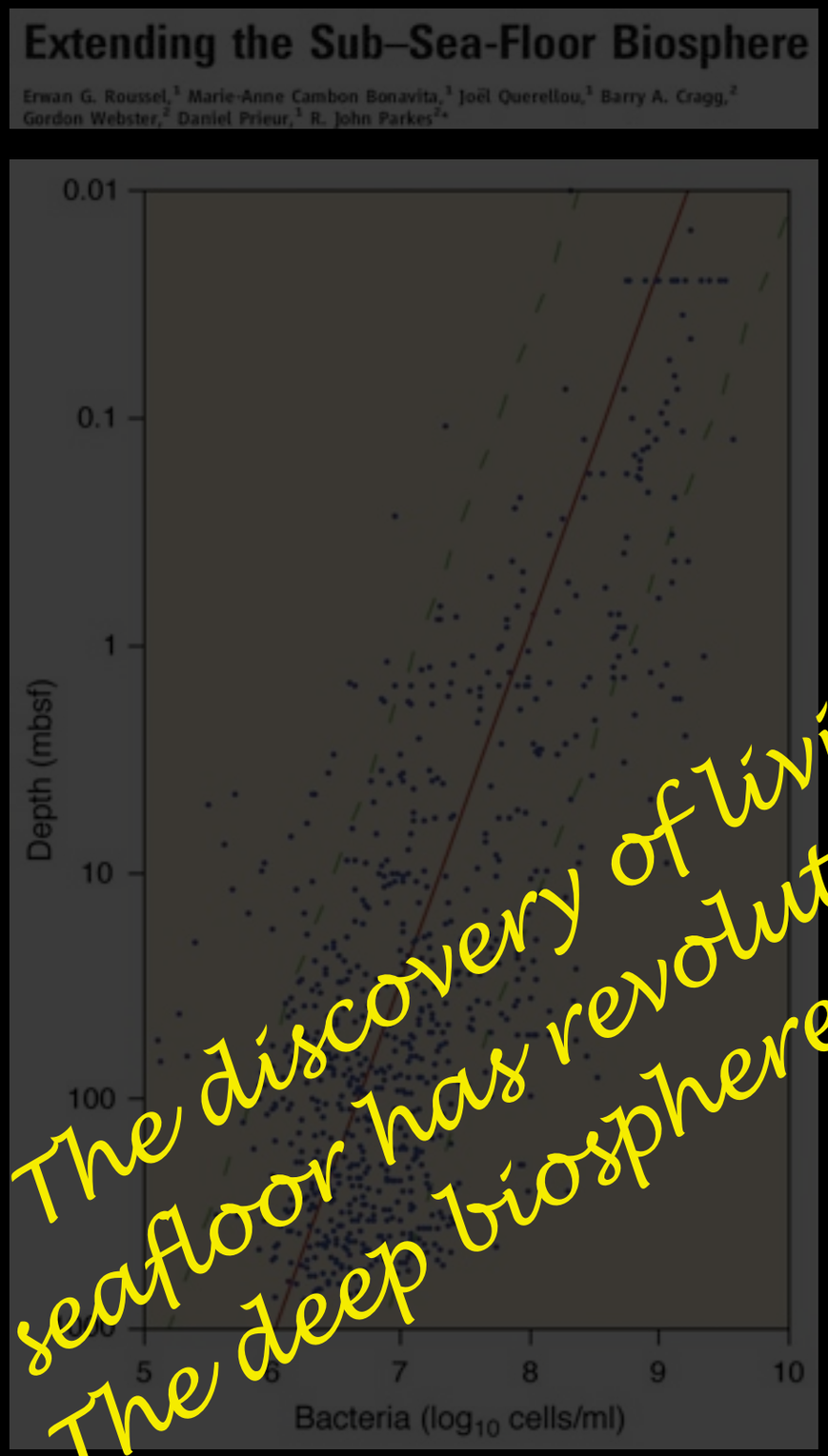

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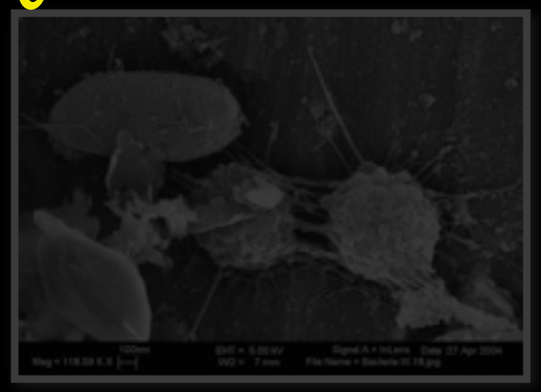
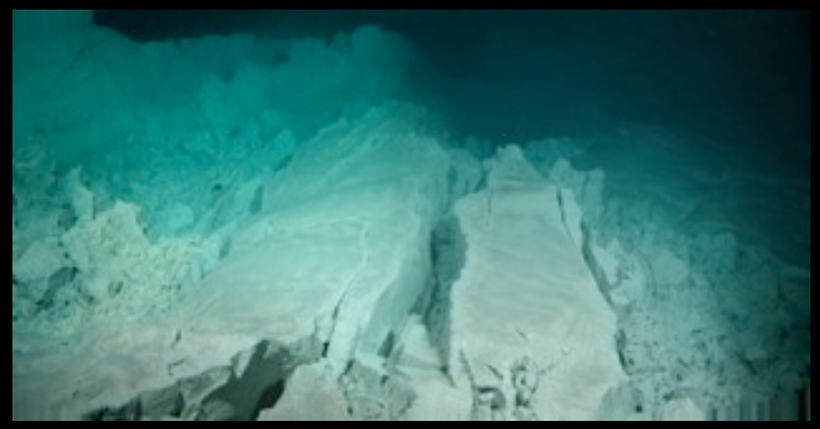
The discovery of living microorganisms beneath the seafloor has revolutionized our concept of the biomass. The deep biosphere is one of the last frontiers in science.



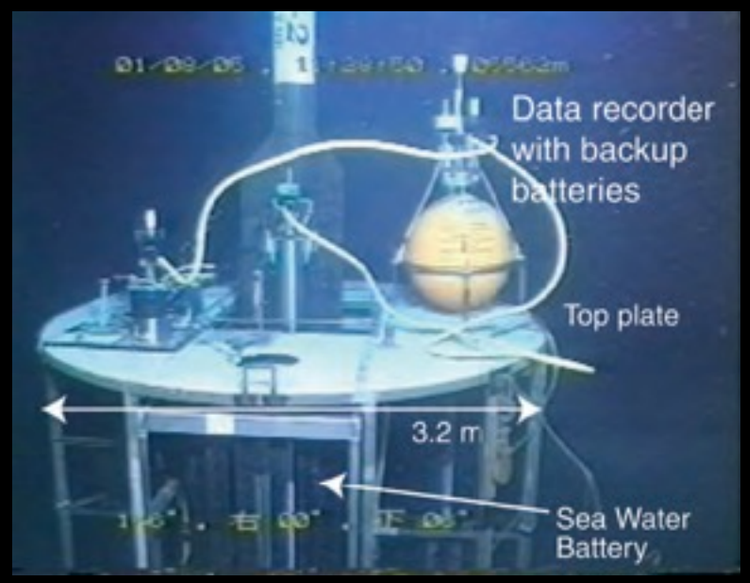
FLOCS
(Flow-through osmo colonisation system)

Geodynamics and monitoring



Seafloor after 2004 Sumatra M9 EQ: abundant landslide scars

Sumatra tsunami hitting Thailand



- instrumented boreholes down to >5 km below seafloor
- strain and seismicity used for earthquake mitigation
- open access real-time data transmission planned for 2011

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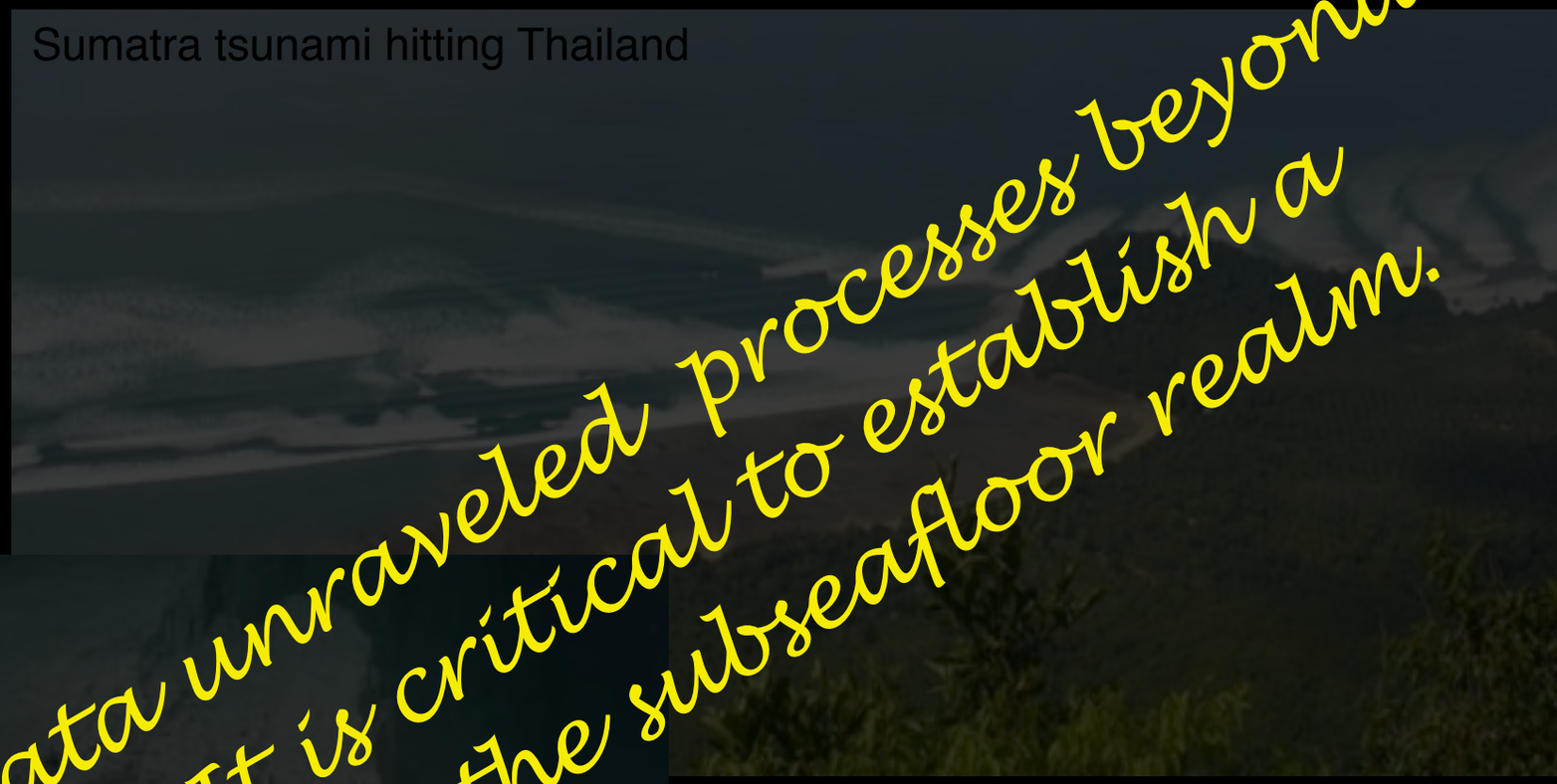

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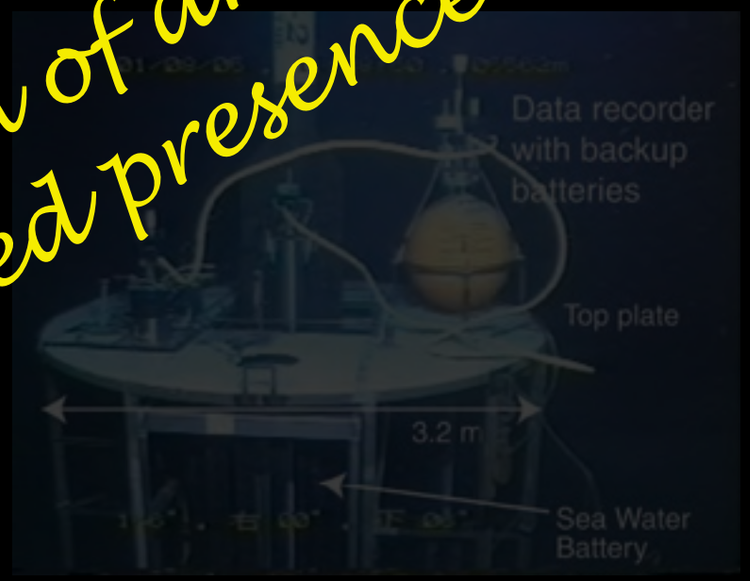

Borehole time series data unraveled processes beyond the depth of drilling. It is critical to establish a continued presence within the subseafloor realm.

- instrumented boreholes down to >5 km below seafloor
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pt.3 what's next?

- formulate emerging scientific hypothesis

  CSA as mechanism already established, outcome of individual IPs and CPs may be enhanced by collaboration with national initiatives or international programmes

- assess economic potential of marine resources

  Joint calls as effective mechanism need to be exhausted, e.g. between Environment, Food, Energy, etc.

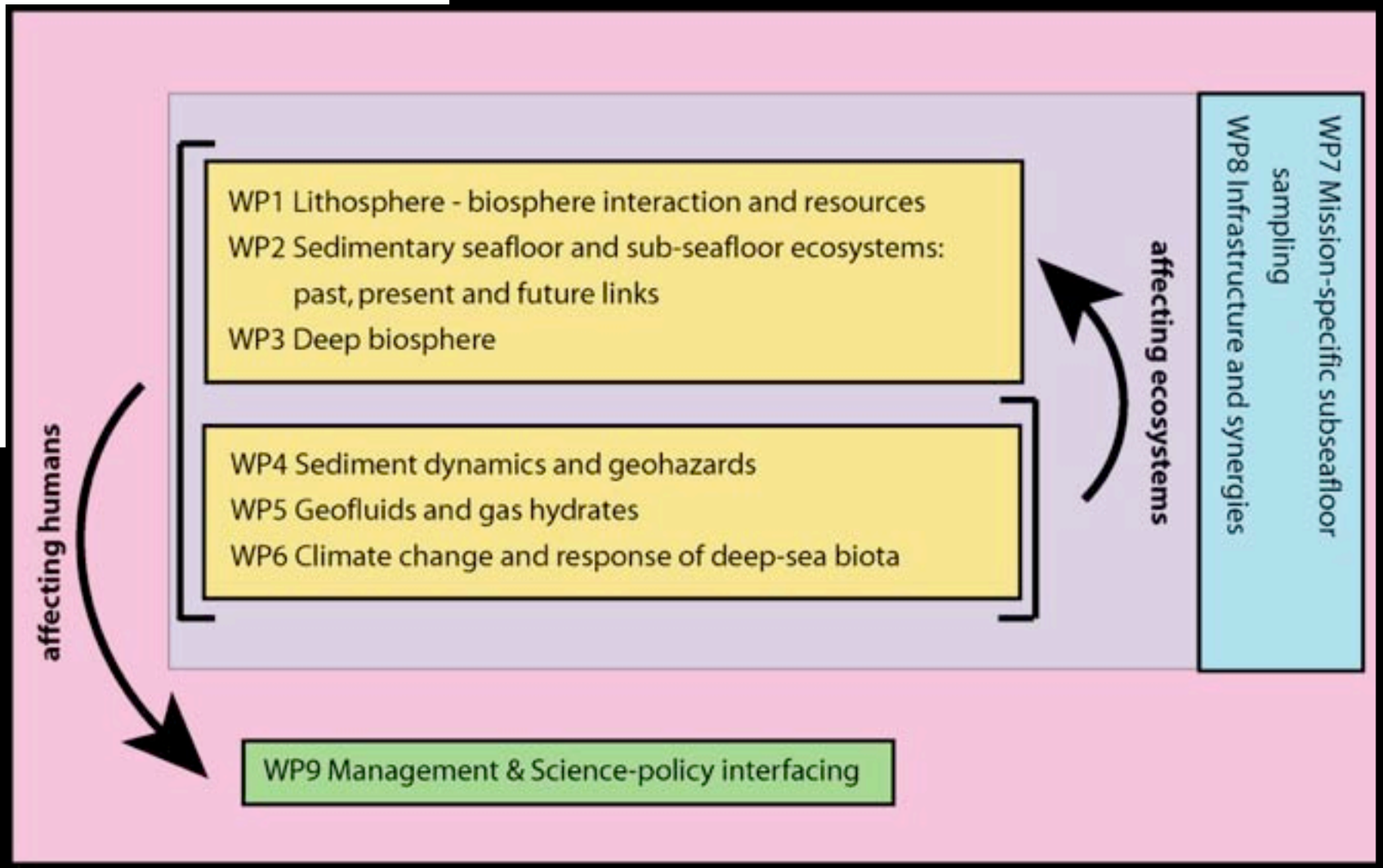
- maximise use of former EU investments

  Explore the 4th dimension, partly done in ESONET-EMSO, but could be optimised when combined with Ecosystem research and Drilling/Sub-seafloor Sampling

DS^{3}F: Deep-Sea & Sub-Seafloor Frontier

DS^{3}F

Call FP7-ENV-2009-2.2.1.6
Coordination & Support Action
Proposal # 244099



http://www.deep-sea-frontier.eu

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Marine resources

Countries try to extend their EEZ beyond 200 nm to trench-slope break (based on UN Convention, Law of the sea)

- Hydrocarbons (including gas hydrates, asphalt, etc.)
- Sulfide ores, Mn knolls, etc.
- Fishery, hydro power, etc.

HC seeps, Black Sea

S deposits, Mid-Atlantic Ridge

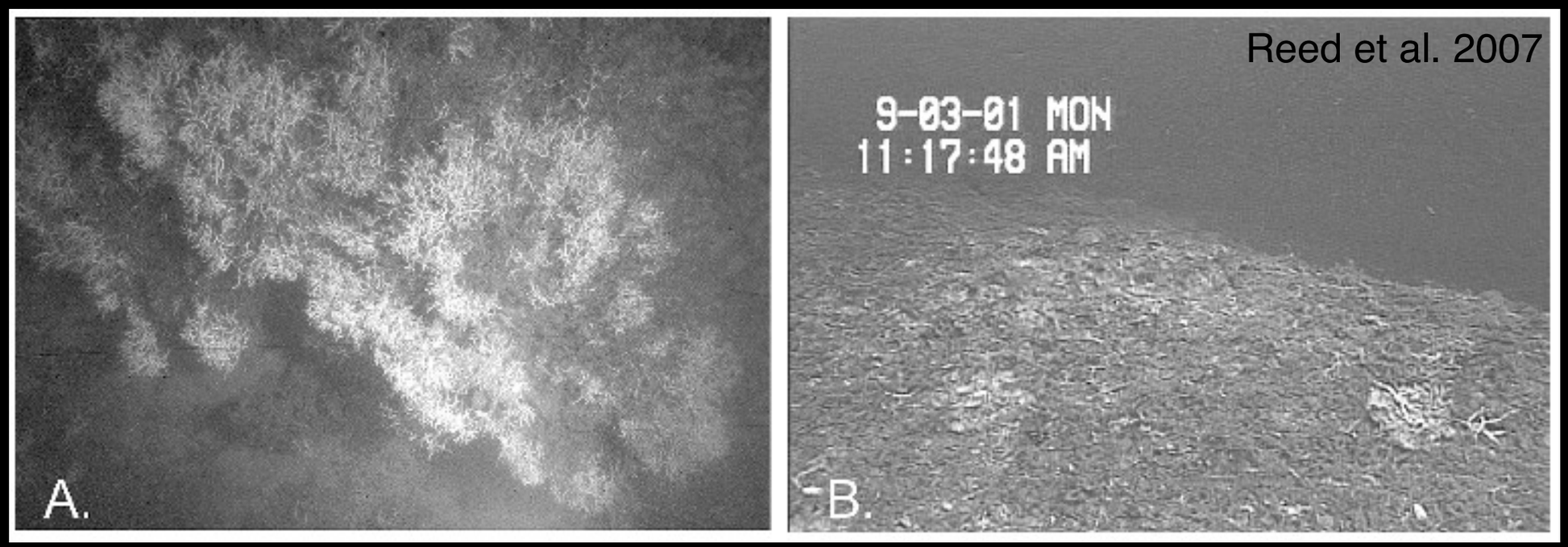
Marine resources

Countries try to extend their EEZ beyond 200 nm to trench-slope break (based on UN Convention, Law of the sea)

→ Emerging need for technologies that lower risk (e.g., GoM) or damage to ecosystems

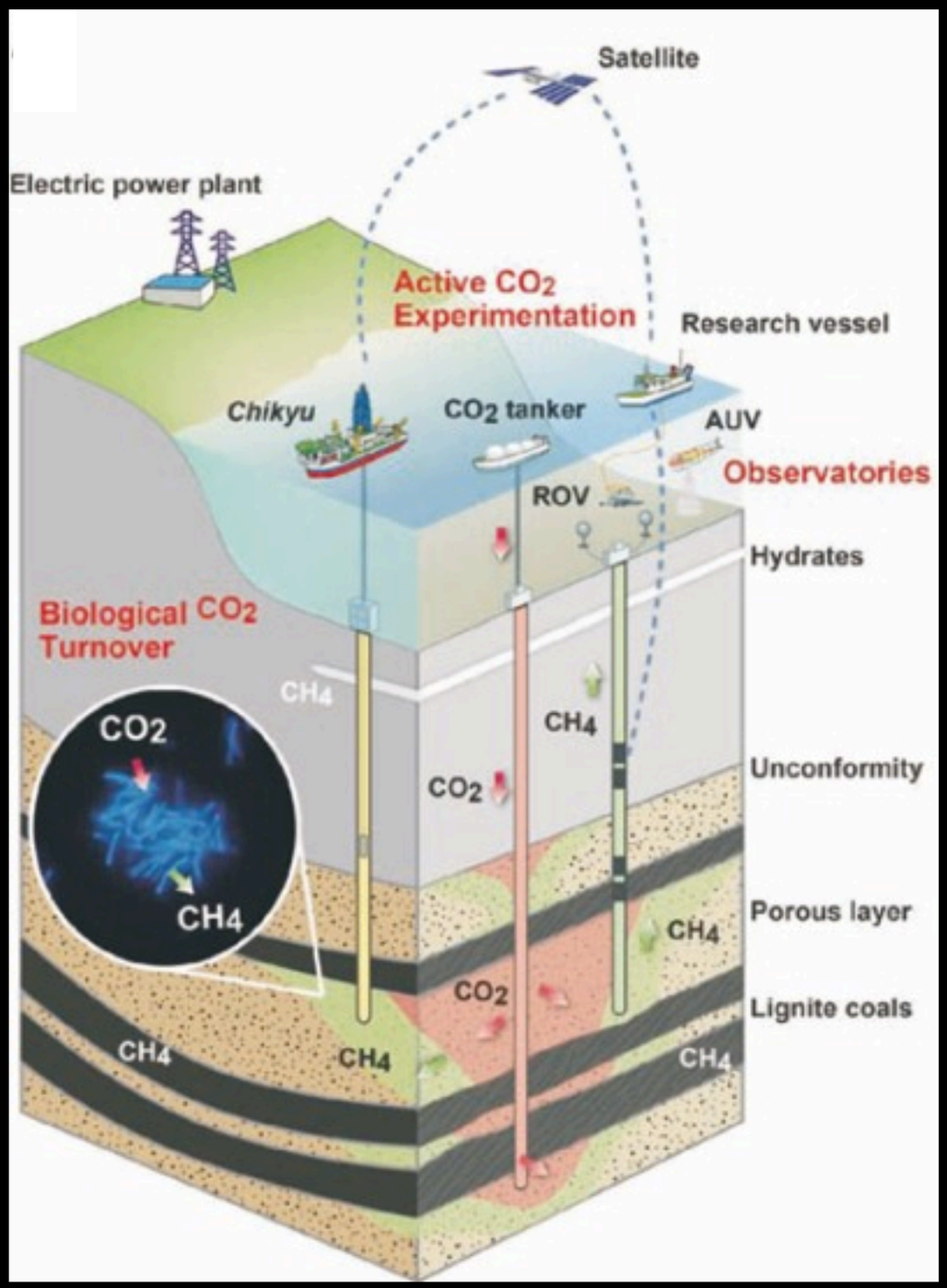
→ Given the thematic breadth ideally suited for EC JPI and Joint Marine Calls

Cold-water coral before/after trawl fishing



Resources backwards

Sub-seafloor capture and storage of CO2



Combine environmental necessities with state-of-the-art scientific research

Have observatories and active experiments on microbial reactions, quantification of turnover, etc.

The ocean floor contains a significant fraction of the potential global storage inventory, so we have to find safe, sustainable ways to use it!

Resources backwards

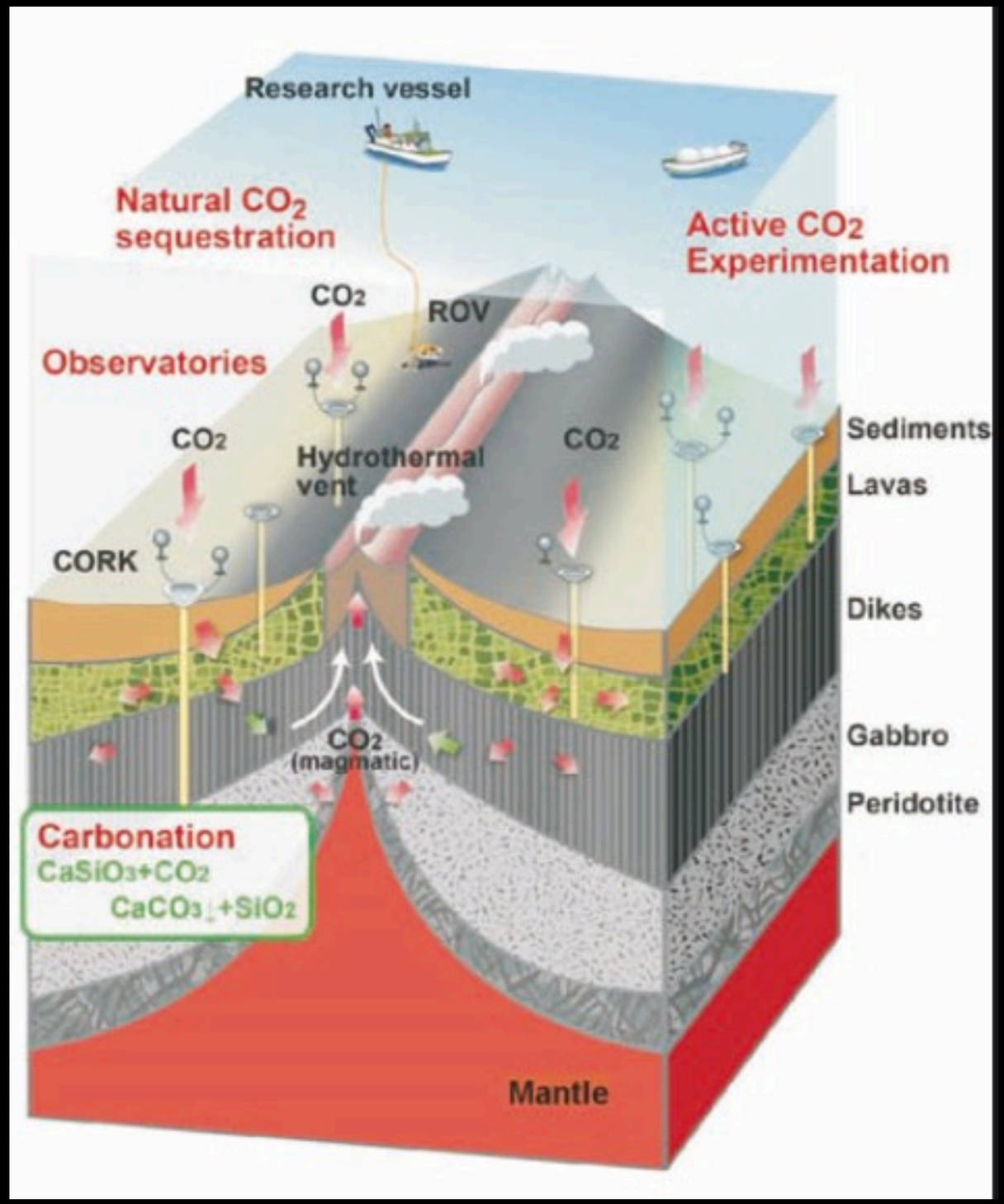
Sub-seafloor capture and storage of CO2

Explore regions where natural CO2 sequestration takes place

Carbonation may potentially mitigate ocean acidification by discharging CO2-depleted, alkaline fluids

→ EU projects are underway to start to address the most-burning issues

ECO2
Sub-seabed CO_2 Storage: Impact on Marine Ecosystems



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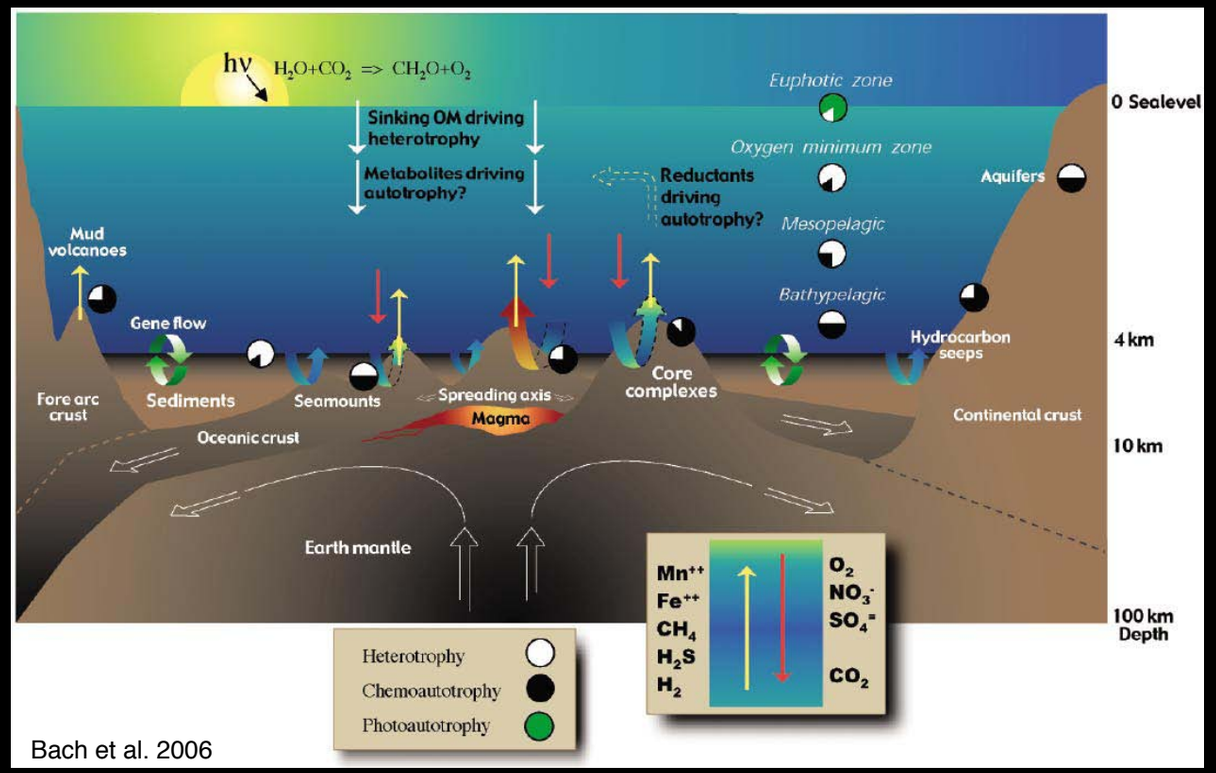
New frontiers

pt.3 what's next?

Sub-seafloor biomass exceeds that in ocean and land (Whitman et al., 1997)

- particularly MORs (in Europe: MAR) are zones of activity



Bach et al. 2006

Next generation of questions:

How do mass and energy transfer between pelagic waters, the benthos, and the crust affect the distribution and activity of microbes?

How large is chemoautotrophic production in the deep sea/seafloor?

What are the rates and products of metabolic reactions? How do they affect biogeochemical cycles and global mass balances?

Are there bioactive molecules, genetic resources, etc. for societal benefit? How is this to be regulated?

New frontiers

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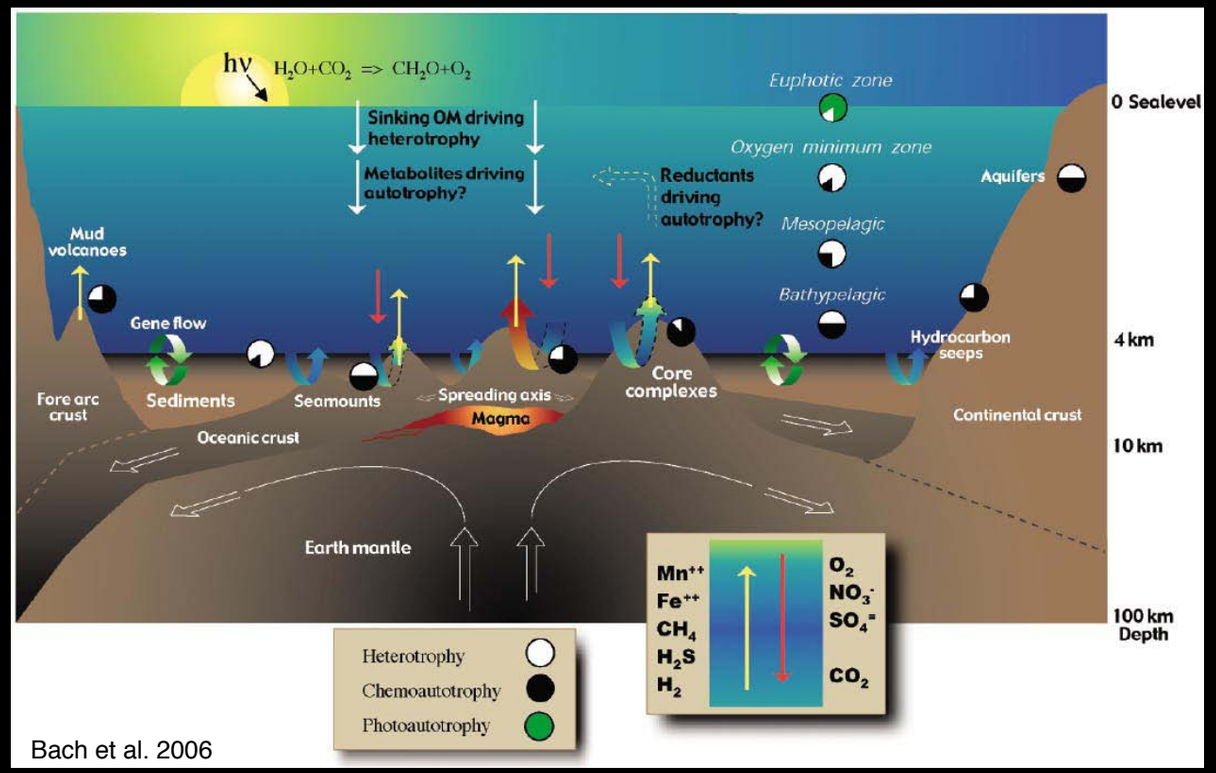

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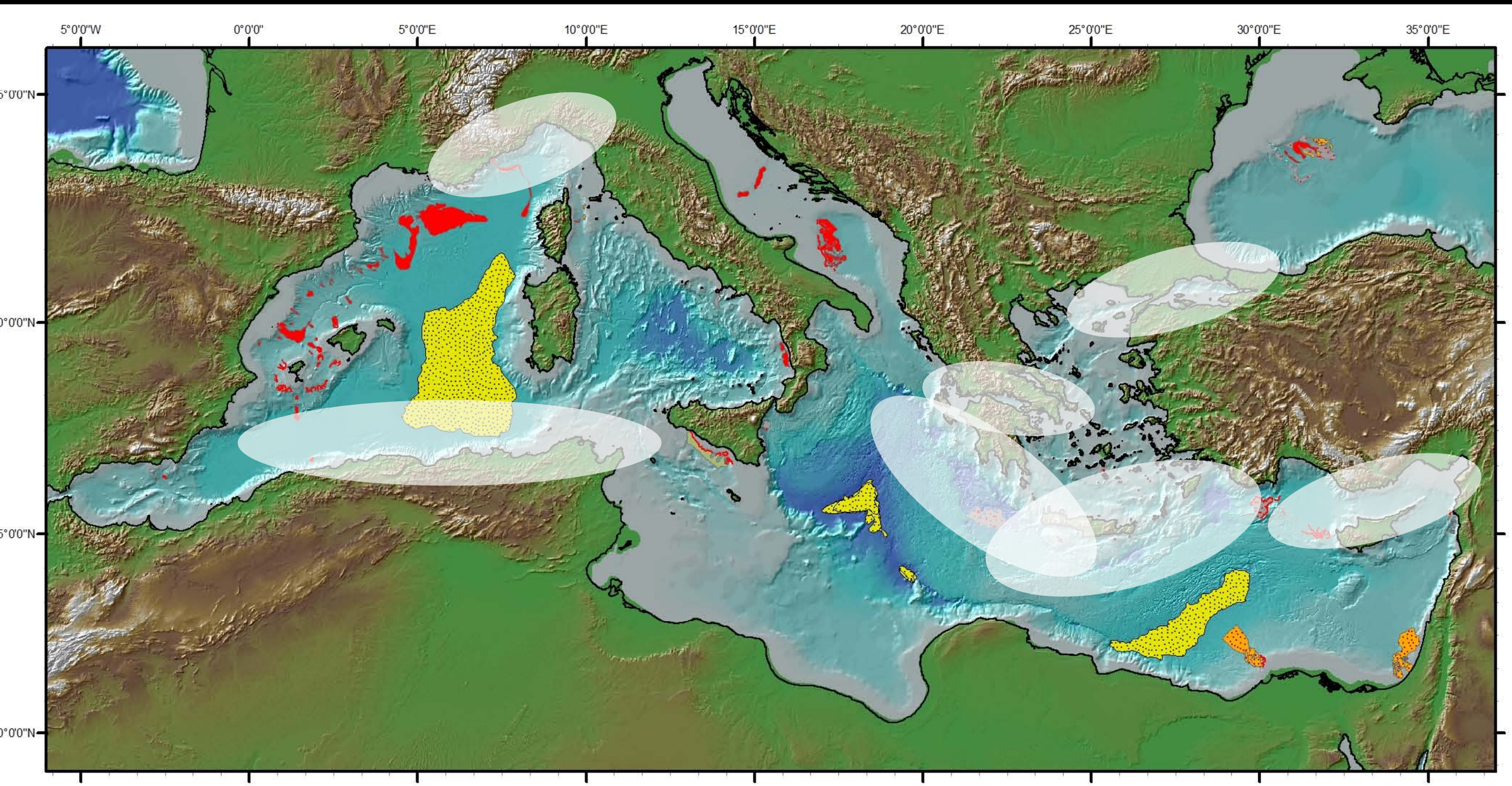
Combined ecosystem/biosphere research with observatory and subseafloor component will provide significant step forward in MOR research.

New frontiers

- **Geohazards**, short-term events such as EQs, landslides, tsunamis, identified as one key research priority in future marine research
- often devastating damage and casualties, but governing factors and episodicity yet to be completely understood
- when remaining within European territory, the Mediterranean Sea probably represents the most vulnerable area as a marginal ocean basin prone to extreme climate and further in a tectonically unstable area between Africa colliding with Eurasia

State-of-the-art, integrated, multi-disciplinary research in a hazard-prone ocean margin!



seismicity

Mediterranean with 46000 km of coastline, along which 160 M people (+135 M tourists/a) live

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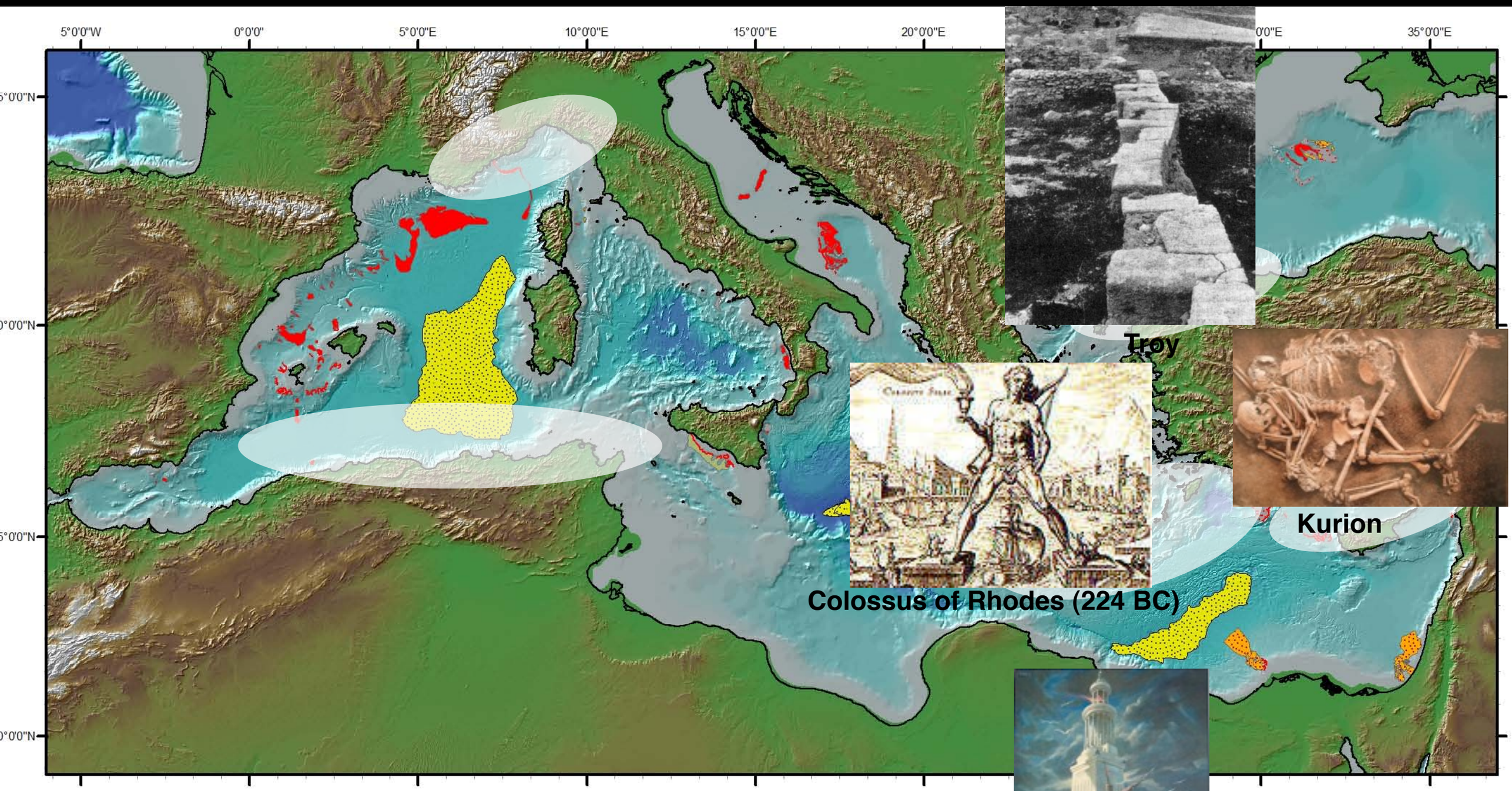

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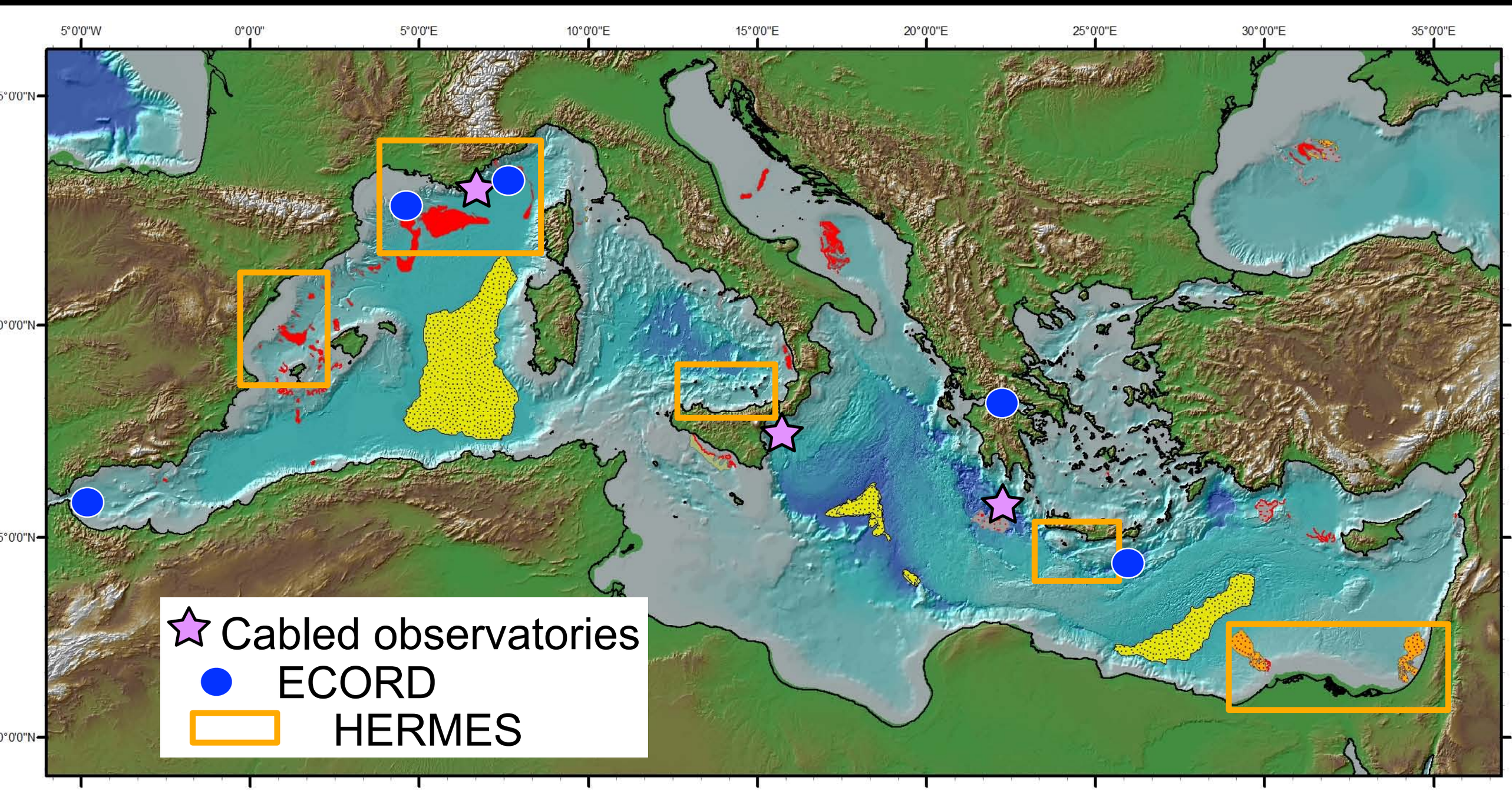
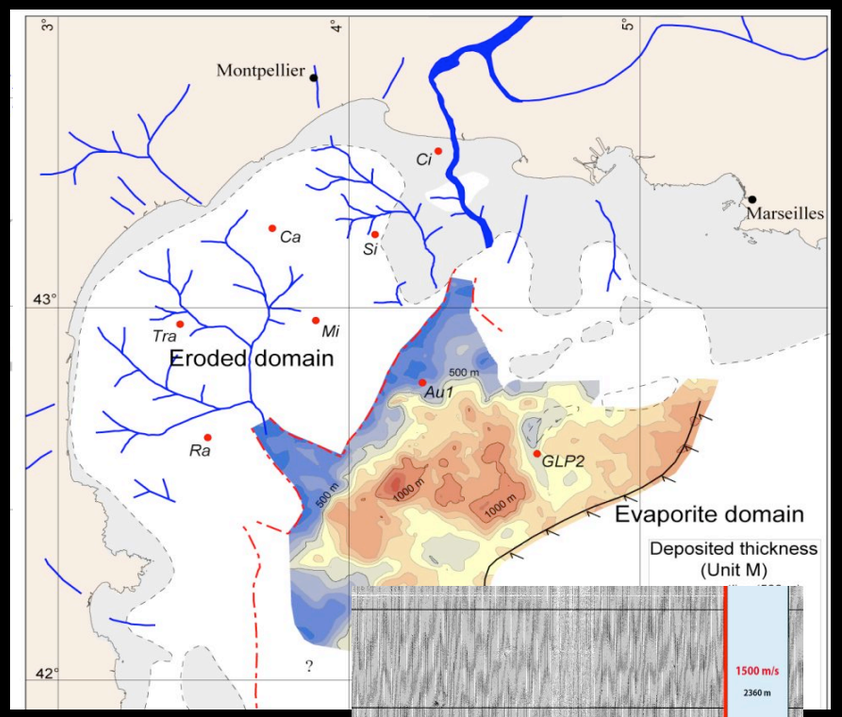


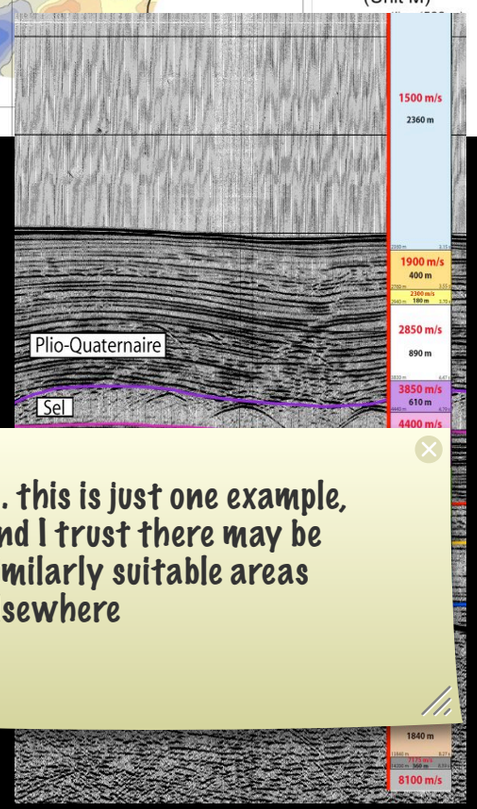
→ Ligurian Basin with prerequisites for an integrated approach

Ligurian Sea, western Mediterranean

Gulf of Lions/Rhone delta

- life in extreme environment
- high-resolution climate record



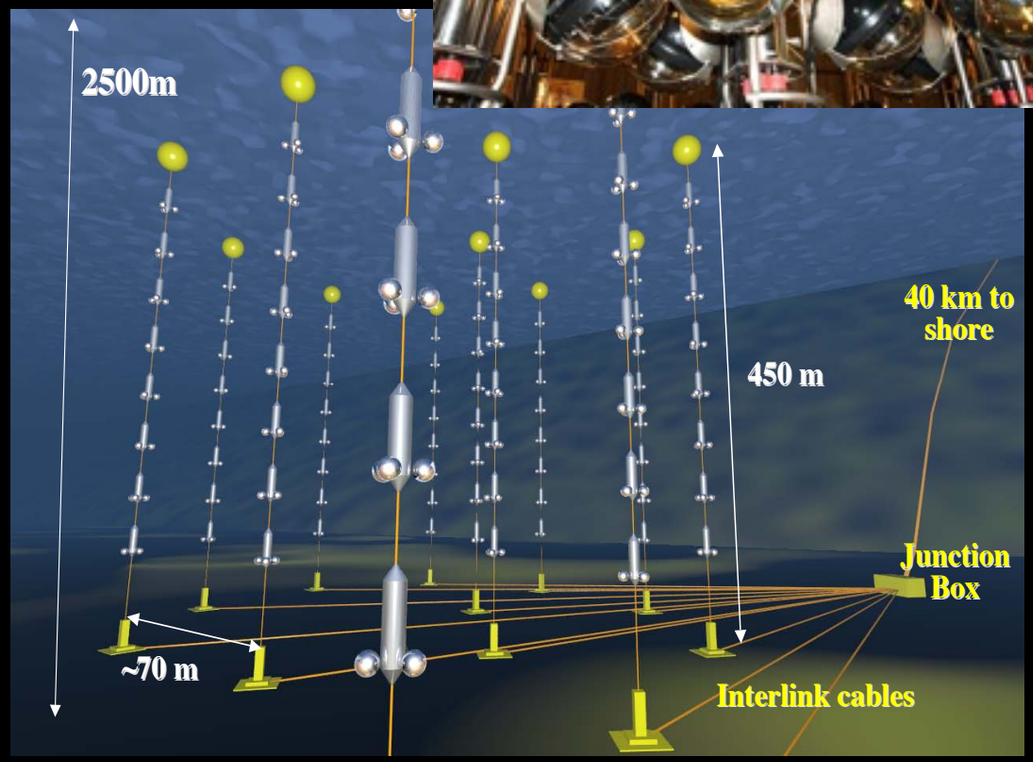


Seismic reflection profile illustrating ... ents in most ... 0 Ma)

.... this is just one example, and I trust there may be similarly suitable areas elsewhere

Toulon

- real-time access to the deep-sea
- neutrino telescope in place
- hydrodynamics, marine ecology, geosciences, biogeochemistry



Var delta/Nice slope

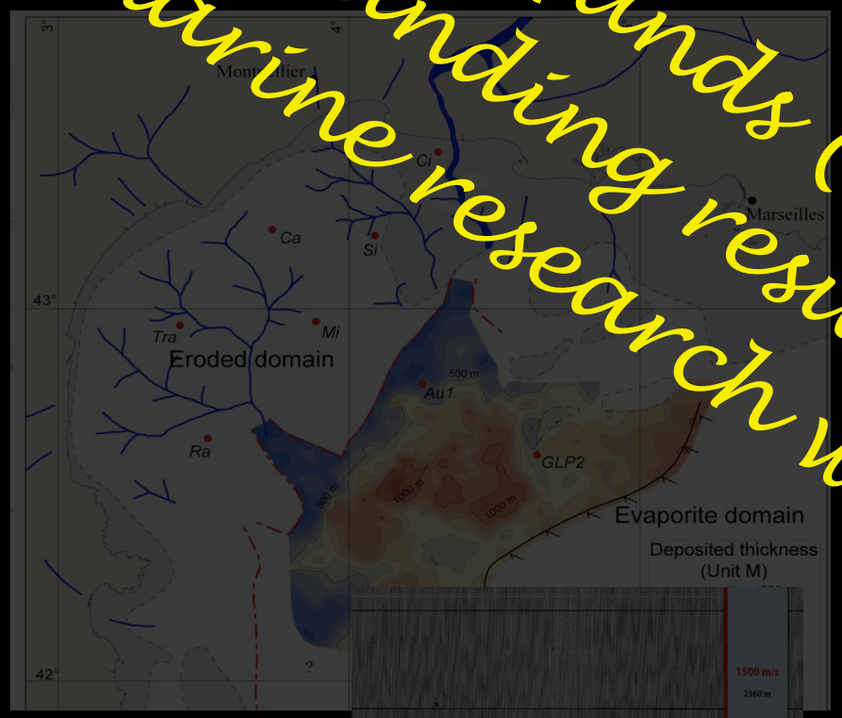
- sediment dynamics & biodiversity
- geohazards and socio-economics

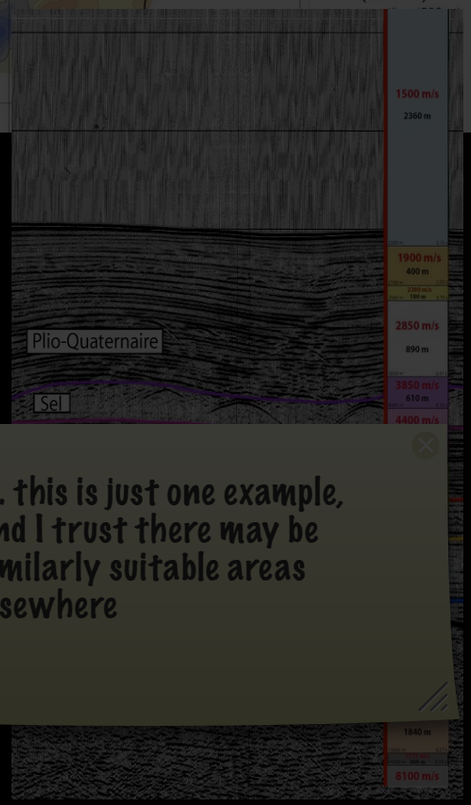
Long-term piezometer

Ligurian Sea, western Mediterranean

Gulf of Lions/Rhone delta

- life in extreme environment
- high-resolution climate record





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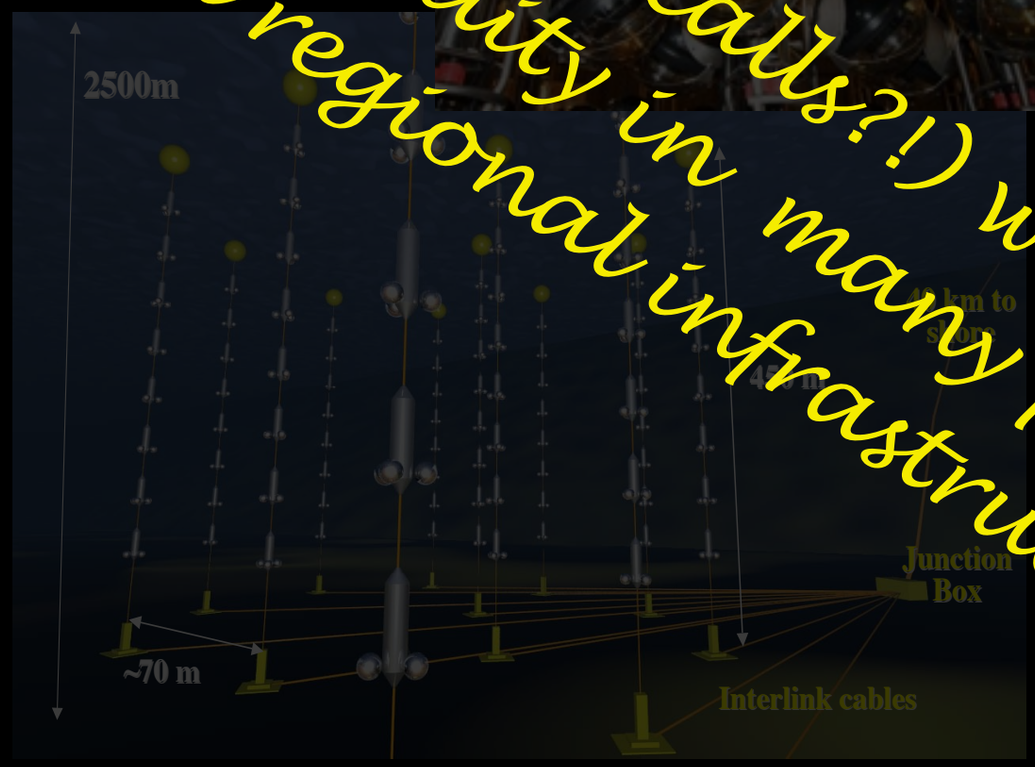

Var delta/Nice slope

- sediment dynamics & biodiversity
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Long-term piezometer

Focused funds (in consecutive calls?!) will ensure outstanding results & visibility in many fields of marine research with a regional infrastructure.

pt.4 what's the point?

- Dissemination of key objectives in Science and Engineering Development (R&D) are essential
>>> to policymakers, funding agencies, industry, etc.

- Dissemination of key results equally crucial
>>> to the above, but also the public

- Sustainable management of data (and samples)
>>> important to all

- Education/training as central component to involve the most brilliant minds of the next generation
>>> important to all

Europe's role in Deep Sea Research

- technologically, Europe is strong (e.g. renewable energy, CO_2 sequestration, etc.) - large environmental consciousness
- deep biosphere and marine biology dominated by European scientists
- exploitation of Europe's diversity (*- turns into +*)
- jointly, a lot can be achieved in Joint calls (on a scientific) and an overarching European Maritime Policy (on a political, economical and societal level)

About /Home

Deep-Sea and Sub-Seafloor Frontiers (DS^{3}F)

The Deep-Sea and Sub-Seafloor Frontiers project (DS^3 F) provides a pathway towards sustainable management of oceanic resources on a European scale. It will develop subseafloor sampling strategies for enhanced understanding of deep-sea and subseafloor processes by connecting marine research in life and geosciences, climate and environmental change, with socio-economic issues and policy building. A long-term research approach will be established covering: (i) sustainable ocean management, particularly the deep sea, with enhanced exploitation (fishery, hydrocarbon exploration), (ii) the necessity to unravel the deep-seated geological processes that drive seafloor ecosystems, and (iii) release of the potential of seabed archives for paleo-environmental reconstruction and improved prediction of future climate change

Subseafloor drilling and sampling provide two key aspects for understanding how deep-sea ecosystems presently function and how they may respond to global change: (a) an inventory of current subsurface processes and biosphere, and their links to surface ecosystems, utilizing seafloor observation and baseline studies and (b) a high resolution archive of past variations in environmental conditions and biodiversity. For both aspects, an international effort is needed to maximize progress by sharing knowledge, ideas and technologies, including mission-specific platforms to increase the efficiency, coverage and effectiveness of subseafloor sampling and exploration.

The deep biosphere has been discovered only within the past two decades and comprises a major new frontier for biological exploration. We lack fundamental knowledge about [illegible] distribution, diversity and physiological activity of deep subsurface communities, life's extremes and their impact on seafloor and deep ecosystems. Similarly, the geodynamic processes fuelling biological activity and how these processes impinge upon the emission of geofuels, hydrocarbon formation and other resources, need to be understood. This CSA will develop the most efficient use of subseafloor sampling techniques and existing marine infrastructure to [illegible] ecosystems, and provide a comprehensive "white paper" for a sustainable use of the oceans and a Maritime Policy.

DEEP SEA MATTERS!

http://www.deep-sea-frontier.eu