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MARINF/99
Paris, July 1995
English only

UNITED NATIONS EDUCATIONAL, SCIENTIFIC
AND CULTURAL ORGANIZATION

DEEP-SEA DEPOSITIONAL SYSTEMS AND MUD VOLCANISM IN THE MEDITERRANEAN AND BLACK SEAS

through the UNESCO/ESF joint Training-through-Research programme
and the "Floating University" project

Abstracts of the third post-cruise meeting

Cardiff University of Wales, UK
30th January - 3rd February 1995

UNESCO

fifty years

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FOREWORD

The "Floating University" project grew out of co-operation between UNESCO/TREDMAR and Moscow State University (MSU). The "University Field Courses in Marine Sciences" was the theme of an international meeting organised within the framework of this co-operation in July 1989 at the White Sea Biological Station of MSU. At the meeting, it was recommended in particular that Universities and institutions "... should co-operate in providing marine science field training, including shipboard training..." and also that "Research projects should be initiated in which scientists and students from MSU and those from foreign universities and institutions can participate". It was also recommended that "universities should revise, as appropriate, their science curricula and field training in light of the challenges presented in the UNESCO Report in Marine Science, No 52, (published in 1988), Year 2000 Challenges for Marine Science Training and Education World-wide".

Based on the above recommendations, the first Training-through-Research (TTR) cruise was organised in the Black and Mediterranean Seas in 1991 on board the R/V *Gelendzhik* of Yuzhmorgeologiya Co., Russia.

The European Science Foundation, which groups 56 scientific institutions in 20 countries, became a supporter of certain activities within the programme after the success of the first cruise. This support came through the ESF *Network on Advanced Study Workshops on Mediterranean Marine Geosciences.*

The purpose of this joint UNESCO-ESF programme is to bring together the numerous institutions working on the geology of the Mediterranean, and to promote advanced "Training Through Research" communication and exchanges between scientists and students of different countries.

In addition to UNESCO and ESF, many countries, including France, Germany, Greece, Israel, Italy, Monaco, Morocco, the Netherlands, Russia, Spain, Tunisia, Turkey, the Ukraine and the United Kingdom have provided financial, material and intellectual support to the cruises. The Russian Committee of Geology, through Yuzhmorgeologiya, has pledged to make the *Gelendzhik* available for new "Floating University" cruises over the coming years. The 2nd TTR cruise took place in 1992 in the Western Mediterranean. This cruise was followed by the 3rd TTR cruise in the summer of 1993. This time the investigated areas were the Black Sea and the Eastern Mediterranean. The 4th TTR cruise (summer 1994) took place in the Central and Western parts of the Mediterranean Sea.

After the 2nd TTR cruise, a successful post-cruise meeting was organised, in Moscow, to discuss results obtained so far and to plan for future joint research activities. After the 3rd TTR cruise, a post-cruise meeting was organised in the Netherlands. During the 4th cruise it was decided to organise the meeting in the United Kingdom.

The meeting report and abstracts have been compiled and edited by Mr Stephen Morris, Chairman of the meeting, for publication by UNESCO and ESF in the MARINF series.

TREDMAR Programme
UNESCO

THIRD STUDENTS' POST-CRUISE MEETING

Introduction

The third post-cruise meeting was held, during the first week in February, 1995, in the Department of Earth Sciences at Cardiff University. The use of national coordinators as active contacts in the participating countries proved to be very successful and a large number of delegates attended the meeting.

The main objectives were to present and discuss the results of ongoing analysis and interpretation of data obtained during the Training-through-Reserach (TTR) cruises. The discussions were held over a period of two and a half days and the remainder of the week was devoted to a Field Excursion to Mid Wales and social events, including a visit to the National Museum of Wales.

The opening remarks made by Stephen Morris (Chairman of the Organising Committee) were followed by addresses from Professor David Rickard (Head of the Department of Earth Sciences), Professor Brian Smith (The University Principal), Dr Adrian Cramp (Head of the Cardiff Marine Geosciences Research Group) and Dr Alexei Suzyumov (UNESCO). All the opening speakers commented upon the importance of the TTR Programme and the international cooperation of so many organizations. The presentations which followed were all of high quality and genereated much useful discussion. There was evidence of collaboration between various institutions following the success of this and previous cruises: Grigorii Akhmanov stayed in Cardiff for two months following the meeting to work with Simon Wakefield on mud volcanic breccias; Ekaterina Ivanova and Anna Lototskaya are now studying with Professor Jan van Hinte at the Free University in Amsterdam; Michael Ivanov visited the Free University following the meeting as did Alexandre Volgin; Stephen Morris and Neil Kenyon have agreed on a collaborative project to interpret side-scan sonar images from the Valencia Channel Mouth; and Eugene Basov went to NIOZ to work in co-operation with Tjeerd van Weering.

At a meeting which preceeded the third post-cruise conference, the scientific planning committee agreed to fulfill, as part of the Fifth TTR cruise:

> *".... a comprehensive geological and geophysical investigation of gas and fluid escape through the seafloor in the Mediterranean and Black Seas, as well as related structures, such as, mud volcanoes and clay diapirs".*

Acknowledgements

Stephen Morris was ably assisted in the organization of the meeting by Bryan Cronin, Simon Wakefield, Zoë Moore, Julie Herniman, Alison Jones and Martin Gee in Cardiff and the national coordinators, Serguei Bouriak (Moscow State University) Goof Buijs (Free University, Amsterdam). Invaluable assistance was also provided by Ekaterina Ivanova, John Woodside and Alexei Suzyumov.

This Organising Committee would like thank the following organizations and companies for the generous support, the essential funding, and the other facilities they provided for this meeting: UNESCO, ESF, The Royal Society of London, Cardiff University and its Department of Earth Sciences, Free University of Amsterdam, Amoco, BP Exploration, The Cambrian Group, Chevron UK Limited, Enterprise Oil Limited, Mobil North Sea Limited, Shell UK Limited, Elf Petroland Nederlands B.V., Shell Nederlands B.V., and The National Museum of Wales. Peters Savoury Products are gratefully acknowledged for contributions to the catering.

SESSION 1: THE BLACK SEA

Formation of the Black Sea and Mediterranean Ridge mud volcanoes

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Black Sea and Mediterranean Ridge mud volcanoes were studied during several UNESCO - ESF cruises of the R/V *Gelendzhik* with high resolution seismic, long range and deep tow side-scan sonars, and different kinds of corers. Three types of mud volcanoes in the Black Sea and six types in the Mediterranean were distinguished according to differences in their size, shape, distribution of the mud flow and inner structure. Some types of mud volcanoes from both localities look very similar to each other, but their deep structure is very distinctive. These differences in deep structure is explained by their origin and development in different geological settings.
The Black Sea mud volcano formation is controlled by following conditions:

- the high sedimentation rate of the Plio-Quaternary deposits;
- the presence of the thick and plastic Maikopian (Oligocene-Lower Miocene) clays, which are an excellent impermeable screen for fluids;
- the high hydrocarbon potential of the Maikopian Formation and probably older sedimentary units;
- the presence of small-amplitude normal faults creating weakened permeable zones in the overlying sedimentary sequence.

Thus, the origin of all Black Sea mud volcanoes is strongly related to hydrocarbon gas generation and high rate of sedimentation. We suggest that the Mediterranean Ridge mud volcanoes have no single universal mechanism of their formation. Some, Napoli Dome for instance, seem to be very similar in origin to the Black Sea mud volcanoes. Meanwhile, the majority of the mud volcanoes and clay diapirs are thought to have been formed under a strong lateral compressional stress and intensive tectonic overburdening of the source formations resulted in their squeezing out to the seafloor.

Black Sea deep water mud volcano area: seismic and acoustic images probably connected with gas charge: the evidence of gas responsibility for bright spots (data from the 1st and 3rd TTR cruises)

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Russia

On the single channel seismic profiles produced in the first TTR cruise, a number of images probably connected with gas charge, such as acoustically transparent columnar disturbances, acoustic voids and bright spots, were observed. The high resolution profiler of the MAK-1 acoustic system, used in the TTR3 cruise also produced images that can be explained by the presence of gas, such as acoustic turbidity zones and columnar disturbances. Some of them are connected with lineaments and pockmarks observed in the MAK-1 sonographs.

These bright spot images are widely-distributed and convenient for attempts at analysis of gas nature by examining the dynamics of the reflected wave field. All the bright spots are situated at a depth of 300-900 metres below the sea-floor and three maps of the bright spots have been produced. The analysis of the noise/signal power ratio and frequency fields and the statistical method of assessing absorption coefficient have been used in order to assess the acoustic absorption of rock within these zones. The result is that the absorption constant within a bright spot is 3 to 10 times as much as that of the average over the rest of cross-section at the same depth. Elevated absorption indicates that density is reduced and can be used as reliable evidence of gas responsibility for the bright spots in the area.

The result of mineralogical analyses in turbidites from the central part of the Black Sea.

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Russia

The area of mud volcanic activity in the central part of the Black Sea was studied during several cruises of the Moscow State University (R/V *Akademik Petrovsky Feodosiya*) and the Training-Through-Research programme (R/V *Gelendzhik*). Cores obtained from abyssal plain beyond the mud volcanoes and from the top of the MSU and Vassoevich mud volcanoes contain sandy-silt layers. About 30 samples with sand and silt from 11 stations have been analysed by sieving, division in heavy liquid and microscope analysis. The purpose of this work has been to look at the distribution of sands and silts in the deep, less accessible part of the Black Sea and to define the sources for the material in particular areas of the sea floor.

Grain-size, mineralogical composition and content of heavy fraction have been defined and the results have been compared with those from other mineralogical provenances in the northwestern part of the Black Sea. I have used the minerals which are the most typical for different areas as the basis for quantitative correlation and comparison with the onshore provenances and with the similar provenances in the northwestern part of the Black Sea. Two distinct mineralogical provenances in the central part of the Black Sea have been identified using this technique.

New data on mud volcanism in the Black Sea region

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Russia

The mud volcanism in the Black Sea area has interested scientists since the second century. There are several areas which are characterised by manifestation of on- and off-shore mud volcanism and diapirism in the Black Sea region.

Onshore mud volcanism is displayed on the Kerch and Taman' peninsulas. The submarine area has been discovered in the southern part of the Sea of Azov and in the central part of the Black Sea. In addition, using seismic data, several areas of clay diapirism have been distinguished in the Black Sea. They occur near the depressions of Sorokin, Indol-Kuban' and Tuapse. These depressions were formed during Maikopian time (Oligocene-Early Miocene) and are characterised by a very thick sedimentary cover of the Maikop Group (up to 6 km). Thus, mud volcano and diapir structures form a belt of mud volcanoes and diapirism in the Black Sea region and mainly relate to the thickest ductile Maikopian sequence.

In the summers of 1991 and 1993 aboard the R/V Gelendzhik, geological and geophysical investigations were carried out, in the context of the UNESCO' s Training and Education in Marine Science (TREDMAR) Programme, to investigate mud volcanoes in the central part of the Black Sea. The area of development of mud volcanism in the central part of the Black Sea is very well displayed in relief through volcanic up-buildings of different shapes; the largest volcanoes are MSU and Yuzhmorgeologiya mud volcanoes (2.0 and 2.5 km in diameter, respectively).

Pelagic sediments show the normal stratigraphic and lithologic sequence of the deep-water Black Sea sediments with high accumulation rate and, at the same time, display relationships with mud volcanism in this region. This relationship is seen from the presence of slide and slump structures in sediments. These structures are related to the phases of mud volcano activity, which are respectively dated to the Late Pleistocene and Early Holocene. In addition, from a geochemical point of view, it is possible to distinguish two main factors that control the distribution of elements here (organic matter and carbonate sedimentation).

Sediments from some cores were extremely gas-saturated and contained gas hydrates. Gas analysis demonstrates that methane makes up to 98% of the total gas composition. Supposedly, a young biogenic gas is derived from Maikopian strata, which are extremely enriched in organic matter. The isotopic analysis of gas hydrates demonstrates stable volumes of $\Delta^{13}C$ from -63.3 to -61.8 ‰ (Ginsburg et al., 1990), which also indicates the biogenic origin of gas hydrates.

Rock fragments from mud volcano breccia are mainly represented by different types of siltstone, sandstone and carbonate rock. The dating by microfossil, pollen and spore and lithological analysis shows that siltstones were probably derived from the Maikop Group (Oligocene-Lower Miocene) and sandstones may originate from layers of Cretaceous (?) to Recent age. These ages are confirmed by the comparison of lithologic types of rock fragments from the Black Sea mud volcanoes with data from the Taman' Peninsula mud volcanoes and well-cores obtained during fieldwork last summer.

According to the morphologic patterns of volcanoes, the ages (by $\Delta^{14}C$ AMS) of their activity and the lithologic characteristics of breccia of mud volcanoes, at least two types of mud volcanoes can be distinguished in the studied area. The first type is the Tredmar type mud volcano that is active today and is characterised by the eruption of fine material (not coarser than sand fraction, less than 1mm) with a dominance of minerals in breccia up to 90% of the sand fraction and a high carbonate content (10-12% $CaCO_3$). The second type is MSU and other studied volcanoes. They are characterised by mainly Late Pleistocene and Holocene activity. The breccia contains primarily rock fragments which are represented by the coarse fraction (up to cobble). In addition, the breccia contains a low carbonate content (usually less than 1% of $CaCO_3$).

These data show that this area of mud volcanism has been active recently and that the mud volcanoes in proximity to one another have different patterns of activity and sediment composition, owing to differences in the structure of their maternal sequences.

SESSION 2: THE VALENCIA CHANNEL MOUTH AND BALEARIC ABYSSAL PLAIN

Cycle terminations in the Western Mediterranean

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Since the seawater returned from the Atlantic into the Mediterranean basin at the beginning of the Pliocene, there have been many sea-level fluctuations. These can be determined in the seismic data from the north-east of Menorca and cause unconformities and lapout structures on the sequence boundaries because of the movement of salt domes. ODP-site 372 and the seismic profiles obtained by exploring the site were used to define the Pliocene-Quaternary boundary and to date the cycle terminations.

Cores from sandy lobes on turbidity current pathways to the Balearic Abyssal Plain

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The two main environments for sand in the deep ocean are believed to be fills of aggradational channels and channel mouth lobes. On TTR4, Leg 3 we studied two areas identified as likely sandy channel mouth lobes. They appeared to be very different from each other.

West of Corsica and Sardinia there is a braid-like pattern of high backscattering. It is progressively less well seen on the 6.5kHz, 12 kHz and 30kHz side-scan sonar records, perhaps due to the 50cm or so of superficial muddy sediment cover that is not easily penetrated by high frequency sound. These cores are typically

4-5 m long with graded sand beds that are unusually thick for the deep ocean (up to 2.8m thick) and are unusually coarse grained (up to gravel size). The cause of the high backscattering was not immediately apparent.

Beyond the Valencia Channel there is a variety of bedform zones, from fields of large flute marks to trains of non-cohesive waves, to narrow "V" and chevron shaped "sand bodies". They are plotted from 12kHz, 30kHz and 100kHz side-scan sonar records and indicate an expansion of turbidity current flow beyond the mouth of the Valencia Channel. The flow may be waning as it approaches the flat basin plain. Cores averaged only 68 cm long. A thick pteropod layer (48 cm) may indicate the composition of the "V" shaped bedforms. The I.O.S. multi sensor split core logger was modified to take the very narrow (35mm) square section cores. The results of the P-wave, magnetic susceptibility and gamma radiation (bulk density) measurements are presented.

Turbidity flow processes interpreted from side-scan sonar images of the Valencia Channel Mouth, NW Mediterranean

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The Valencia Channel Mouth was studied as part of Leg 3 of TTR4, on board the R/V *Gelendzhik* in July 1994. The OKEAN (long range side-scan sonar, 15km swaths at 9.5 kHz) survey of an area between 4°40' to 6°10' E and 39°30' and 40°40' N, shows three main morphological regions: (1) a broad, shallow, asymmetric channel that feeds turbidity currents towards the south-east and is flanked by largely featureless overbank areas, with minor, blotchy variations in back-scatter and that passes down-fan; (2) an extensive area of regular "steaked" bedforms marked by lineations of contrasting high and low back-scatter, originating deep inside the mouth of the broad channel and diverging at an angle of up to 45° between either side of the survey area where to the south-east it passes into the next region; and (3) a region of large "chevron-shaped" bedforms of high back-scatter material on a background of low back-scatter, with the apices facing up-fan. Interpretation of the distribution of these 3 features suggests that turbidity currents are fed on to the distal Valencia Fan by the broad, shallow channel.

A MAK-1 (deep towed side-scan sonar, 100 kHz) survey was taken from east to west across the channel and shows it to be erosive, as it cuts into and truncates internal reflectors that are picked out in the sub-bottom profile (4.9 kHz). The channel base comprises a series of eroded, shallow, linear depressions floored by fields of large megaflute-like features. The divergent trend of the streak patterns indicates that the flows are no longer laterally restricted following their emergence from the mouth of the channel and may represent a field of braided distributary channels. A MAK-1 (30 kHz) survey was conducted in a flow normal orientation in region 3. The sea floor is flat and the sub-bottom profile indicates that the chevrons are positive (depositional) features, though very low in relief. The chevrons are up to 200 m across and are probably the down-flow development of the field of mega-dunes in the upper part of the image. It is inferred that these flows, emerging from the streaked region, become unrestricted and that sheetflow, with super-critical flow conditions, may have been achieved. A diamond-shaped pattern of flow surface disturbances may have been initiated in the flow by the emergence from the walls of the distributary channel mouths. This would explain the deposition of regular "V" shaped "sand" bodies beneath localities of lower bed shear stress, associated with the flow surface disturbances. The turbidity currents underwent rapid deflation and flowed at subcritical conditions on to the distal part of the Balearic Abyssal Plain.

SESSION 3: THE EAST AND WEST CORSICO-SARDINIAN MARGINS

Analysis of Late-Quaternary deep-sea benthic foraminifera from the Corsico-Sardinia region, related to some palaeo-oceanographic changes

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Benthic foraminifera were studied from two gravity cores, 138G and 139G, taken during TTR4 on the R/V *"Gelendzihk"*. Age determination of the cores was carried out on the ship by *E. Ivanova* and *A. Lototskaya*, based on studies of planktonic foraminifera and nanoplankton.

Core 138 is located on the east of Sardinia and core 139 on the west. A total of 55 samples were weighed, washed, dried and divided into 3 fractions: 63-125 cm; 125-250 cm; and >250 cm. Benthic foraminifera from all fractions were identified. Foraminifera (200 specimens or more from every sample) from the 125-250 cm fraction were used for quantitative analysis (relative frequencies and diversities were determined). The P/B ratio was calculated for all fractions. The number of identified species amounted to 38 and the most abundant species in these cores were *Cassidulina carinata, Cibicides pseudoungerianus, Melonis simplex, Gyroidinoides* spp.and *Bryzalina* spp..

Foraminiferal analysis of two cores from the central Mediterranean Sea

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The Netherlands

Within the framework of the program "Paleoceanography of the Mediterranean Sea", two cores located east and north-west of Sardinia were studied. The target of this programme is to study paleoceanographic changes in the Mediterranean during the late Quaternary. A time-frame is based on the following parameters:

1. Shipboard analysis of the calcareous nannoplankton. The base of the *E. huxleyi* acme zone (~73ka) could be identified in both cores;
2. The carbonate curve (this is a good proxy to identify glacial/interglacial periods);

3. The presence/absence pattern of *G. inflata* as described by Muerdter (1984). Typically this foraminifera is absent between 36ka and 13ka;
4. Calibration of the carbonate curve to the ^{18}O curve for the eastern Mediterranean as presented by Thunell (1978).

The abundances for six planktonic and benthic species were determined. For the planktonic species four groups were distinguished for tropical, sub-tropical, cool and "cold" conditions. By means of these criteria five time slices could be determined. The planktonic foraminiferal assemblages follow the changes from glacial to inter-glacial and vice versa.

Sedimentary processes on a steep canyoned slope west of Corsica and Sardinia

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Previous multibeam bathymetry and GLORIA surveys have shown that the western Corsica-Sardinia margin is characterised by a steep slope incised with numerous small canyons and gullies which transport sediment directly from the slope and terrestrial drainage basins to the Ligurian basin floor.

Two of the three MAK lines taken during the 3rd leg of TTR4 provide high-resolution side-scan images of the slope features, one from the very steep Nurra Escarpment, and the other traversing the Valinco Canyon. The data from the MAK sonographs allow features to be recognised which can determine the relative importance of the different processes active in redistributing sediment on the slope. These processes can be described as either "gravity collapse processes" (e.g. rock-falls, slides, scarps, glide blocks, etc.) or "sediment gravity flow processes" which include deposition, sediment reworking and erosion from sediment gravity flows. The features observed on the present-day slope-surfaces are a result of the activity of both types of sediment redistribution processes.

The extent and variation of many sediment disruption features across the slope, and their fresh appearance on the side-scan image, suggests that the slope is an area of complex sediment redistribution and that these processes have probably been highly active within the recent geological past.

SESSION 4: THE SOUTHERN TYRRHENIAN SEA

Geochemical studies of core 126G, Stromboli Canyon, SE Tyrrhenian Sea

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Nine cores were taken on the second leg of TTR4 on board the R/V Gelendzhik in the Tyrrhenian Sea in June 1994. In this study the upper 3 metres of core 126G taken from the inner bend of the Stromboli Canyon was investigated using geochemical and sedimentological data obtained through smear slide, XRF, CHN and SediGraph*5100 analyses. Core descriptions show the core to contain a dark turbiditic horizon, slumps, bioturbated muds and ash / silt layers.

Graphs of Al, Si, Ti, $CaCO_3$, Mn, Co, Ni, Zn, Fe, Mg, Cr, P, Ba, Sr, Na, K, Pb, Zr, V, As, Cu, Mo, Corg and S / Cl were plotted versus depth, element/element graphs of Na / K, Ba / Sr, P / Ba, P / Sr, Fe / Mg, Ti / Al were also drawn and showed linear relationships.

With reference to past studies it was recognised that the elements within this core were subject to several influences and controls. Smear slide analyses showed the turbidite to be volcaniclastic and certain elements within the turbidite were found to be controlled by the presence of volcaniclastic minerals. The profile patterns of Mn, Co, Ni, Cu, Zn and S / Cl showed that the turbidite had caused anoxia and subsequent diagenesis. Biogenic influences were seen to affect Ba, Sr, $CaCO_3$, P and Pb throughout the core.

Post-cruise processing of seismic data

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Because of the need for accurate interpretation, the processing of seismic data must be used to solve the following problems: improving the signal/noise ratio, improving the resolution and correcting the geometry of reflectors.

1. Normal Moveout Correction. This operation applies normal moveout correction from the constant velocity field. Normal moveout is applied according to the following formula;

$$T_X^2 = T_0^2 + X^2/V^2$$

T_x = the actual reflection time of the seismic event due to NMO effects

T_0 = the zero offset reflection time of the seismic event

X = the actual source-receiver offset

V = the NMO or stacking velocity for this reflection event

2. Stack of traces for each shot. This process vertically stacks input assemblages of traces. The straight mean stack sums the sample values and is divided by the number of samples summed raised to a user-supplied power (0.5 for square root of contributing sample count sealing). After this, the stack signal/noise ratio is improved to $N^{0.5}$ times.

We used a simple 2-D Median filter, which sorts the samples within the filter application window and passes on the median (middle) sample of the sorted array. This filter improves coherency of the traces.

3. Bandpass filter. This process applies a frequency filter or filters to each trace that is put into the system. The filter algorithm operates in the frequency domain. We used a single bandpass filter which was applied to all traces at all times. The Bandpass Filter cuts out the high-frequency noise.

4. Muting. This is a cosmetic procedure which cuts noise before the first break.

5. Deconvolution. The pressure wave from an air-gun shot is normally followed by a series of pressure pulses called bubble pulses. These are caused by successive oscillations of the globular mass of compressed air, called the air globe, that remains after the shot is completed. At the instant of minimum volume of the oscillating air globe, a positive pressure pulse is generated. Successive pulsations generate additional pulses, with each successive pulse being weaker than the preceding one.

The compression of impulse determines the selection of a prediction interval. The minimum prediction interval is to achieve the complete whitening of the impulse amplitude spectrum, leaving the zero of autocorrelation untouched. Such a procedure is called spiking. Deconvolution is called predictive with a longer predictive interval. We used spiking deconvolution to improve the resolution of the time section (roughly two times) and predictive deconvolution to neutralize the bubble pulse .

6. Migration. The result of migration processing stages is a time cross-section. Reflections are situated on the same vertical line not depending on the real position of reflectors. Migration can produce images with the correct position of reflectors from time seismic section.

Marine geology of an area of continental slope in the South-eastern Tyrrhenian Sea

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An area of continental slope in the south-eastern Tyrrhenian Basin has been investigated using side-scan sonar and seismic surveys. A highly varied and dynamic submarine topography that includes deep canyons, volcanoes, and steep, irregular slopes has been revealed. This project summarises the physiography and geology of the area and presents an understanding of some of the important dynamic processes operating there.

Lower parts of the continental slope reach a maximum depth of 3000 m in the north west, whilst Stromboli Island and the coast of Calabria represent the only land areas present. Dominating the physiography of the continental slope are the large, active Stromboli Canyon and the volcanic arc system of Panarea, Stromboli and Lametini.

Evidence has shown the large and still currently active Stromboli volcano to have highly unstable, steep slopes with large slumps and sediment chutes on its flanks. High resolution sonar images from the Stromboli Canyon have revealed large sediment waves, erosional scour features and steep scarp slopes. These records, representing some of the first high resolution sonar images to be obtained in the area, provide vital information for the interpretion of some of the large, and often highly erosive, turbiditic processes operating within the canyon. On muddy terrigenous slopes to the east, slump scars over 1000 metres across and channelled debris flows have been identified. These gravitational slope processes indicate the highly unstable nature of sediments on the continental slope.

Analysis of seismic data: its application for the reconstruction of the evolution of the Tyrrhenian Sea

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Part of Leg 2 of TTR4 on the R/V "*Gelendzkik*" was carried out in the southern Tyrrhenian Sea near the Marsili and Vavilov seamounts and also across the Sardinian margin. The geophysical investigations included multichannel seismic profiling and side-scan sonar surveys. The area is interesting to many researchers because the mechanism of the opening of the basin is not fully understood. It is known to have been related to horizontal movements under the influence of the African and European subduction zone. There are a range of models for the origin and development of the basin, of which the most popular is a back-arc basin. This model suggests two zones of spreading (the Vavilov and Marsili Basins) and a subduction zone (Aeolian Islands).

The seismic profiles show features which can be used to reconstruct some of the tectonic events that could be related to the evolution of the Tyrrhenian Sea. On the upper part of the Sardinian margin, (line 145) there are strongly deformed layers complicated by sub-vertical faults. This may be a zone near the axis of the rift that began to open in the Tortonian. Alternatively, the rifting can be interpreted from the presence of pre-rift, post-rift and syn-rift sediments which are characterised by an increase in thickness with dip (line 142).

Interestingly, there are many sub-meridinal faults across the area under investigation. They may be parallel to the axis of rift in the passive Sardinia margin and they originated from east-west stretching during the rifting. Further away from the axis, they begin to trend eastward and may be connected with the rotation of some of the blocks.

A sedimentological investigation of cores TTR4-128G and 129G from the Glauco Seamount (Southernmost Tyrrhenian Sea): first results

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UK

Sedimentological and geochemical investigations have been carried out on 72 samples from two cores collected during the oceanographic cruise TTR4 on board the R/V *Gelendzhik* in the southernmost Tyrrhenian Sea. The cores are located along the northeastern flank (core 128G) and top (core 129G) of the Glauco seamount, southwestern end of the Marsili basin. The sedimentation in this area is hemipelagic. These sediments contain several ash fall and tephra layers related to the volcanic activity of the Eolian arc, combined with distal volcaniclastic and terrigenous turbidites issuing into the area via the Stromboli Canyon and a number of minor canyons radiating from the Eolian arc. The Glauco cores are dominated by hemipelagic sediments which appear locally oxidized. Interbedded with the hemipelagic sediments are brown silty layers which are glass and quartz-rich. These were described on board-ship as distal volcaniclastic turbidites.

The purpose of this study was to identify the number of turbiditic events recorded in the sediment column and to determine their provenance. Grain-size analyses were carried out using a Sedigraph 5000ET. Smear-slides and X-Ray Fluorescence analyses were used to determine major, minor and trace elements. The sandy residues were investigated using a binocular microscope.

The results from the grain-size analyses and smear-slide/residue investigation indicated a prevalent hemipelagic sedimentation interbedded with a number of ash fall and tephra layers some of which are clearly reworked in the core 128G (on the Glauco flank). No distal turbidites were detected. The following is a resume of the main sedimentological and compositional characteristics observed in the sediments recovered.

Hemipelagic sediments: nannofossil ooze foraminifer- and pteropod-rich. Aeolian quartz and micas often present. The sediment is light in colour (10YR 5/4 yellowish brown*) ungraded and bioturbated. Locally pyritized intervals have been observed. The grain-size distribution is characterized by small fluctuations in sand and silt distribution and the grain-size frequency distribution curves (grain-size spectra) show multi-modal curves that reveal the presence of shells of various sizes.

Ash fall and tephra layers: composed of thin elongate angular glass with elongate vesicles or by angular blocky glass with spherical vesicles and biotite. Forams are always present. The sediment is brownish or dark brown (2.5Y 4/2 dark greyish brown*, 5Y 2.5/1 black*), typically inversely graded with gradual base. The grain-size distribution is characterized by positive picks in both sand and silt distribution (tephras) or on the silt distribution only (ash layers). Spectra are very similar to the hemipelagic ones that reveal the presence of glass of various size.

Reworked tephra layers: observed in core 128G only and are composed of elongated or blocky glass, often broken, and mica biotite. Foraminifera and aeolian quartz are also present. The sediment is brownish (2.5Y 4/2 dark greyish brown*) with sharp base. In the coarser-grained and thicker layers a normal grading is evident. The grain-size distribution reveals positive picks in sand and/or silt and spectra show repetitive modes within the reworked interval.

*from Munsell Soil Colour Chart

Sandy and silty layers in the Holocene-Upper Pleistocene sediments of the Marsili Basin (The Tyrrhenian Sea). Their origin, composition and possible sources

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Russia

Geological sampling carried out during the 2nd leg of the TTR4 Cruise in the area of the Marsili Basin produced 9 cores containing about 70 sandy and silty layers. A total of 25 samples were studied for their grain-size distribution and mineralogical composition.

The methods used included detailed core description on board the ship, sieving of sands and silts, extraction of heavy fraction from these sands and silts, and microscope investigations of the obtained fractions. Normally, the above-mentioned sandy and silty layers represent different types of gravity flows. More often, they are turbidites, and sometimes grain-flow deposits and debrites.

The differences between turbidites, grain-flow deposits, and debrites are clearly shown by the cumulative curves. The main components of sands and silts are volcanic glasses, which can be divided into felsic and mafic, according to their composition. The most common are felsic glasses that are mainly fragments of andesitic, ryolithic pumices or shards of the same composition. The amount of such felsic glasses is about 90%. Mafic glasses are usually represented by fragments of sideromelan.

Felsic glasses are the main components for almost all sandy layers studied in this area, but some sands have other compositions. Such sandy layer have been described in the cores obtained from the area, which is located close by the Marsili Seamount. Fragments of the mafic glasses are usually presented by sideromelan, and they are the main components of these sands. In addition to volcanogenous components, there are typical terrigenous ones, such as, quartz, biotite, chlorite, epidote, garnet, rutile and others.

The principle source for these sands and the silts in the Marsili Basin, on the basis of sand and silt composition, is the eroded volcanogenous rocks of the islands of the Eolian Arc. The Marsili Seamount can be proposed as a source for black sand layers, which have been described in core 127. The South Apennines and the offshore part of Calabria are the sources for terrigenous material, which plays an insignificant role in the sedimentation in this area.

Tectonic control on sediment transport in the Marsili Basin, SE Tyrrhenian Sea

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UK

In 1994 two oceanographic cruises on board the R/Vs *Gelendzhik* and the *Urania*, in the south-easternmost part of the Tyrrhenian Sea, aimed of investigate the mechanisms of transport and redistribution of sediment in small ocean basins such as the Marsili Basin, a part of the Tyrrhenian sea.

Sediment input into the basin is mainly from the Stromboli Canyon which represents the primary conduit through which sediments, coming from the basin margin and upper slope, are transported towards deep environments. The Eolian arc produces large volumes of pyroclastic sediment which accumulates on the upper slope, making it inherently unstable. Frequent earthquakes, related to the convergence of the African and European plates, cause regular collapse of the Calabrian margin into tributary canyons and the Sicilian margin into upper reaches.

Fourteen cores have been collected with a total sediment recovery of 57 m. Two types of turbidite beds have been described: "volcaniclastic", rich in volcanic glass, which comes from the Eolian volcanic arc; and "terrigenous", containing minerals from metamorphic terrains which come from the Calabrian and Sicilian continental slope and are transported along tributary canyons into the Stromboli Canyon.

The sediments recovered and the seismic lines provide strong evidence of slope instability of the Italian continental margin, the Eolian arc slopes and the Lametino Seamount slopes where there is clear tectonic control on the morphology.

SESSION 5: THE EASTERN MEDITERRANEAN AND MEDITERRANEAN RIDGE

The Eratosthenes Seamount: results of the seismic data processing

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A seismic survey was carried out in the region of the Eratosthenes Seamount in the easternmost part of the Mediterranean Sea in 1993 (TTR3). The aim was to obtain data about the shallow structure of this seamount which would help to locate the drilling sites for the ODP program in 1995. However, some fine details of the structure of the upper sedimentary cover were not seen on initial seismic sections because of poor resolution, low signal/noise ratio and some artefacts.

To improve the quality of these seismic sections and to provide a more detailed imaging of separate reflectors, the most interesting parts of profile PS-120 were selected for processing. The post-processing consisted of: SEG-Y input, normal move-out correction, stack, normalising to a single time, amplitudes recovery, predictive deconvolution, wavelet estimation, dephazing, zero-phase deconvolution, bandpass filtering, migration, and coherency enhancement. The resolution was increased approximately 2 times after the deconvolution and air-gun bubble pulse was removed. Some interesting details concerning the sedimentary cover and the basement rock appear after the processing due to deconvolution and coherency enhancement. It can be concluded that such processing helps to interpret seismic data more comprehensively.

The lithology of mud breccia from the new Western Mediterranean Ridge mud volcanoes

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During the study of a portion of the Western Mediterranean Ridge on the R/V *Gelendzhik* in the summer of 1994 (TTR4), a few domes were discovered near the well-known Cobblestone Area 3 Diapiric Field (Cita, M.B. and Camerlenghi, A., 1990).

Five cores were obtained from different dome-shaped structures using gravity coring techniques and standard descriptive methods. Three of the cores contain a lithologic unit which consists of a mud matrix and pluri-centimetric to millimetric clasts from a variety of source rock (mud breccia). The mud breccia is unconformably overlain with a veneer of Holocene pelagic sediment, dominated by ooze and marl lithologies.

A structural, visual and analytical comparison of mud breccia obtained from different, newly discovered mud volcanoes was made on the basis of a precise description of thin sections and x-ray data. These studies indicate similarities between the mud breccia in core TTR4-162G (Aros mud volcano) and that in core TTR4-164G (Novorossiysk mud volcano), and differences with the mud breccia in core TTR4-160G. The data analysis suggests a complex origin of mud diapirism on the Mediterranean Ridge.

Sidescan sonar data processing: applications for geological interpretation

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Digital side-scan sonar image processing techniques have been developed for different side-scan sonar systems to produce data ready for geological interpretation. Generally, for all systems, the main steps of side-scan sonar data processing are the same: Filtering, Smoothing, Slant-Range Correction, Time-Varying Gain and Angle Gain Normalisation Mapping, but there may be some differences related tothe working parameters.

MAK-1 deep-towed acoustic system, used during the TTR4 cruise, consists of high resolution side-scan sonar operating on 30 or 100 kHz and 4.7 kHz sub-bottom profiler. Thus, processing tools of this system can be divided on two groups: side scan sonar processing functions and sub-bottom profiler processing functions. The first includes all standard tools and an improved radiometric correction to normalise angle-dependent back-scatter intensity variations. The second group involves correction for vertical position of vehicle, smoothing and removal of delays. These functions were applied to sub-bottom profiler records.

As an example of MAK-1 processing data, using routines written by the author, a digital mosaic of two side-scan sonar lines from the Marsili basin (Mediterranean Sea) was presented.

Planktonic foraminifera in the pelagic sediments from the Olimpi mud diapiric area (Eastern Mediterranean)

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Core 80G from the Moscow dome of the Olimpi mud diapiric area (Eastern Mediterranean, TTR-3 cruise, 1993) recovered 499 cm of mostly pelagic sediments. It contains three sapropels and one tephra layer. The sapropels were initially described onboard as S_1, S_5 and S_6. The tephra layer was identified as Y_5.

The detailed study of planktonic formanifera shows strong changes in its assemblage along the core. Relatively warm intervals are represented in the core by the sediments from 341 cm to 191 cm and from 71 up to the top with a short break around 81-91 cm from the core top. They were accumulated during oxygen isotopic stages 5 and 1 respectively. The foraminiferal assemblage consists mainly of species such as *Gs. ruber*, *Gs. sacculifer*, and *Gl. aequelateralis*. These intervals alternate with others characterised by large amounts of temperate water species, such as, *O. universa*, *G. glutinata*, and *Gl. inflata* and the cool-water species *N. pachyderma*, *G. bulloides*, *T. quinqueloba*, and *Gl. scitula*.

The sapropels were confirmed to be S_1 by relatively warm assemblage of planktonic foraminifera with a dominance of *Gs. ruber* and a large number of *O. universa*, *G. glutinata* and *G. bulloides*. The percentage composition of *Gs. ruber* reaches 68.7% from the total assemblage which is the highest number for all of the samples. This is in agreement with data of some other researchers (Violanti et al., 1991). The S_2, S_3 and S_4 layers are missing in the core. The next sapropel layer down core after Y_5 tephra layer is S_5. The planktonic foraminifera assemblage is dominated by warm water indicators; other species making up less than 50% of it. Many of the warm water species such as *Gs. sacculifer*, *G. rubescens* and *G. digitata*, appear and reach their maximum abundance in this interval. The lowermost sapropel layer in the core is identified as S_6 because of its thickness and the presence of two sublayers which characterise this sapropel. S_6 is considered to have accumulated during cold climatic conditions (Parisi, 1987). It contains a very specific assemblage of planktonic foraminifera with a very low diversity (4 compared to 5 for S_1 and eleven for S_5), a high bioproductivity (foraminifera number 100,326 compared to 1,858 for S_1 and 3,712 for S_5) and a dominance of cool water species, mainly *T. quinqueloba* and *G. bulloides*. It also contains a large number of *N. dutertrei*, which is an indicator of low surface water salinity (Cita et al., 1977; Thunell, Williams, 1982).

The age of the sapropels and Y_5 tephra layer is known to be 9-8 ka for S_1, 126-116 ka for S_5 (Parisi, 1987), 180 ka for the top of S6 (Parisi et al., 1987) and 40 ka for Y5 (Cita et al., 1977). Accumulation rates can be estimated, for the upper part of the core, from S_1 down to Y_5 - 3.7 cm/1000 years and, for the lower part, from S_5 down to S_6 - 2.6 cm/1000 years (the part in the middle is probably incomplete because S_2, S_3 and S_4 were not represented in the core).

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Response of calcareous nannofossils to the climatic changes over the last 200 kyrs in the Eastern Mediterranean: detailed study of core TTR3-80G

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The Netherlands

The deep-sea core TTR3-80G from the Mediterranean Ridge plateau (south of Crete; 33°39'00N 24°34'72E) was chosen for a quantitative study of calcareous nannofossils to provide a detailed biostratigraphic framework for further research. This hemipelagic core contains a time record extending over the past 200 kyrs and includes a "marker-bed" (manganese-rich thin black layer, dated at 4 kyrs BP), a tephra layer Y_5 (40 kyrs BP) and the sapropels, identified by their assemblages of planktonic foraminifera and calcareous nannofossils, S_1, S_5 and S_6.

Standard stratigraphic time framework for the core is provided by correlation of isochronous lithologies and standard nannofossil biostratigraphy. The core sediments are represented by two biozones: *Emiliania huxleyi* and *E. huxleyi* Acme. The beginning of the *E. huxleyi* Acme zone, determined by the dominance of *E. huxleyi* in the coccolith assemblage, is calibrated with isotope/faunal stage 4 (53-54 kyrs BP).

Changes in abundance of different calcareous nannoplankton species or pairs of species through the core gives the opportunity to reconstruct the fluctuations between glacial and interglacial conditions over the last 200 kyrs: Riss Glaciation (approximately 200-127 kyrs BP), Termination II (127-104 kyrs BP) and Wurm glaciation (approximately 104-10 kyrs BP). A short return to the warmer conditions during the Riss glaciation occurs at about 164-150 kyrs BP, and during the Wurm glaciation, around 40 kyrs BP. These boundaries are estimated using the sedimentation rates (2.2-2.5 cm/kyr during the Pleistocene). It does not appear possible to determine stages of the last deglaciation (last 15 kyrs) on the basis of coccolith assemblage changes because of relatively low sedimentation rates.

Each sapropel recovered in the core is characterised by peculiar assemblages of calcareous nannofossils differing from the upper and lower layers. "Warm" sapropels S_1 and S_5 are marked by a peak in *Florisphaera profunda* and a decrease in *Helicosphaera carteri* abundances. Inside sapropel S_5, the lowermost part seems to be the warmest (by the increase in *Florisphaera profunda* numbers). "Glacial" sapropel S_6 is represented by a peak in *H. carteri* and can also be divided into two intervals of different palaeoconditions.

The core reveals a great abundance of redeposited Miocene-Pliocene calcareous nannofossils which probably originated from the Moscow mud volcano. The absence of this material in the sapropel layers shows that sapropels were probably deposited under the stagnant anoxic conditions when there was no transportation of material on the sea-floor.

Inorganic Geochemistry of Organic-Rich Sediments: Palaeoceanographic Evidence from the Eastern Mediterranean.

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UK

In the Neogene sedimentological record, organic-rich sediments, termed sapropels (Kidd *et al.*, 1978), have been recovered from a number of semi-enclosed marginal seas and basins these have been compared with the black shale sequences from the geological record. Detailed research has failed to fully comprehend the significance of these sediments. Clearly they represent abrupt changes in palaeoceanography and are essential components for the reconstruction of palaeoclimates and the consideration of global change.

In this contribution geochemical data are presented from sapropels recovered from the eastern Mediterranean during the TTR3 cruise aboard the R/V *"Gelendzhik"*. Major oxides and some minor elements were determined by ICPAES, and REE. The elements, U and Th were determined by ICPMS. Organic carbon determinations were carried out on a CHN analyzer. Sedimentological analyses were carried out by sedigraph.

The sediments from the Eratosthenes Seamount show that the sapropels present have complex and distinct geochemical signatures as compared to the intercalated calcareous oozes. Furthermore the different sapropels exhibit differing geochemical signatures suggesting different modes of genesis.

The geochemical signature of the most recent sapropel S_1, deposited approximately 7-10 Ka ago, suggests an increased productivity with oxic bottom waters during deposition. This casts doubt on the traditional anoxia model and suggests that S_1 accumulated as a consequence of enhanced photic zone productivity in a fully oxic water column. In contrast, another sapropel, S_5, deposited some 125 Ka ago, has a geochemical signature that suggests the presence of bottom water anoxia, supporting the anoxia hypothesis, with concomitant indications of enhanced productivity.

Geochemical signatures such as these indicate that conditions for the genesis of these sapropels are far more complex than has previously been thought. In order to fully understand the significance of sapropels it needs to be appreciated that there is not necessarily one model that accounts for their formation.

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Discrimination of mud flows of the Mediterranean Ridge mud volcanoes on the basis of MAK-1 sonograph analysis

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Mud volcanoes on the Mediterranean Ridge were investigated using multichannel seismics and swath survey with the OKEAN long-range side-scan sonar and MAK-1 deep-towed system during TTR3 and TTR4 of the R/V *Gelendzhik*.

Investigations with the MAK-1 system provided more detailed information about the mud volcanoes. The mud volcanoes on the Mediterranean Ridge can be distinguished according to their morphology and possibly from the time of their origin. It would be interesting to know whether they originated instantaneously or through a number of sequential mud-volcano eruptions which added to their superstructure.

The images of the mud volcanoes from the Olimpi area, south of Crete and from the Cobblestone area, west of Crete have been analysed. Applying image-processing, including median filtration, minimum filtration and histogram equalisation, mud flows of different generations and connected with certain stages of mud volcanic activity have been distinguished with sufficient precision. Old flows of the mud volcano should have a smoother surface as a result of erosion caused by submarine streams. Also, the older the flow, the thicker the overlaying pelagic sediments should be. Each of these reasons, or both of them together, may result in older flows having lower backscattering. Therefore, the main sign for distinguishing the generations is their difference in the level of backscatter.

It is possible that eruptions of the investigated mud volcanoes occurred in several stages. The images show that the areas covered by flows are reduced gradually from one stage to another. This could be explained by either a reduction in their activity or an increase in the viscosity of the erupted mud.

Grading in mud volcanic breccia

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The objective of this analysis of mud breccia, sampled from the crest of the Mediterranean Ridge, is to determine whether the flow-like features in the mud diapir fields are caused by extrusion, resulting in debris flows or by intrusions of mud breccia. Descriptive sedimentological and quantitative analyses, such as the ratio of clasts versus mud in different levels of the flows, were performed on the mud breccia recovered in 19 cores: 5 cores from the large flat-topped Moscow dome and 2 cores from the cone-shaped Leipzig mud volcano, obtained during the TTR3 cruise; 1 core from the Milano dome, 3 from the Bergamo dome, 1 from the Napoli dome and 1 from the Monza dome, all from the Prometheus 2 area, obtained during cruises BAN88 and BAN89.

Macroscopic examination showed that there were no big clasts in the mud breccia in most of the exposed cores in the top and bottom of the mud flows, at the boundaries with the hemipelagic clay. After sub-sampling and grain size analyses, it became obvious that there were graded beds at these boundaries. Grading in clast size has been observed in the top and bottom parts of mud flows and is considered to be the result of extrusion just beneath and above the contact with the adjacent hemipelagic sediments. For mud flows resulting from extrusion, a sequence has been defined with three intervals consisting of graded beds at the top and bottom of the flow, separated by a massive intermediate part. The composition of the clasts show five lithologies of which the main bulk consists of silty mudstone. The flow-like features are mainly the result of extrusion processes or reworking processes like debris flows.

The results of grain-size and mineralogical analyses of sediments in the distal part of the Ajaccio Canyon

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During the third leg of TTR4, the Ajaccio Canyon and its basinward extension were studied using the long-range side-scan sonar OKEAN, the deep-towed MAK-1 acoustic system (side-scan sonar and sub-bottom profiler) and multichannel seismic profiling. Ten gravity cores were also taken in the study area. The points of sampling were chosen according to the MAK-1 sonograph data.

MAK-1 line 28 crossed the area of well-defined belt of longitudinal, so-called braid-like bars on the distal floor of the trough. The belt extends from the foot of the Sardinia slope to the foot of the Rhone Fan. The braid-like bars, or stringers, are highly-backscattering bedforms divided by narrow strips of low backscattering. Four gravity cores taken in the area of the stringers recovered sediment, comprising several layers of sandy turbidites (up to 2.5m thick), interbedded with thin pelagic sediment. Two cores taken in the middle part of MAK line 29 overlap with the OKEAN profile, and also produced thinner turbidites.

Grain-size and mineralogical analyses of 60 samples taken from turbiditic layers and interbedded pelagic sediment (cores 141-146) were carried out in order to model the processes that form the braid-like bars and to study them as possible analogues to hydrocarbon reservoirs.

This report contains the results of statistical processing of grain-size analysis data and comparison of parameters of these sequences with parameters of analagous ones which host hydrocarbon accumulations. Quantitative data is also used to make correlations between the average grain-size of the sediment and its reflection on the sonographs.

Tracing a seasonal upwelling by means of the Aquaflow System, NW Indian Ocean

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Past and present oceanic productivity of the oceans shows a wide range of variation. At present, most high productivity areas are found in upwelling regions, generally situated at western margins of the continents (e.g. Peru, Gulf of California, Southwest Africa). An exception to this is provided by the monsoon-induced upwelling system in the northern and especially northwestern Indian Ocean.

For a better definition of palaeo-upwelling systems, detailed knowledge of the present-day dynamics, processes and sediments of upwelling systems is considered of key importance. The NW Indian Ocean, e.g. the Somalia Basin and the Arabian Sea, has properties that are unique in the world, namely a seasonally reversing monsoonal wind system which leads to seasonal upwelling off Somalia, Yemen and Oman. To study these processes, two cruises were held, one (C1, August 1992) during the upwelling season off Somalia, Oman and Yemen, the second (C2, February 1993) during the non-upwelling period and visiting partially the same stations.

Below are described the studies at the surface water carried out during cruise NIOP C1/C2, and the preliminary results and conclusions.

The aquaflow system is a ship-borne instrumentation system designed for the constant measurement of conductivity, temperature, dissolved oxygen content and chlorophyll concentration of seawater at +/- 5m water depth. Changes in temperature, salinity, dissolved oxygen and chlorophyll concentrations can be traced online. During C1 (upwelling period), a major coastal upwelling zone (low temperatures, high chlorophyll content) was traced in the Yemen area and minor zones were found in the Somalia area. In contrast to the results of C1, the temperature, salinity, chlorophyll and dissolved oxygen during C2 (non-upwelling period) do not show much variation. Locally, there may be an effect of updoming. Surface water temperature variations are very small and temperatures range from 25.5 to 26.5°C.

Subaerial exposure in relation to depositional geometry (the Mid-Cretaceous sea level project), N. Italy

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As part of the Mid-Cretaceous Sea Level Project, three sections of the Friuli Carbonate Platform (N. Italy) were measured. The objective was to investigate some Cretaceous sedimentary cycles, in order to establish the role of changing accommodation (global eustacy and local to regional tectonism) and sedimentation (environmental) rates in depositional geometry. This is done by correlating timeequivalent carbonate platform top, platform margin and deep-water sediments in several Mid-Cretaceous basins around the world.

The Fruili Carbonate Platform (Northern Italy) is one of the localities in this project. The platform top is exposed at Val Cellina, the margin at Monte Tremol (Monte Cavallo Group) and the basin at Cismon. These three sections hold previously documented events which provide data for stratigraphic correlation. The sections (+/- 150m stratigraphy each) were measured and described bed for bed and hand samples were taken (+/- sample resolution). This precision is needed in order to identify features that will aid in interpreting depositional packaging as well as aiding correlation. Several geological methods are used and combined so that a wide array of evidence can be obtained. The most important of these are: event bracketting, biostratigraphy, chemostratigraphy and cyclostratigraphy.

The Mid-Cretaceous sea level project is performed by a team of research associates including Bruce W. Fouke, Yuri Podladtchikov and Sandra Nederbragt, in close cooperation with geologists who have knowledge of the general geologic framework of the project areas. For the Friuli Platform part of this project three students (Olaf Duizendstra, Wouter Ordelman and Goof Buijs) are added to the team.

The origins and implications of sheeted dyke intrusion directions: MOR geology in Cyprus

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A major proportion of the oceanic crust is made of sheeted dykes which are generally believed to intrude vertically upwards, from (often) continuous subaxial magma chambers. The origin is in contrast to observations in active rift zone volcanoes from intraplate settings (Hawaii) or divergent plate boundaries (Krafla/Iceland), where dikes intrude horizontally outwards from the volcano, as vertically aligned blades. The latter mechanism is also viable for mid-ocean ridges (MORs), but in the absence of any other data on intrusion directions from mid-ocean ridges, either hypothesis is equally possible. Horizontal intrusive directions imply a focused magma generation at MORs, while vertically upward intrusive directions favour a continuous magma supply. Distinction of these hypotheses is fundamental to our understanding of MORs.

In an attempt to provide "ground-truth" for these questions, we studied flow directions of dykes in the upper portion of a sheeted dyke complex and the extrusive series of Cyprus, using structural techniques and measurements of the Anisotropy of the Magnetic Susceptibility (AMS). Our study focused on dykes in the region of the Kampia massive sulphide ore body. We determined the attitudes of at least 280 dykes, where approximately 80 displayed mesoscale flow indicators such as elongated vesicles or flow lineations on the quenched margin-surfaces of dykes (hot slickensides). Most dykes studied are steep (>75°) and parallel to the main trend of Troodos sheeted dykes (NNE-SSW) and few dykes trend NS dipping 60° towards the east. Mesoscale flow indicators indicate a wide range of flow directions with a slight preference for shallow to intermediate angles (30-70°).

About 800 oriented samples were taken from the margins of 67 dykes, and AMS measurements resulted in approximately 55 meaningful flow lineations. This

AMS data generally confirm vesicle lineation data, but some inconsistencies were found with striations on quenched dyke margins. We observed a tendency towards shallow intrusive directions high up in the sheeted dyke complex and steeper to vertical directions in the massive sulphide ore body.

Our data are consistent with vertical intrusive directions near an extrusive centre supporting the Kampia hydrothermal system, with horizontally intruding dykes running to and along the deposit from the intermediate to shallow extrusive series. This shows that intrusive and extrusive centres can be separated from each other. Our data also shows that dykes in Cyprus did not simply intrude vertically upwards as it might be expected from traditional simple models of mid-ocean ridge intrusive behaviour, but that there is a very complex plumbing system involving horizontal and vertical intrusion directions. This suggests that our intrusive models of magmatic spreading centres may have to be revised.

ANNEX I

Programme

Monday 30th January

09.00 Opening Remarks. Professor Brian Smith

10.00 Official opening
Stephen Morris. Chairman
Professor David Rickard. Head of Department of Earth Sciences
Professor Brian Smith. The Principal. Cardiff University of Wales
Dr Adrian Cramp. Head of Marine Geosciences Research Group
Dr Alexei Suzyumov. UNESCO

10.40 SESSION 1: THE BLACK SEA
Chairperson: *Bryan Cronin*

Michael Ivanov - Comparative characteristics of Mediterranean and Black Sea mud volcanoes
Serguei Bouriak - Acoustic images probably connected with gas charge: the evidence of gas responsibility for bright spots
Elena Kozlova - The result of grain-size and mineralogical analyses in turbidites from the central part of the Black Sea
Eugene Basov - New data on mud volcanism in the Black Sea region

12.25 - 12.40 Coffee/tea break

12.10 SESSION 2: THE VALENCIA CHANNEL MOUTH AND BALEARIC ABYSSAL PLAIN
Chairperson: *John Woodside*

Anatoly Limonov - The Valencia Fan: does it really exist? (no abstract submitted)
Eelco Felser - Cycle terminations in the Western Mediterranean

14.00 - 15.00 LUNCH

15.00 Session 2 continued
Neil Kenyon - Cores from sandy lobes on turbidity current pathways to the Balaeric basin plain
Stephen Morris, Neil Kenyon and Alberto Palanques - Turbidity flow processes interpreted from sidescan sonar images of the Valencia Channel mouth. NW Mediterranean

15.55 SESSION 3: THE EAST AND WEST CORSICO-SARDINIAN MARGINS
Chairperson: *Bryan Cronin*

Ekaterina Nezlina - Analysis of Late Quaternary deep-sea benthic foraminifera from the Corso-Sardinian region related to some palaeoceanographic changes
Anja Oosting and Jasper van der Hoef - Foraminiferal analysis of two cores from the central Mediterranean Sea.

Julian Clark - Sedimentary processes on a steep canyon slope west of Corsica and Sardinia

Tuesday 31st January

09.30 SESSION 4: THE SOUTHERN TYRRHENIAN SEA
Chairperson: *Stephen Morris*

Alison Jones - The geochemistry of core 126G, Tyrrhenian Sea
Pavel Shashkin and Ilya Korotkov - Processing of seismic data from the south-eastern part of the Tyrrhenian sea
Martin Gee - Marine geology of an area of continental slope in the south-eastern Tyrrhenian Sea

10.35 - 11.25 Coffee/tea break

11.25 Session 3 continued
Evgeniya Shelavina - Analysis of seismic data: its applications for the reconstruction of the evolution of the Tyrrhenian Sea
Geert de Vries and Renata Lucchi - First results of sedimentological analysis of cores 128G and 129G
Andrei Akhmetjanov - Grain-size distribution and composition of silts and sands from the Tyrrhenian Sea

12.20 SESSION 5: THE EASTERN MEDITERRANEAN AND MEDITERRANEAN RIDGE
Chairperson: *Simon Wakefield*

Ilya Korotkov - The Eratosthenes Seamount: results of seismic data processing
Tatyana Rodionova - Organic carbon quality study in marine sediments
Grigorii Akhmanov - The lithology of mud breccia from the new Western Mediterranean Ridge mud volcanoes
Alexander Volgin - Sidescan sonar data processing: applications for geological processing

13.40 - 14.45 LUNCH

14.45 Session 5 continued
Ekaterina Ivanova - Planktonic foraminifera in the pelagic sediments from the Olimpi mud diapiric area (Eastern Mediterranean)
Anna Lototskaya - Response of calcareous nannofossils to the climatic changes over the past 200 kyrs in the Eastern Mediterranean: detailed study of core TTR3-80G
Gerard O'Sullivan, Adrian Cramp and Simon Wakefield - Inorganic geochemistry of organic-rich sediments: palaeoceanographic evidence from the Eastern Mediterranean

15.45 - 16.10 Coffee/tea break

16.10 Session 5 continued
Ekaterina Akentieva - A detailed study of the mud volcanoes and associated features: their morphology and distribution on the Mediterranean Ridge (sidescan sonar data from 1993/94 cruises, Eastern Mediterranean)
Rudie van der Meer - Grading in mud volcanic breccia

17.15 Demonstration of an experimental turbidity current in the Cardiff Sedimentology Laboratory; *Stephen Morris*

Wednesday 1st February

10.00 SESSION 6: OTHER GEOGRAPHICAL REGIONS
Chairperson: *Bryan Cronin*

Seger van den Brenk - Tracing a seasonal upwelling by means of the Aquaflow system, NW Indian Ocean
Goof Buijs, Olaf Duizendstra and Wouter Ordelman - Subaerial exposure in relation to depositional geometry (the Mid-Cretaceous Sea-Level Project), N. Italy

11.00 SLIDE AND VIDEO SHOWS

Stephen Morris - Conglomeritic channel infills from the Plio-Pleistocene of Central Greece
Stephen Morris - Some TTR4 slides
The TTR4 video

12.30 - 14.00 LUNCH

14.00 Visit to the National Museum of Wales

Thursday 2nd February

Field trip: The Caban Conglomerate Formation, Rhayader, Mid Wales
Leaders: *Bryan Cronin and Stephen Morris*

Friday 3rd February

10.00 Field trip to Penarth, to see upper Mercia Mudstone Group, Rhaetic and Lower Liassic rocks

19.00 Social Events

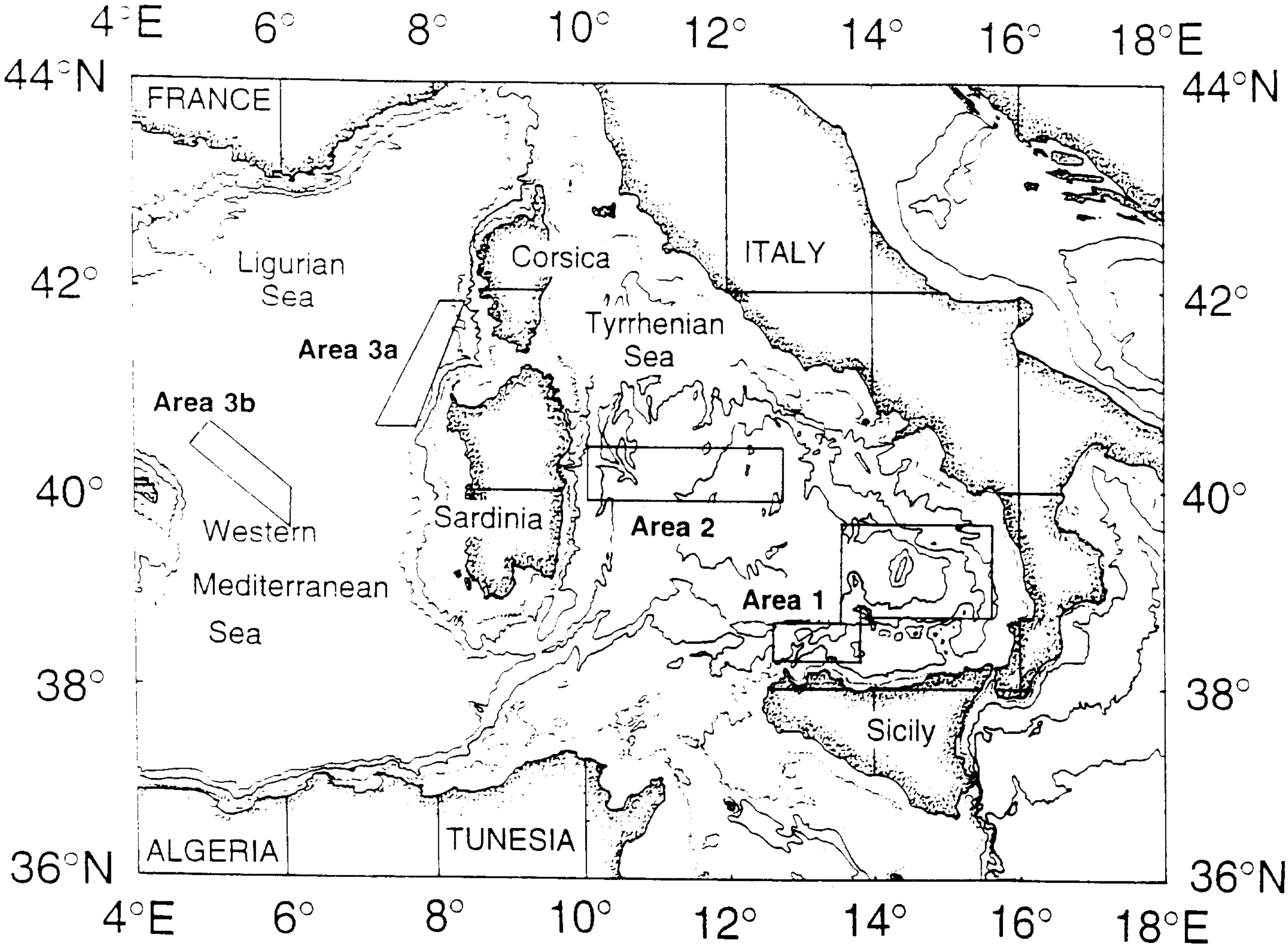
ANNEX II

Post-Cruise Meeting Participants

Micheal Ivanov (Moscow State University, Russia)
Anatoly Limonov (Moscow State University, Russia)
Serguei Bouriak (Moscow State University, Russia)
Tatyana Rodionova (Moscow State University, Russia)
Pavel Shashkin (Moscow State University, Russia)
Evgeniya Shelavina (Moscow State University, Russia)
Andrei Akhmetjanov (Moscow State University, Russia)
Grigorii Akhnanov (Moscow State University, Russia)
Ekaterina Akentieva (Moscow State University, Russia)
Eugene Basov (Moscow State University, Russia)
Alexander Volgin (Moscow State University, Russia)
Elena Kozlova (Moscow State University, Russia)
Ekaterina Nezlina (Moscow State University, Russia)
Ilya Korotkov (Moscow State University, Russia)
John Woodside (Free University, Amsterdam, The Netherlands)
Anja Oosting (Free University, Amsterdam, The Netherlands)
Jasper v d Hoef (Free University, Amsterdam, The Netherlands)
Ekaterina Ivanova (Free University, Amsterdam, The Netherlands)
Anna Lototskaya (Free University, Amsterdam, The Netherlands)
Seger v d Brenk (Free University, Amsterdam, The Netherlands)
Rudie v d Meer (Free University, Amsterdam, The Netherlands)
Paul Verweij (Free University, Amsterdam, The Netherlands)
Goof Buijs (Free University, Amsterdam, The Netherlands)
Olaf Duizendstra (Free University, Amsterdam, The Netherlands)
Eelco Felser (Free University, Amsterdam, The Netherlands)
Mello Pott (Free University, Amsterdam, The Netherlands)
Wouter Ordelman (Free University, Amsterdam, The Netherlands)
Johan de Koning (Delft University, The Netherlands)
Simon Wakefield (Cardiff University, UK)
Adrian Cramp (Cardiff University, UK)
Bryan Cronin (Cardiff University, UK)
Stephen Morris (Cardiff University, UK)
Gerard O'Sullivan (Cardiff University, UK)
Alison Jones (Cardiff University, UK)
Martin Gee (Cardiff University, UK)
Julie Herniman (Cardiff University, UK)
John Roberts (Cardiff University, UK)
David Rickard (Cardiff University, UK)
Neil Kenyon (Institute of Oceanographic Sciences, Surrey, UK)
Rebecca Rendle (University of Bangor, UK)
John Millington (Leicester University, UK)
Julian Clark (University College London, UK)
Taniel Danelian (Edinburgh University, UK)
Michael Marani (Instituto di Geologia Marina, Bologna, Italy)
Alexei Suzyumov (UNESCO)

ANNEX III

Survey sites of TTR4



Leg 1:		The Ionian Sea
Leg 2:	Area 1	The Southern Tyrrhenian Sea
Leg 3:	Area 2	The Eastern Corsico-Sardinian Margin
	Area 3a	The Western Corsico-Sardinian Margin
	Area 3b	Balearic Abyssal Plain