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Geosphere-biosphere coupling:

Carbonate Mud Mounds and Cold Water Reefs

International Conference and
Sixth Post-Cruise Meeting
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PREFACE

1998 was declared "the International Year of the Ocean" (IYO) by the United Nations. This year many cultural and scientific events, including this Conference, are ocean-related, but the World Exhibition in Lisbon (Portugal) will be the IYO highlight. For this occasion I chose the song "O Mar" interpreted by *Madredeus*, a popular music group of Portugal, which merges the Portuguese culture and the mystery of the Ocean, as well as Man's eagerness to understand the systems, processes and genesis of the Ocean. During this Conference one of the most mysterious phenomena of the seabed was explored.

O Mar	**The Sea**
Não é nenhum poema	*It would not be a poem*
o que vos vou dizer	*What I am going to say*
Nem sei se vale a pena	*Neither I know if it is worth*
Tentar-vos descrever	*To try to describe you*
O Mar	*The Sea*
O Mar	*The Sea*
E eu aqui fui ficando	*Here I have been standing*
só para O poder ver	*Only to be able to see it*
E fui envelhecendo	*And I' ve been getting older*
sem nunca O perceber	*Never understanding it*
O Mar	*The Sea*
O Mar	*The Sea*
(Pedro Ayers Magelhães)	

"Carbonate Mud Mounds and Cold Water Reefs" is a timely topic in marine geosciences. The controlling factors for the genesis and growth of ahermatypic cold water reefs have been a subject of debate ever since they were first described in the 19th century from cruises of HMS *Porcupine*, south-west of Ireland. Geological interest arose in the early nineties, when various studies reported a possible relationship between the growth of deep water reefs and specific oceanographic conditions or geologically controlled seeps of methane gas on the seabed. A key question in deep water mud mounds and reef systems is the understanding of the onset and stabilization of these large structures, and in particular what role bacteria, algae, corals and hydrocarbons may play. At the meeting speakers presented the state of the art on this subject with actual examples from offshore Norway, Porcupine, Faeroe and Florida Straits, and fossil examples from e.g. Morocco, Algeria, Italy, Belgium and Barbados.

The Conference was also the annual post-cruise meeting of the international Training Through Research Programme (TTR). This programme was designed in 1990 by an international group of scientists under the auspices of UNESCO and, later, the European Science Foundation to benefit from the advantages provided by combining the training of students and young scientists with "cutting-edge" research. It is sponsored by the Intergovernmental Oceanographic Commission (IOC) of UNESCO through its Training, Education and Mutual Assistance (TEMA) component. The main objective of the Programme is to generate and share advanced knowledge through state-of-the art training and education and acquisition of high-quality data during the TTR cruises for the achievement of various scientific goals. In July and August 1997, the R/V *Prof. Logachev* successfully carried out the TTR-CORSAIRES cruise (TTR7) in the North Atlantic (Porcupine Basin, Faeroe and Rockall), following reconnaissance surveys of R/V *Belgica* and R/V *Pelagia*. The theme of the Conference arose from the attention paid to the mysterious phenomena of mud mounds, temperate corals and structural features associated with fluid venting.

The Conference included presentations of data in connection with the TTR7 cruise and previous TTR cruises, in addition to papers by independent scientists who are working on this topic.

This Conference would have been impossible without the support of a number of organizations. We are grateful for financial support from the Intergovernmental Oceanographic Commission (IOC) of UNESCO, the Flemish Government, the University of Gent, the MAS3-CT95-OO45 CORSAIRES project and STATOIL Exploration (Ireland) Ltd.

Ben De Mol
Chairman, Organizing Committee

SUMMARY

The "Carbonate Mud Mounds and Cold Water Reefs" (TTR7 post-cruise) Conference was held from 7 to 11 February, 1998 at the University of Gent, Belgium. This meeting brought together over 90 participants from 11 countries (Belgium, Denmark, France, Germany, Ireland, Italy, the Netherlands, Norway, Russia, United Kingdom and USA). Attending were representatives of industry, international organizations, researchers and students with different specialities (sedimentology, geophysics, geochemistry, microbiology, biology) and research interests falling in the area of the Conference theme.

The Conference started with a field trip, "Waulsortian - and Frasnian reefs in Belgium", and the following days were divided into six scientific sessions:

- Carbonate mud mounds and cold water corals: are they methane-related?
- Porcupine: cold water corals, mud mounds, sedimentology, stratigraphy and tectonic setting
- Open session with contribution on the Miocene cold-seep carbonates, lithoherms of Florida Straits and Haakon Mosby mud volcano in the Norwegian Sea
- Rockall-Faeroe: cold water corals, mud mounds, sedimentology, stratigraphy and tectonic setting
- Fossil mud mounds
- Results of previous TTR cruises

In total some 40 oral presentations and 15 Poster presentations were made.

The field trip entitled "Waulsort - and Frasnian reefs in Belgium" covered outcrops along the type localities of the Devonian Frasnian mound and the Carboniferous Waulsortian mounds. A transect was followed from Givetian mounds and "Red Frasnian reefs" to the Waulsortian reef settings and the fore-reef sediments of Rocher Bayard. Those type localities amply demonstrated a variety of sedimentological features.

During the six scientific sessions an overview was given of the recent discoveries of reef and mound structures in the North Atlantic Ocean, with the results of the AIMS96, the *Belgica* '97 and *Logachev* TTR7 scientific cruises and some industrial cruises (ENNEX, 1985; STATOIL, 1996). There appears to be three distinct types of mounds in five main areas in the North Atlantic (South Porcupine Basin, main Porcupine Basin, SE Rockall Trough, NW Rockall Trough and off Norway).

Modern seabed mound and reef features in Porcupine Basin and their fossil counterparts with examples in Morocco, Italy and Barbados are often related to petroleum systems and hydrocarbon seepage. Either active or past fluid venting could have provided some of the energy basis and carbon source for ecosystems independent of photosynthesis (bacteria, corals, echinoids,...). Bacteria feeding on the hydrocarbon energy supply produce carbon dioxine as a metabolite, which is subsequently precipitated as calcium carbonate in seawater. Such carbonate precipitation may have lead to the formation of a hardground, which could become a preferential site for colonization by reef-building organisms. Hydrocarbons may have migrated from deeper reservoirs along faults or discontinuities, but gasses which originated from the destabilization of gashydrate layers or from vent sites in an intrusive environment might be taken into consideration as well.

In other examples it was clear that the highest density of corals is found in areas with a rugged seabed topography with glacial features as tills, iceberg ploughmarks or other elevated structures. It would appear that the corals have settled on these mounds to take advantage of the increased currents and of the associated suspended material supply. Some results show that there is a possible relation between the water stratification with nepheloid layers and the occurrence of cold-water corals.

The TTR7-related presentations of the geophysical field data and the first sedimentological and geochemical analyses can be summarized as follows. Seismic, sidescan sonar and subbottom

profiler data suggest that some local acoustic anomalies might be connected with gas flux or shallow gas accumulations. The shallow core examinations on deck, however, did not show any visible evidence of the presence of gas or any geochemical clues. These observations were confirmed by measurements in fresh sediments. The values obtained are typical of normal basinal sediments. The continuous TV records and discrete photographic pictures taken along lines running over carbonate mounds revealed neither gas seeps through the seafloor nor associated phenomena. According to the conclusions drawn by the biological team, none of the more than 100 epibathyal species defined from carbonate mounds belongs to chemosynthetic communities. In other words, they cannot be looked upon as being related to methane seeps or enhanced bacterial activity.

These results, together with low methane concentration in sediments (from chromatography data) and low EOM content, cannot suggest the existence of detectable hydrocarbon fluxes through the carbonate mounds in the shallow sediments along the investigated profiles. The mineralogical composition of carbonate components (carbonate inclusions, fragments of shells and corals etc.), as well as isotope values of $\delta^{13}C$ and $\delta^{14}C$ for coral fragments collected from different parts of the sequence recovered, attest to the conclusion that a stable hydrocarbon flux has been absent on the samples sites during the whole Holocene and part of the Pleistocene, at least over 70 ka. Thus, the question of the nature and origin of the carbonate mud mounds of Porcupine Basin remains open. Surface evidence suggests that - at present and in the recent geological past - the distribution and the patterns of active growth of cold water corals inhabiting these mounds are closely controlled by climatic variations and bottom currents. On the other hand, the numerous buried ring reefs ("Magellan mounds") mapped by R/V *Belgica* argue for a past fluid flow event, and some acoustic anomalies can be interpreted in terms of local gas accumulations or fluxes. What probably eludes our efforts might be patterns in space (focused versus diffusive fluxes) and/or time (transient versus steady-state flows). An indirect evidence for this could be some observations of abnormal increases in the concentration of methane in the uppermost parts of several cores. Together with the observation of possible gas plumes on the subbottom profiler records, this might suggest charging of the sediment with methane-saturated water from nearby venting sites.

The questions included, among many others, the genesis of mound features, the cold-seep carbonates, the environmental conditions for the growth of ahermatypic deep-water corals, taphonomy of mound features, physical oceanographic circumstances near the mound features, and relations between the geosphere and the biosphere.

Also, the results of previous TTR cruises were presented with special emphasis on mud volcanoes in the Mediterranean Sea and their relation to the destabilization of gas hydrates.

On the first day a debate was held entitled "Deep Biosphere- Geosphere Coupling" with panel members: Dr. Jean Boissonnas (EC DG XII MAST), Dr. Agnes McLaverty (STATOIL), Dr. Alexei Suzyumov (UNESCO), Dr. André Freiwald (University of Bremen), and as moderator Dr. J.P. Henriet (University of Gent). The participants discussed fundamental questions, environmental issues and educational challenges. The debate concluded with a call for further concerted action between European universities and industry.

One of the highlights of this meeting was the Signature of a Bilateral Research Agreement between the Universiteit of Gent and the Lomonosov Moscow State University by Prof. Dr. ir. J. Willems, Rector of the University of Gent, and Prof. Dr. V. T. Trofimov, Vice-Rector of the Lomonosov MSU, representing Prof. Dr. V. A. Sadovnichiy, Rector.

The discussions around the posters and the lively debates at coffee time and beyond were evidence of a very stimulating intellectual ambiance. All participants expressed great satisfaction with the Conference as having fully accomplished its objectives and facilitated fruitful contacts between the attendees.

MESSAGE TO THE CONFERENCE ON CARBONATE MUD MOUNDS AND COLD WATER CORAL REEFS

from G. Kullenberg, Executive Secretary of the Intergovernmental Oceanographic Commission of UNESCO

It is an honour for me to convey to you the best wishes of success with the Conference and the related follow-up, on behalf of the Intergovernmental Oceanographic Commission.

1998 has been proclaimed by the United Nations' General Assembly as the International Year of the Ocean, following the Resolution adopted by the IOC Assembly in 1993. In this regard, the following is conveyed in a message from the Director-General of UNESCO.

For modern science, the sea is the very source of life on Earth. It is, so to speak, the amniotic fluid from which all living forms spring. Throughout history, the oceans have been vital to human civilization - as a resource base, as a route to other lands and other peoples or as an outlet for population overflow. Over 90 percent of the planet's living and non-living resources are found within a few hundred kilometres of the coasts. On or near these coasts live two-thirds of the world's people. Without the sea, the life of Earth would be impossible. Our planet would be a barren desert like Mars - about which, paradoxically, we probably know more than we do about the oceans.

For the human imagination, the sea has always been as symbol of vastness and freedom. Now, at the close of the second millennium, competition for scarce resources is showing this freedom to have its limits. Growing demand is placing the marine environment and resources under increasing strain. History teaches that scarcity can be the cause of conflict and war. However, it may be hoped that the will today exists to shape our destinies otherwise.

In an historic speech on 1 November 1967, Malta's Ambassador to the United Nations, Arvid Pardo, called for international regulations to prevent the oceans from becoming a theatre for escalating conflict between nations, to halt the poisoning of our oceans through negligence, and to protect its resources from exhaustion. His words did not fall on deaf ears. The United Nations General Assembly adopted a declaration providing that all sea-bed resources beyond the limits of national jurisdiction constitute the common heritage of mankind. Fifteen years later, the United Nations Convention on the Law of the Sea - which attracted a record 159 signatures - provided the international community with an effective legal framework covering navigational rights, territorial sea limits, rights of passage, questions of economic jurisdiction, the conservation and management of living marine resources, and procedures for the peaceful settlement of disputes.

But the value of legal instruments is dependent on how far they are respected and enforced. This planet does not belong to the adults of today and should not be managed on the basis of short-term considerations of economic gain or political power. If the signatures of our children were needed to ratify decisions that affect their future, many of the destructive actions perpetrated today would certainly cease.

The United Nations has declared 1998 the International Year of the Ocean as a celebration of this source of life and civilization. But this international year is also a reminder of the need to protect this most precious of resources, an affirmation of our commitment to safeguard the rights of future generations, for whom we hold our planet - and its life-sustaining oceans - in trust'.

We know now that the ocean plays a crucial role in sustaining life of Earth and is a key element in climate change. But ocean issues are not receiving the attention they ought to be given.

The ocean is a resource that is less well known than some distant planets and undoubtedly contains a resource potential that remains partly untapped. But this resource is limited, both in capacity and in its ability to absorb the effects of development and pollution. Signs of stress are already visible, especially in low-lying coastal areas and small islands.

The picture of the ocean that is emerging from shared observations all over the world is not very comforting. The catalogue of symptoms of disease include: pollution, exhausted fishing stocks, disappearing coastlines, rising sea level, increasing surface temperature that threaten the deep ocean currents, more frequent storms, melting ice caps...

When we understand the ocean system better, we will be able to predict some of the changes expected in the next century and, hopefully, offset them through intelligent, cooperative action. In the shorter term, better and more systematic observations of the ocean will enable us to forecast imminent disasters from storms, floods and drought and mitigate their effects, by warning the population at risk.

The International Year of the Ocean (IYO) is an attempt to bring ocean issues to the attention of decision-makers and the general public.

Many activities are going on and considerable progress has been achieved through dedicated international research programmes. These have also laid the foundation for the establishment of the Global Ocean Observing System, together with technological developments. In association with models, computer-power and data assimilation techniques, the ocean observations provide for forecasting of major climate variations. These can be used for management and planning of agriculture, fisheries, water resources, coastal and urban protection.

Your Conference is based on basic science and international cooperation, which has yielded very important results. Science is being done together with training and IOC-UNESCO is proud to be able to provide some support. I hope you will also communicate the scientific results to a wider audience, beyond those of the scientific realm, and explain what the implications of the research results are. This is very important part of the International Year of the Ocean - to reach out and establish communication and dialogue. This will help generate understanding and support for research. Your spirit of cooperation should help achieve such a wide dialogue.

I wish you a very successful Conference and programme for 1998 International Year of the Ocean.

Paris, 6 February 1998

OPENING AND WELCOMING SPEECH

From Prof. Dr. De Leenheer, Vice-rector, University of Gent.

Flanders and the University of Gent have the honour to host the 7th "Post Cruise Meeting" of the IOC/UNESCO's successful "Training Through Research" Programme.

This unique programme has - throughout the years - offered education at sea to a blend of Western European and Russian students, on board of large Russian oceanographic vessels. For all these students such education at sea means a confrontation with the marine environment, a confrontation with the rigorous of advanced field research, and an unforgettable human experience.

But I believe this meeting has something special to offer, something new.

First of all - of course - because this is TTR's first port call in Gent....

And throughout your stay here, you will notice that Gent has not only a remarkable historic flavour, but also a most dynamic university, with the highest expansion rate on the whole Belgian academic scenery. 22.000 students are keeping us young, and busy. Gent has an ancient academic tradition too. Even if the present university was founded in 1817 by Willem I, King of the Netherlands, Gent challenged the Spanish occupants by declaring itself a Calvinistic Republic in 1580, and immediately founded its first University right here, in this former Dominican monastery. A first university which had to close its doors in 1584, 5 days before Alexander Farnese terminated the "Gent Republic".

But if the TTR Programme has selected Gent for its 7th Post-Cruise Meeting, it is certainly not only for its past combativity.

It is my pleasure to observe how Flanders with Gent and Leuven Universities have actively joined the IOC/UNESCO TTR venture, by an original contribution in close partnership with The Netherlands, in particular Amsterdam University and NIOZ - the Netherlands Institute of Oceanographic Research. A joint venture supported - in its educational dimension - by the "Floating University" project of the Flemish Government.

Through coordinated initiatives, as I heard, the 1997 TTR programme has turned into a true multi-ship venture, with the oceanographic vessels "*Belgica*" and "*Pelagia*" clearing the way for Russia's "*Prof. Logachev*" respectively in Porcupine Basin and along the Rockall margins. Cruises strongly supported by the EC projects "ENAM 2" and "CORSAIRES".

These cruises became not only an educational success, but also led to astonishing scientific discoveries, highlighting a hitherto unexpected dimension and diversity of deep-water coral habitats - in a most promising hydrocarbon province along Europe's margins.

Is this association purely fortuitous, or is there any scientific logic, a link, a true relationship between hydrocarbon accumulation and migration towards the surface, and a response of the deep biosphere, building giant mounds on the seabed?

How can such question be addressed, through which research efforts? These are key questions which will no doubt fuel heated debates and lead to sound recommendations. And we are most honored that Dr. Jean Boissonnas, Head of the EC Marine Science and Technology Programme, is personally following this debate with great attention.

But through these discoveries, this meeting has grown beyond a normal post-cruise meeting - into a true International Conference. One of the first 1998 conferences under the auspices of the IOC "Year of the Ocean". Let me express my sincere gratitude to Dr. Gunnar Kullenberg, Assistant Director General of UNESCO and Executive Secretary of IOC, for being among us today, if unfortunately not personally certainly through his appreciated message stressing the importance granted by UNESCO to this Conference and its scientific and educational messages.

It is a conference where top level experts from the whole world, from universities, scientific agencies, government agencies and the oil industry are bringing their expertise, shaping a uniquely stimulating environment both for senior scientists and for our young students, who will proudly - and no doubt slightly nervously - join the debate with their preliminary results. I wish them all success.

Let me assure you that at the level of Gent University, we are following these educational and research efforts with the greatest attention. It is with this concern that Gent University and Lomonosov Moscow State University, which hosts the famous "UNESCO Centre of Marine Geology and Geophysics", will today, as a conclusion of this morning session, sign a bilateral agreement in which this "Training Through Research" at sea is a central theme for the forthcoming years. And we are most honoured that Prof. Victor Trofimov, Vice Rector of Lomonosov Moscow State University, has been delegated by Rector Sadovnichyi for signing this important agreement.

It was Michajl Vasil'evich Lomonosov, grown up at sea as a son of a fisherman before becoming one of the most brilliant scientists and scientific "entrepreneurs" of the Eurasian continent - not the least in Earth sciences - who wrote:

"...it is something grand, to penetrate with Man's mind the depths of the Earth, wandering around with the strength of ideas and shedding light on objects and facts, veiled by an eternal night..."

May these words inspire your venture.

MESSAGE OF THE MAIN INDUSTRIAL SPONSOR: STATOIL

Statoil was founded in 1972 and is wholly owned by the Norwegian state. Its objective is, either by itself or in partnership with other companies, to carry out exploration, production, transportation, refining and marketing of petroleum and petroleum-derived products. Through Borealis it is also a leading petrochemical and plastics producer.

Statoil, with headquarters in Stavanger, has some 15,000 employees. Net operating revenue for the group totaled NOK 107 billion in 1996. Statoil is the leading player on the Norwegian continental shelf and the biggest petrol retailer in Scandinavia. It also ranks as one of the world's largest net sellers of crude oil and is a substantial supplier of natural gas to continental Europe.

The group has pursued a gradual expansion outside Scandinavia in recent years and now has operations in 25 countries. Its exploration and production activities focus on the North Sea and Ireland, Greenland, Western Africa, Southeast Asia, China, Australia, Azerbaijan, Kazakhstan, Russia, the U.S. Gulf of Mexico and Venezuela. Its petrol retailing operations are in Scandinavia, Ireland, Poland, the Baltic countries and Russia.

Statoil has been active in Ireland on the petrol retailing side since 1992 and today is among the market leaders in the Republic with a network of some 340 stations. Its acquisition of Aran Energy two years ago led to the establishment of Statoil Exploration (Ireland) Ltd. and its exploration office in Dublin. This company is now the holder of ten exploration licenses west of Ireland covering 57.5 blocks and gross acreage of some 14,000 square kilometres. Statoil is active in the entire Atlantic Margin, from Ireland to West of Shetland to the West Coast of Norway.

ABSTRACTS

Carbonate Mud Mounds and Cold Water Corals: are they methane related?

A CATALOGUE OF IRISH OFFSHORE CARBONATE MUD MOUNDS

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Petroleum Affairs Division, Department of the Marine and Natural Resources, Dublin, Ireland

A catalogue of carbonate mud mounds from the Irish offshore is presented, recognised at the seafloor or buried at shallow depth, based on all oil industry seismic reflection data acquired from 1969 to 1997. It updates a previous publication based on 1969-1990 seismic data for the main Porcupine Basin (Hovland et al., 1994) and includes new areas of mounds in the South Porcupine, SE Rockall Trough and NW Rockall Trough. Mounds are listed by area, year of seismic survey, seismic line identification, shotpoint number at centre of mound and corresponding lat/long co-ordinates of that shotpoint. In addition the relevant portion of each seismic line is shown at 5-10cm/second vertical scale. A summary map of all the recognised mounds is also provided. Tracklines of follow-up research cruises (AIMS96-GLORIA; *Belgica*'97-high resolution seismic; *Logachev* TTR7-high resolution seismic, high resolution sidescan) are also shown, and the co-ordinates of all known gravity core sampling locations (Ennex, 1985; Statoil, 1996 and *Logachev* TTR7, 1997) are provided.

There appears to be three distinct types of mounds. The main Porcupine Basin mounds are the largest, are often moated and occur in an elongate belt across the centre of the basin. In 1993, improved seismic acquisition and processing techniques allowed buried mounds in this area to be identified for the first time. The South Porcupine and SE Rockall Trough mounds are generally smaller and are aligned along the basin margin faults. The NW Rockall Trough mounds are large but of low relief, seismically more transparent, and occur updip of the main basin margin faults. At least one example appears to have formed on a pre-existing high.

The significance of the formation of these mounds and their spatial distribution is discussed in the context of the current petroleum generation models for these basins.

DO CARBONATE REEFS FORM DUE TO FLUID SEEPAGE?

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Buried carbonate reefs are favoured hydrocarbon prospecting targets, mainly due to their high porosity and potential for containing large quantities of petroleum. The question of the true relationship between reef structure and the internally trapped fluids (hydrocarbons) is here raised as one of cause - and effect. In other words, which came first, the hydrocarbons or the carbonate reef itself?

Modern bioherms and seabed carbonate reefs in, amongst other locations, the North Sea and the Gulf of Mexico, are shown to form in close association with active hydrocarbon seepages. Mainly based on results from ecological studies at deep-ocean vent communities, a new model for carbonate reef formation is promoted: that such reefs form at locations containing high concentrations of seeping fluids (solutions and gases) that provide some of the energy basis and carbon source for ecosystems independently of photosynthesis. Therefore, on burial and effecting sealing ('capping'), these carbonate reefs become hydrocarbon reservoirs, trapping and accumulating the very minerals on which they- in the first place- were dependent.

CARBONATE PRECIPITATES AT THE OREGON ACCRETIONARY MARGIN: THEIR RELATIONSHIP TO VENT FLUIDS AND THE INFLUENCE OF GAS HYDRATES

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Authigenic carbonates associated with cold vents have been investigated at the Oregon margin since 1984 (Suess et al., Ritger et al.) on several research cruises and ALVIN dives as well as on ODP Leg 146. During RV SONNE cruise 1996 carbonates intercalated with massive gas hydrates were recovered in sediments of the second accretionary ridge (TVG 18). The investigation of this new finding at TV6 18, and numerous other carbonate samples that were taken by TV grab at the northern summit provides more detailed information on the formation of the carbonates. We will present several carbonate types and their relation to fluid venting, tectonic activity along the ridge and gas hydrate formation and/or decomposition.

At all sites carbonates were found that differ in morphology, texture and mineral composition. Different carbonate types include slabs which are composed of homogeneous micritic matrix with smooth surfaces and slump structures; tectonised slabs; bioturbation casts; irregular intraclast breccias which are more or less cemented and occasionally post cementationally tectonised; layered diagentic pseudobreccias; breccias composed of bioturbation casts, shells, intraclast and diagenitic cemented parts. The breccias show a petrographic spectrum from mud and grain supported calciarenite to clast supported calcirudite breccias. XRD measurements and semiquantitative analyses of the carbonate minerals reveal a complex carbonate composition and diagenesis especially at the northern summit. Calcite, high Mg-calcite (up to 20 Mol% $MgCO_3$), protodolomite (35-40 Mol% $MgCO_3$) and dolomite/Ca-dolomite (>40 Mol% $MgCO_3$) were distinguishable. Aragonite is also the main carbonate phase at the northern part of the area and at TVG 18. Carbonates at cold vents are typically derived from methane fluid expulsions with higher amounts of H_2S. At the northern summit we observed a methane plum with CH_4 values up to 75,000 51/L by CTD sampling. The source of the methane can be determined by $\delta^{13}C$ isotope values of the carbonates and the fluid migration depth can by estimated from Sr isotopes. With respect to the data from ODP Site 892 Sr isotopes from the carbonates (0.709128 to 0.709202) show no influence of deep derived fluids.

At the southern summit intraclast calcirudite breccias were recovered together with associated gas hydrates at TVG 18. Thinsections from pure layered hydrates show a sponge like structure of 1 to 20mm elongated bubbles. Within the surrounding sediment fractures in the form of small hydrate filled veins could be observed. The layered bubble structure as well as the fracturing is probably caused by the migration of free gas through the sediment during which the upper sediment column (< l0m) was pushed up and fractured. The hydrate gas consists of methane ($\delta^{13}C$ -65.03‰ PDB), H_2S and a few ppm of ethane and propane indicating a biogenic methane source. Porewater squeezed from sediment cores is strongly enriched in H_2S and depleted in sulphate. At TVG 18 aragonite as the main carbonate mineral occurs as a matrix cement as well as yellow mostly botryoidal vein and porespace rim cement. Micritic Mg-calcite with a mean $MgCO_3$ content of 17 Mol% is also present. Isotope measurements show $\delta^{13}C$ values between -40.57 and -54.17‰ PDB which are typical for carbonates derived from oxidation via sulphate reduction of biogenic methane mixed with smaller amounts of $C0_2$ from organic matter oxidation. The $\delta^{18}0$ values from 3.27 to 4.84‰ PDB are linearly correlated with the Mg-calcite and aragonite content. To determine whether the different isotope fractionation from Mg-calcite and aragonite is responsible for the correlation we used the measured water temperature of 4.06°C and the equations from FRIEDMAN & ONEIL (1977) for Mg-calcite and from HUDSON & ANDERSON (1989) for aragonite (~0.75‰ at 4.06°C with respect to calcite) to correct the analyses to calcite equivalent data. Even after this correction a linear correlation with lighter $\delta^{18}0$ values for aragonite exists, so that all isotope values could be explained as a mixture between aragonite with 4.850/~ and Mg-calcite with 3.650‰ $\delta^{18}0$. These differences can not be explained by changes in temperature during the crystallisation (aragonite 3.86°C and Mg-calcite 0,36°C in water with 0‰ SMOW). Calculations for the $\delta^{18}O$ of the source water at the measured temperature of 4.06°C results in 0.05‰ SMOW for aragonite and 0.94‰ SMOW for Mg-calcite. Increasing $\delta^{18}O$ values of the interstitial water may be explained by decomposition of isotopicaly heavier gas hydrates. During this time the release of more methane induce increasing sulphate reduction and the geochemical environment becomes more anoxic. These conditions favour a Mg-calcite precipitation where as aragonite is the 'normal' carbonate cement under present like more oxidised conditions with none or only less hydrate decomposition. These investigations imply that gas hydrate stability has an impact on carbonate precipitation in methane seeping areas.

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FLUID MIGRATION, GAS HYDRATES AND GIOGENIC CARBONATE MUD MOUNDS: FUNDAMENTAL QUESTIONS AND OUTLOOK ON RESEARCH ACTIONS

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Recent studies have further defined the amount of gas hydrates preserved in seabed sediments along the world's continental margins. Estimates have considerably increased over the last decades as a consequence of intensive marine geological research.

Gas hydrates may strongly alter the characteristics of the seabed by local or large scale gas leakage. The partial or complete dissociation following changes in P/T conditions at or below the seabed may release significant quantities of methane gas, which might contribute to global climate change.

Leakage of methane and other alkanes through the sediment column may create pockmarks and also result in the bacterially mediated formation of carbonates under the shape of mounds and cold water coral reefs, carbonate knolls and chimneys. Pockmarks can also be formed by the percolation of methane gas, formed by the biological decay of organic matter under anaerobic conditions.

Gas seeps and bacterially mediated carbonate formation are often associated with enhanced growth of organisms and increased biodiversity, with specific habitats.

Gas hydrates in the seabed are a potential hazard. Changes in P/T conditions, for example as a result of changes in sea level or bottom water temperature, can cause the destabilisation of slopes. Earthquakes may add to trigger large scale slides. Such slope failures can affect present or future man-made structures on the seabed (pipelines and cables, artificial structures). Research in the past few years around Europe's margins, in particular in the framework of EC projects, has revealed a variety of such processes.

Some sites offer exceptional perspectives of pluridisciplinary projects - of global relevance. A new insight can be gained in the wider interaction between geologically controlled fluid flows, climate control on hydrate growth and decay through temperature variations of deep water currents, and the biological response of the ocean, both in terms of nutrient fluxes and the local development of large reef habitats on the seabed.

In addition, the extensive clusters of mounds increasingly discovered around Europe's margins, in particular in identified or potential hydrocarbon provinces, raise challenging questions about their potential "message from the depths": geochemical signatures of deeper fluids and/or records of fluid migration "pulses" from sedimentary basins, and their modulation by tectonic or environmental controls. Buried mound provinces such as the recently discovered "Celtic ring" reefs in Porcupine Basin, southwest of Ireland, clearly bear witness of distinct palaeo-events of fluid expulsion. A project of scientific drilling of such surface reefs and buried mounds may shed a new light on truly fundamental questions in basin dynamics, in their widest dimension - including the dynamics of some of the most intriguing deep ocean life systems. Interested scientific teams are invited to join this European venture.

THE FOSSIL COLD SEEP CARBONATES OF MONFERRATO (NW ITALY): AN EXAMPLE OF LOCALIZED CARBONATE PRECIPITATION INDUCED BY METHANE-DEGRADING BACTERIA.

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A relationship between methane-rich fluids and genesis of deep water mud mounds has been recently proposed; an increasing number of mud mounds is now interpreted as the result of bacterially mediated carbonate precipitation around localized fluid seeps on the sea floor (cold seeps). However, paleontological, petrographical and geochemical evidence is needed in order to confirm such an interpretation for suspect carbonate masses. Definition of useful criteria comes from studies on both present day and fossil cold seeps.

Hydrocarbon-rich fluid emissions on present day sea floors are typically evidenced by the luxuriant chemosynthetic fauna associated with carbonate crusts and "chimneys" that stand in contrast to the desert and flat surroundings. All carbonates obtained from present-day seep sites are characterized by extreme depletions in ^{13}C. These environments are essentially anoxic sites surrounded by oxygen-rich bottom waters. The transitional oxic to anoxic habitats support microbial communities with different modes of life: free in the water column above the seeps, within the tissues of specialized benthic fauna with which they have symbiotic relationships, in mats at the sediment-water interface, within the sediments.

Several examples of fossil cold seeps have been reported. The characteristics of one of the first described example recognized in the Cenozoic sedimentary succession of Monferrato (northern Italy) may represent a good reference for recognition of a methane-related origin of anomalous carbonate masses. The Miocene rocks cropping out around the small village of Marmorito consist of a strongly deformed succession of siliciclastic sediments located behind the most recent frontal Apenninic thrusts. Two different types of anomalous carbonate-rich rocks have been recognized:

- Lucina limestone: cream- to light-brown-coloured marly limestone packed with large bivalve (lucinid) remains. They occur only as centimeter- to metre-sized blocks so that their original stratigraphic relationships with the surrounding rocks are completely lost.

- Marmorito limestone: light to dark grey calcite- and dolomite-cemented mudstones and sandstones crosscut by multiple generations of carbonate-filled veins. They are barren of fossils and represent carbonate-cemented portions of the local siliciclastic sequence. Vein fills are polyphasic and several generations of cements are recognisable.

These outcrops of anomalous carbonate-rich rocks have been interpreted as the result of seeping of methane-rich fluids on ancient sea floor on the ground of both isotopic analyses and comparison with carbonates described in present-day venting sites. The stable isotopic composition of carbonate minerals forming the anomalous masses differs greatly from that of normal marine carbonates being characterized by strong depletion in $^{13}C/\delta^{13}C$ are comprised between -20 and -40‰ PDB. This depletion is interpreted as the result of the incorporation into the carbonates of isotopically light CO_2 deriving from bacterial degradation of methane, whose carbon isotopic composition is the lightest in nature ($\delta^{13}C$ from -35 to -60‰ PDB).

Additional lines of evidence are provided by petrographic features and by permanent records of bacterial activity imprinted in the carbonates of the Monferrato cold seeps. Most striking petrographical features of these carbonates are represented by abundant pore filling calcitic and dolomitic cements and by polyphasic fillings of veins and cavities showing several generations of cements (calcitic, aragonitic, dolomitic) and of internal sediments. Evidence of intense bacterial activity is represented by several structures and fabrics as: laminated sediments lining both the floor and the roof of cavities; peloidal fabric shown by most of internal sediments; dolomite spheroids with dumbell-shaped hollow cores. Ongoing research on distinctive biomarkers in the organic extracts of the Marmorito limestone are providing new evidences of microbial processes.

The isotopic signatures, the biological and sedimentological features led to interpret both Lucina limestone and Marmorito limestone as fossil analogues of present-day cold seep carbonates. However their genesis took place in different settings and followed different paths:

- the Lucina limestones are the result of colonisation of areas of diffuse methane-rich fluid venting at the sea floor by specialized communities of bivalves living buried in the uppermost oxic layer of sediments. The food chain was supported by the concurrent bacterial anaerobic oxidation of methane and reduction of sulphate. The precipitation of ^{13}C-depleted carbonate took place near the sea floor after the upward migration of the oxic-anoxic interface because of sedimentation.

- the Marmorito limestone are the result of precipitation of interstitial carbonate cements at a certain depth below the sea floor due to the bacterially induced oxidation of a diffuse flow of methane-rich fluids migrating upwards through the sedimentary column. After the creation of this plug, the diffuse flow was not possible anymore so that the rising methane opened different generations of fractures in cemented mudstones and sandstones.

THE DEVONIAN CARBONATE MUD BUILDUPS OF THE AHNET BASIN (ALGERIAN SAHARA) - ANCIENT ANALOGUES OF MODERN DEEP WATER BUILDUPS?

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In the Ahnet Basin of central Algeria, a unique Devonian underwater scenery consisting of almost 200 mud mounds, 15 mud ridges and 2 mud "atolls" is revealed (Wendt et al. 1997). All these buildups have been totally exhumed by the desert climate, perfectly exhibiting their original morphologies and their relation to the surrounding off-buildup strata. The most conspicuous buildups are large mud mounds (20-40m high, 100-200m in base-diameter) and mud ridges (40-100m high, up to 8.5km long).

All these buildups seem to have been established contemporaneously in a short time span in the early Givetian. Growth times of individual buildups are approximately in the order of 50.000-250.000 years; accumulation rates are 0.4-0.8 m/1000 a and are 10-20 times higher than in the off-buildup facies.

The fauna of the buildups lacks the typical Devonian frame-builders like stromatoporoids and colonial rugose corals. Crinoids and scattered tabulate corals (auloporids) are the prevailing faunal elements. Brachiopods are also common; solitary rugose corals, molluscs, trilobites, siliceous sponges, ostracodes, styliolinids, bryozoans, and problematica (*Receptaculites*) occur rarely. The total absence of calcareous algae and micritization suggests growth of the buildups in a deeper ramp environment below euphotic conditions.

The lithology of these buildups consists of stromatactis-bearing, skeletal wackestones with the bulk of the buildup volume consisting of microspar. The purity of the buildup carbonates (> 95% $CaCO_3$) and the higher accumulation rate with respect to the argillaceous off-mound strata suggest that these carbonates must have been produced *in situ* and a microbial origin appears most likely. However, neither thrombolitic structures nor peloidal textures, so characteristic of Palaeozoic mud mounds, have been identified in these mounds. The only evidences of microbial activity are thin, darkbrown crusts of probable cyanobacterial origin which line the walls of some stromatactis cavities. This suggests a close relationship between carbonate production and stromatactis formation. Microbial communities probably flourished on the mound surfaces, precipitating fine-grained carbonates and consolidating steep mound flanks by their mucilages. After having been embedded, microbial communities decayed and left behind stromatactis cavities which were subsequently filled by calcite cements.

The buildups are underlain by thin lenses of coral thickets which form the pioneer stage of mound development and served as substrates for microbial carbonate production. With ongoing vertical and lateral growth, closely spaced mounds amalgamated into mud ridges and mud "atolls". The mounds and ridges are perfectly aligned along two directions that correspond exactly with the lineament and fault system known from the Pan-African (Precambrian) basement around the Ahnet Basin. These faults may have acted as conduits for upward migrating hydrothermal fluids and hence the mud buildups could have formed at sites of hydrothermal venting. This hypothesis is confirmed by some mineralizations (pyrite, barite, and apatite) within the buildups and the $\delta^{13}C$-depleted isotopic signature of late diagenetic calcite cements. The isotope values of fibrous, marine calcite cements are, however, quite normal marine and hence do not support the assumption of hydrothermal influences.

Close recent analogues of ancient carbonate mud mounds are not known. Modern deep water buildups cannot be regarded as recent counterparts, because they are no carbonate mud buildups *sensu stricto* formed by *in situ*-produced carbonate mud. Modern aphotic, deep-water coral bioherms are true ecological reefs, composed mainly of the deep-water coral *Lophelia*. The recently discovered seabed mounds off western Ireland and north-west Australia (Hovland et al. 1994) resemble carbonate buildups of the Ahnet Basin concerning bathymetric position (100-1000 m), dimensions (100-1800m in diameter, 20-200m in height) and shapes (12-33° slopes). These mounds, however, are not carbonate buildups, but were merely settled by deep-water corals or codiacean algae. What they have in common with the ancient carbonate buildups of the Ahnet Basin is their possible relation to fault systems which acted as conduits for hydrocarbon-seepage, evidenced by extremely depleted $\delta^{13}C$ values (Hovland et al. 1994).

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THE ORIGIN OF THE EARLY DEVONIAN KESS-KESS MUD MOUNDS OF THE EASTERN ANTI-ATLAS (MOROCCO): EVIDENCE FOR SUBMARINE VENTING OF METHANE-RICH FLUIDS

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Spectacular conical Early Devonian mud mounds up to 55m high outcrop in the eastern Anti-Atlas of southern Morocco. The mounds constitute massive structures which in the field appear to be composed of a single lithology. There is no differentiation into a core facies and flank strata. Coarse detrital deposits or slumping phenomena are absent on the flanks. The mound facies is predominantly composed of skeletal wackestones and mudstones riddled by common small-sized stromatactis cavities. Small tabulate corals (auloporids, thamnoporids, and favositids) are the most abundant organisms, displaying an exceptionally high diversity. A total absence of stromatoporoids and calcareous algae is a feature of the Kess-Kess mounds. Conodonts, trilobites, and dacryoconarids prove the Emsian age (*inversus* Zone) of the buildups, which are essentially microbially mediated mud mounds developed in a deep-water environment on the Hamar Laghdad elevation created by a submarine eruption. Transition between the mound and the intermound bedded facies is gradual. It can be recognized at the bottom of the mounds primarily by changes in the frequency of individual biotic components and by a prevailing crinoidal packstone texture of carbonates. The mounds and the intermounds carbonates host a large number of dykes and sills of younger sediments. The more or less linear and usually near-vertical dykes are especially frequent near the faults. The infill of neptunian dykes consists of internal sediments (micritic and fine-grained bioclastic material) and calcite cement. Preliminary conodont biostratigraphy of infilling sediments shows that opening and filling was episodic, resulting in complex internal sediment and cement stratigraphy. At least five episodes of dyke formation can be distinguished.

During the Lochkovian, basaltic glassy lava was issued on the sea floor and amalgamated with wet sediments to form up to a 100m thick peperite complex. Its deposition created obviously a flat submarine rise which subsequently became a site of extensive crinoid colonisation. At the moment, it is not clear whether the crinoid colonisation had profited at that time from volcanic emanations, or whether the crinoids and other benthic organisms only used enhanced water circulation at this place. The isotopic data point to the marine character of the early cements in these carbonates. The mud mounds occurrence coincides well with the greatest thickness of the crinoidal limestones. In addition, they show a distinct trend in their spatial distribution, following a network of radial and tangential faults which were formed during Emsian times as a result of the doming caused by the underlying subvolcanic laccolithic intrusion. Geochemical results (REE data) although only at a preliminary stage document that the mound carbonates and the calcite cements in the neptunian dykes were precipitated from brines constituting a mixture of hydrothermal fluids and sea-water. The radial and tangential faults served as conduits for ascending hydrothermal fluids, the origin of which was the magmatic centre beneath the Hamar Laghdad. The springs were dynamic and episodically active until the Famennian but only during the Emsian were the vents sites of extensive carbonate production.

The carbon isotopic signals recorded in the mound carbonates have a complex origin resulting from the mixing between different carbon reservoirs. Typical is a strong depletion in $\delta^{13}C$ (between -4‰ and -18‰PDB) which suggests a contribution from thermogenic methane derived from the underlying basaltic intrusives. Aerobic bacterial oxidation of methane is favoured as a main process driving the carbonate precipitation and the rapid lithification of the mounds. The bacterial "infection" of the vent sites, stimulated and controlled by fluids entering the carbonate system on the sea floor, possibly played the crucial role in the origin of the Kess-Kess mounds.

SEEPAGE RELATED OR NOT? COMPARATIVE ANALYSES OF PHANEROZOIC DEEP-WATER CARBONATES

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Isolated, fine-grained carbonates of deep-water settings may originate from exclusively marine sources or from the seepage of methane and other reduced fluids. In modern seas, marine versus subsurface-sourced carbonate structures can be distinguished using direct measurements of water chemistry as well as video imaging of fluid flow. The Phanerozoic rock record bears a large number of isolated carbonates questionable in origin. Here we use six examples ranging from the Devonian to the Tertiary to set up a catalogue of distinguishing features including fabric, biota, early diagenesis, stable isotopes, and biomarkers. <u>Fabric</u>: Brecciation is almost omnipresent in cold seep carbonates. It may be related to the formation of pockmarks due to an explosive gas-release (sensu Hovland et al. 1987) or to the growth of gas-hydrates within unconsolidated sediments. Mechanical deformation within marine-sourced mounds occurs as small-scaled collapse structures, peripheral slumping, and sedimentary to early diagenetic dikes resulting from sediment load. <u>Biota</u>: Bivalves (*Bathymodiolus*, lucinid bivalves, *Calyptogena* etc.) and tube-worms (*Lamellibrachia*, *Escarpia* etc.) harbouring chemoautotrophic or methanotrophic bacteria in their gills respectively in their trophosomes are diagnostic for seepage habitats. In the fossil record it is not possible to reveal the presence of endosymbiontic bacteria, but dense aggregations of bivalves or tube worm colonies restricted to carbonates embedded in deep-water sediments account for a seepage relation. The same species of bivalves may occur in the surrounding sediments, but population density and size of individuals are reduced. Other taxa preferentially occurring in the immediate seep environment are decapod crustaceans, recorded from their coprolites, and sponges. Communities of normal marine habitats are largely controlled by bathymetry, substrate and nutrient supply. Therefore marine-sourced mounds exhibit bathymetric zonation and non-specialized heterotrophic organisms. The community structure is dominated by filter-feeding organisms such as sponges, bryozoans, and polychaetes in association with encrusting foraminifera, brachiopods, and occasionally vermetid gastropods. <u>Early Diagenesis</u>: Botryoidal aragonite is reported from a wide range of environments, but its frequent appearance in methane-derived carbonates is striking. We observed early dolomite in some of the cold seep outcrops mentioned below. Its formation may be linked to the exhaustion of sulphate due to sulphate-reducing bacteria as suggested by Ritger et al. (1987). Epitaxial growth of initial micrites results in synsedimentary lithification of large volumes of marine-sourced mounds. Radiaxial fibrous cement is the most common feature within the active marine-phreatic environment. The cement reduces interparticle, intraskeletal and growth framework porosity and is virtually absent within adjacent detrital sediments. Stable isotopes: The depletion of the ^{13}C-isotope is a typical feature of methane-derived carbonates. It is caused by fractionation processes due to bacterial activity in the aerobic, sulphidic, and methanic zone. Kinetic isotope effects associated with CO_2 reduction and acetate dissimilation in the methanic zone produce light methane ($\delta^{13}C$: ca. -60‰ PDB) and heavy CO_2 (ca. +24‰; Boehme et al. 1996). Micritic nodules, which were derived from the degradation of sponge soft tissues, embedded in the Jurassic seep carbonates of Beauvoisin are significantly more depleted in the ^{13}C-isotope (-26,5‰) than the surrounding micrites (-14,5‰), indicating an enhanced chemosynthetic activity within the sponge tissues. Within marine-sourced mounds 'normal marine' isotope signals (+2.9 to +3.4‰) were obtained from the initial micritic phases, sponge related micrites, and early marine cements. Biomarkers: Analysing cold seep carbonates we found several molecular fossils, which originate from methanotrophic bacteria (ring A methylated hopanoids, 4-methyl steroids) thus revealing the presence of these bacteria at the ancient seep sites. In limestones overlying the typical cold seep carbonates of Beauvoisin we also found markers for methanogenic archaea (pentamethyleicosane) associated with carbonates enriched in the ^{13}C isotope (+15,06‰). Marine-sourced mounds reveal a dominance of short-chain n-alkanes and a distinct hump of the unresolved complex mixture indicating strong effects of microbial degradation.

HOW ICEBERGS SHAPE DEEP-WATER CORAL REEFS

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Probably the largest and most extensive deep-water coral reef in the North East Atlantic is located on the Sula Ridge at a depth of 290m on the outer Norwegian continental shelf between Froyabank and Haltenbank. Investigation of the reef using high resolution (500kHz) side-scan sonar and the manned submersible JAGO has confirmed that it exceeds 13km in length, is several hundred metres wide and up to 35m in height.

This sector of the Norwegian shelf was glaciated until 12,000BP and was the site of intense ploughing by drifting icebergs (Lien, 1983). It was assumed that the sandstone substrate of the Ridge largely controlled the geometry of the reef until the recent high resolution (500kHz) side-scan sonar and manned submersible investigations showed a completely different mechanism controlled the growth of the reef. As a result of winnowing processes, large areas of the Sula Ridge are covered by morainic deposits composed of assorted boulders and pebbles. The gently downsloping western flank of the Ridge is furrowed by iceberg ploughmarks oriented in a more-or-less west to east direction which cuts the strike axis of the Sula Ridge at 30°. The plough marks can be 10 - 20m in width and some 7m deep. The levees which flank the plough marks consist of morainic material. In the upslope direction this 'bulldozed' material consists of blocks of sandstone derived from the Ridge.

On the upslope areas, these blocks are extensively colonised by the azooxanthellate coral *Lophelia pertusa*, the occurrence of which follows strictly the orientation of the levees. As the coral colonies grow and develop in height bioerosional processes break down parts of the colonies in-situ and the resulting debris collapses into the furrow. This debris of fallen blocks gradually fills the space between the colonies growing on the levees and forms in turn the substrate for the growth of further colonies such that in the mature reef it is no longer possible to easily distinguish the location of the original plough marks. The frequency of ploughmarks increases towards the top of the Ridge as larger numbers of icebergs have impacted on that part of the Ridge. It is clear that this extensive coral reef has been formed during the interval of less than 10,000 years following the decay of the Fennoscandian ice-shield.

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SUB-SURFACE RELATED LOPHELIA REEFS OFF NORWAY

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Three different *Lophelia* occurrences located along the Norwegian coastline and on the continental shelf are reviewed. The three localities have one aspect in common - their close proximity to pockmarks - craters formed in soft, fine-grained muddy sediments by hydrocarbon and porewater expulsion. Although the *Lophelia* reefs do not form within pockmarks or on their rims (probably because of silting problems), they are located on firmer sea-floors, within one kilometer from them. Furthermore, two of the occurrences are located over organic-rich hydrocarbon-charged Cenozoic sedimentary rocks (of Paleocene and Jurassic age). At one of these locations, where sea-floor sediment sampling has been conducted, there is a strong correlation between coral-bank location and high values of light hydrocarbons (methane, ethane, propane, and n-butane) in the sediments.

A model whereby Lophelia coral banks form as a consequence of local fertilisation of sediment and water resulting from focused hydrocarbon seepage is favoured as an explanation for the occurrence of these particular coral reefs.

SIZE AND ABUNDANCE OF LOPHELIA BANKS IN MID-NORWEGIAN WATERS

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Information on 129 *Lophelia pertusa* localities in mid-Norwegian waters (62° - 65°N) is presented. The positions and depths of 68 coral occurrences, as reported by fishermen and earlier scientific investigations are included in this presentation. Detailed seabed mapping along the Haltenpipe gas-pipeline across the shelf (covering an area of about 600 km^2) revealed 61 banks, of which 57 are recorded and described for the first time. These banks have an average area of 9,347 m^2. The two largest banks within the study area, are located at the north-eastern part of the Sula ridge (length > 5 km, area > 500,000 m^2), and near the coast east of Hitra (length; 800 m, area; 189,400 m^2). Based on results from the mapping of the Haltenpipe gas-pipeline the total number of *Lophelia* banks within the study area (48,000 km^2) probably exceeds 2000, with an estimated total areal coverage of between 14 and 22 km^2. In general, banks occur close to breaks, and with densities up to 9 per km^2. The highest density is found in areas with a rugged seabed topography and with a slope angle > 0.6°. The height of the banks shows a positive correlation with the bank area. The lower depth limit of *Lophetia pertusa* at the shelf break as reported by fishermen, is around 500 m, which coincides with the depth of the boundary layer between the relatively warm Atlantic Water and the cold Norwegian Sea Arctic Intermediate Water.

THE FATE OF A LOPHELIA REEF OR HOW TO CONVERT A CORAL FRAMEWORK INTO A SKELETAL MUD MOUND?

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Azooxanthellate coral assemblages are widely distributed on the margins of deep shelves, isolated banks and deep-seated fjord sills in the North Atlantic. The coral location discussed here is the midshelf-positioned Sula Ridge, a topographic high located northeast from the Frøjabark, Norwegian Shelf. Over a length of 13km, *Lophelia pertusa* forms a giant coral reef in 245m to 315m water depth on top of the ridge. The geometry of the *Lophelia* reef is largely controlled by the orientation of boulder barricades which were ploughed out from the basement by grounding icebergs during the decay of the Fennoscandian iceshield (Wilson and Freiwald, this volume). The nutrition and metabolic demands of the corals and the associated metazoan communities is maintained by a rich zooplankton supply from the fertile surface waters.

The internal architecture of individual reef bodies was investigated by deep-towed side scan sonar and a manned submersible for both ground-truthing and for obtaining high-quality samples from the reef and its interior.

The height of the individual reefs varies from 10 to 35m. The top zone of the reefs is a pure whitish coral framework formed by the thickly calcified and anastomosing *Lophelia* colonies. This zone is 30 to 50cm thick. The white zone stems from coral mucus-coated parts of the skeletal colonies adjacent to living polyps (Freiwald et al., 1997; Freiwald & Wilson, in press).

The transitional zone of the early decomposition of the mucus sheets and the coral polyps is of crucial importance for the fate of the unprotected coral skeleton. The mucus degradation is accompanied by infestations of endolithic flingi and bacteria which start to micritise the exposed parts of the coral skeleton giving way to the formation of micritic envelopes. Moreover, surface-attached microbes precipitate rings of Fe-Mn minerals 1.5 to 3µm across which form coherent rust-coloured crusts during subsequent growth which corrode the coral skeletons. The metal biofilms (cathode function) and the underlying skeletal aragonite (anode function) together with seawater act as an electrochemical cell resulting in aragonite dissolution through electrolysis. Aside these destructive processes, this zone of degradation seems to stimulate various organisms to settle and to metamorphose. Characteristic early colonisers are serpulids, bivalves, hydroids, brachiopods and the hemichordate *Rhabdopleura normanni*. In later taphonomic stages, boring sponges (*Aka* sp.) deeply excavate the interior of the *Lophelia* framework producing sponge chips. This transitional zone of early degradation is generally characterized by a lack of matrix sediment infill.

The sediment-infilled sector starts 30 to 100cm beneath the transitional zone of degradation. This zone of dead coral framework forms nearly vertical flanks and covers volumetrically most of the space of the reef mounds. Excavations undertaken from the submersible into the structure of the mounds reveal a mixed siliciclastic-carbonate mud as the infilling material. The calcareous particles are either imported from the pelagic realm (coccolithophorids, planktonic foraminifera), or are delivered as sponge chips and minute fragmented material from the coral reef itself. The source of the terrigenous muds remains to be confirmed.

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Porcupine Basin: Cold Water Corals, Mud Mounds, Sedimentology, Stratigraphy and Tectonic setting

CARBONATE MUD MOUNDS AND COLD WATER CORALS IN THE PORCUPINE SEABIGHT AND ROCKALL BANK: ARE THEY METHANE RELATED?

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The TTR programme has taken in 1997 a multi-vessel profile, with R/V *Belgica* and R/V *Pelagia* carrying out surveys for preparing the operations of R/V Prof. *Logachev*, respectively in Porcupine Basin and on Rockall Bank. One of the main tasks of the TTR7 programme was the study of seabed carbonate mud mounds in the Porcupine Seabight and on the Rockall Bank and the analysis of their possible relation to hydrocarbon seeps through the seafloor. To tackle this problem, a wide set of methods has been applied, including single-channel seismic profiling, which on board of R/V *Prof. Logachev* has been carried simultaneously with swath surveying of the seafloor with the OKEAN long-range sidescan sonar, and seafloor characterization with the O.R.E.TECH deep-towed medium-to-short-range sidescan sonar equipped with a 5-kHz subbottom profiler. Underwater video-filming and photography and bottom sampling with a large-diameter gravity corer, boxcorer, kastencorer, dredges, and TV-controlled grab-sampler has been carried out along five profiles in Porcupine Basin.

The following sub-sample analyses have been carried out: free gas (by the head-space method), interstitial water, micropalaeontological studies and different sedimentological and geochemical analyses. Furthermore, Eh and pH values have been measured on board on sedimentary cores, and abundant benthic taxa were collected and defined.

The preliminary interpretation of the geophysical field data and the first sedimentological and geochemical analyses can be summarized as follows. Seismic, sidescan sonar and subbottom profiler data suggest that some local acoustic anomalies might be connected with gas flux or shallow gas accumulations. The shallow core examinations on deck however did not show any visible evidence for the presence of gas or any geochemical clues. These observations were confirmed by measurements in fresh sediments. The values obtained are typical of normal basinal sediments. The continuous TV records and discrete photographic pictures taken along lines running over carbonate mounds revealed neither gas seeps through the seafloor, nor associated phenomena. According to the conclusions drawn by the biological team, none of more than 100 epibathyal species defined from carbonate mounds belongs to chemosynthetic communities. In other words, they cannot be looked upon as being related to methane seeps or enhanced bacterial activity.

These results, together with low methane concentration in sediments (from chromatography data) and low EOM content, can not suggest the existence of detectable hydrocarbon fluxes through the carbonate mounds in the shallow sediments along the investigated profiles. The mineralogical composition of carbonate components (carbonate inclusions, fragments of shells and corals, etc.), as well as isotope values of $\delta^{13}C$ and $\delta^{14}C$ for coral fragments collected from different parts of the sequence recovered attest that the stable hydrocarbon flux has been absent on the samples sites during the whole Holocene and part of the Pleistocene, at least over 70 ka.

Thus, the question of the nature and origin of the carbonate mud mounds of Porcupine Basin remains open. Surface evidence suggests that - at present and in the recent geological past - the distribution and the patterns of active growth of cold water corals inhabiting these mounds are closely controlled by climatic variations and bottom currents. On the other hand, the numerous buried ring reefs ("Magellan mounds") mapped by R/V *Belgica* argue for a past fluid flow event, and some acoustic anomalies can be interpreted in terms of local gas accumulations or fluxes. What probably eludes our efforts might be patterns in space (focused versus diffusive fluxes) and/or time (transient versus steady-state flows). An indirect evidence for this could be some observations of abnormal increases in the concentration of methane in the uppermost parts of several cores. Together with the observation of possible gas plumes on the subbottom profiler records, this might suggest charging of the sediment with methane-saturated water from nearby venting sites.

Only drilling the base of the mounds will probably bring the clue towards their origin.

THE GEOLOGICAL DEVELOPMENT OF THE PORCUPINE BASIN

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The Porcupine Basin is a north-south trending basin lying west of Ireland. It is approximately 230km long and is 100km at its widest, narrowing northwards to 65km. Water depth increases southwards from 300m in the north to over 1500m in the south where the basin opens out into the Porcupine Abyssal Plain.

The Porcupine Basin is underlain by thinned continental crust, 9-10km thick. It has a roughly symmetrical profile and contains up to 10km of Mesozoic and Cenozoic strata. A Devonian to Carboniferous succession of non-marine to marginal marine clastics represent the deposits of an early east-west sag basin. Later, Permo-Triassic extension produced a number of small rift basins in which red-bed continental clastics were deposited. Post-rift marine and non-marine shales and sandstones were followed by onset warp and rift clastics of Late Jurassic to Early Cretaceous age. Cretaceous and Tertiary thermal subsidence then took place, with associated basin fill. The subsidence was interrupted in Aptian-Albian times by the development of rift related deltaics and also during the Early Tertiary when a major regression resulted in sandstone deposition in deltaic and submarine fan environments.

Present day features in the Basin include numerous high relief, deep water carbonate build-ups and the development of a deeply incising, low sinuosity channel system draining from the continental shelf south-west of Ireland into the deeper Porcupine Abyssal Plain.

THE CURRENT SWEEP CONTINENTAL SLOPE AND GIANT CARBONATE MOUNDS TO THE WEST OF IRELAND

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The TTR 7 cruise showed for the first time that there are strong currents in the eastern Porcupine Seabight and on the slope southeast of the Rockall Bank. The data confirmed published observations of a strong easterly current on the slope north of Porcupine Bank (Lonsdale and Hollister, 1979). In each of these three areas there were very large (up to 350m high) carbonate mounds in depths of 500m to 1100m. Coring shows that the mounds appear to be built mainly from the breakdown of abundant and relatively fast growing *Lophelia porifera* and *Madrepora oculata*. The main evidence for currents comes from observations with the 30kHz and 100kHz deep towed sidescan sonars. Confirmation of these currents comes from seafloor TV photographs and from sands and gravels in seabed samples. Bedforms include barchan like sand waves and also current parallel forms such as sand ribbons and obstacle marks. The strong poleward flowing slope current known from west of Norway and Scotland (Kenyon, 1987) is thus extended southward almost to the Bay of Biscay. The currents affecting the SE Rockall Bank appear to be particularly complex as there seems to be both a slope parallel flow to the south west as well as a slope transverse directed flow. The slope transverse flow could be due to internal tides (New, 1987) and/or to cascading currents. First results from a high resolution ocean circulation model fit with these geological observations.

The corals appear to favour vigorous currents but can be destroyed by mobile sands. Thus, once established, mounds offer a habitat that is relatively sheltered from mobile sands and rapid build up should take place. Mound shape can be partly explained by their relationship to known and predicted currents. East of the Porcupine Seabight and north of Porcupine Bank the mounds are elongated subparallel to the contour currents. East of Rockall Bank a near continuous blanket of mounds appears to be moulded by both along-slope and across-slope currents. In the mound province north of the Porcupine Seabight the lack of lineation of the mounds could be related to a weaker and/or non-linear current regime.

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CELTIC RING REEFS: A GENETIC HYPOTHESIS

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A high-resolution single-channel seismic survey, carried out with the research vessel R.V. *Belgica* in May 1997 in the framework of European MAST3-projects, has revealed unique acoustic features in the Porcupine Basin sediments, offshore south-west Ireland. Various mound-like structures can be recognised, among which the *Magellan* mounds and the *Hovland* mounds. The boundary between these distinct mound areas is remarkable and is now being investigated with additional support of side-scan sonar data (acquired during the TTR7 *Logachev* cruise) and low-resolution industrial data.

The *Magellan* structures, discovered a few months earlier by a commercial vessel, are located in water depths of 500 to 700m and cover an area of 1200km^2 [N: 52°10 - 52°35, E: 12°15 - 13°10]. In terms of sizes, the *Magellan* mounds are generally larger in the southernmost part of the province - where a few even reach the surface - but tend to fade out in north-eastern direction. They appear as single, buried knolls or highly symmetric twin features, the latter interpreted as cross-sections through ring structures. This identification points towards a possible axial fluid expulsion mechanism. Another important aspect of the *Magellan* structures is the fact that they are almost all clearly rooted to a common stratigraphic horizon. Both this sudden onset and their nearly simultaneous decay and burial argue for a transient event, well confined in time and space. In this paper, a methane hydrate mediating hypothesis is proposed to explain the above observations. This model suggests a causal link between a climatically-controlled fluctuation in the bottom water temperature and the growth and decay of a methane hydrate plate, yielding distributed seep sites. The buried reef bodies are thus interpreted in terms of a possible response of biological communities to such environmental changes.

INFLUENCE OF SURFACE-WATER TEMPERATURE OSCILLATIONS ON THE DEVELOPMENT OF DEEP-WATER CORAL BUILD-UPS IN THE PORCUPINE BASIN (NORTH ATLANTIC)

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The area of deep-water carbonate mounds located in the Porcupine seabight has been investigated during the first leg of the TTR7 cruise. On the tops and slopes of these carbonate mounds living communities of corals associated with other fauna were found. Detailed micro-paleontological and mineralogical analyses of sediments were carried out for the determination of the influence of surface-water temperature oscillations on the development of these communities. Quantitative analysis of coccoliths was applied for the estimation of palaeotemperature characteristics of surface water. X-ray analysis of the sediments (L. Mazurenko, in this issue) is complementary to micropaleontological data. Four samples of the corals were dated using ^{13}C technique.

Two cores AT2G (52.13.66N / 12.33.96W, waterdepth 793m, total length 392cm) and AT16G (52.08.80N / 12.49.80W, waterdepth 691m, total length 389cm) taken on the tops of carbonate mounds have been chosen for the study.

Homogeneous sediments recovered by core AT2G contain abundant coral detritus. On the top of this core living corals were found. Core AT16G recovered an alternation of layers rich in corals and without them. Investigation of coccolith distribution in core AT16G allows us to distinguish five climatic periods that approximately correspond to the five last isotopic stages. In core AT2G only three climatic periods were revealed. Sediments typical of glacial period were not observed in this core. The climatic periods corresponding to cold (glacial) isotopic stages 2 and 4 were not found in the paleontological record. Only transitional periods between glacials/interglacials were encountered. On the top of the carbonate mound sampled by core AT16G, the intensity of coral growth changed in accordance with the changes of surface-water temperatures: during the glacial periods, the coral growth almost ceased, while in the interglacial periods, the growth of corals was rapid. This situation is repeated for another carbonate mound: the coral growth was very active during the interglacial periods. Since glacial sediments were not preserved here there is no evidence for coral growth activity during the cold periods. The coral growth on this carbonate mound (site AT2G) is very active now, more active than on the other one. The growth rate of this carbonate mound in the Holocene is very high -8.25cm per 1000 y. This phenomenon is probably related to the location of carbonate mounds at different water depths. The top of the carbonate mound, on which site AT2G is situated is 102m deeper than that of the other one. Probably at this depth water mass more favourable for coral growth. The data presented support the hypothesis that the development of deep-water coral mounds in the North Atlantic was controlled by changes in oceanic circulation.

SEDIMENTOLOGY AND GEOCHEMICAL CHARACTERISTICS OF A CORE TAKEN FROM A "HOVLAND" MOUND

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Hovland et al. (1994) describe groups of sea bed mounds from the Porcupine Basin between 52°-52°30'N and 12-13°W. The "Hovland" mounds are besides the "Magellan", "Belgica" and "Logachev" mounds the largest outcropping mound features in the Porcupine Basin. These mounds are located in water depths of 650-1000m. For a preliminary geochemical and sedimentological investigation of the on-mound sediments, we choose gravity core AT16G taken during the TTR-7 cruise. The selected gravity core is taken on the crest of a composed mound with a size of 1.5km length and 700m width and an elevation of ca. 100m at a water depth of 690m. The upper 6cm of the core consist of a yellow foraminiferal sand with ahermatypic corals (Madrepora, Lophelia), shell fragments and echinoderm needles. This yellow layer is followed by a sandy facies with alternating layers of coral and shell fragments. The clay fraction in the sediments increases smoothly downwards. The interval between 111-205cm comprises strongly bioturbated silt. Starting of 1.70m bsf black spots and layers are more common and the facies changes into a dark to green clayey silt. This is probably the start of the sulphate reduction zone, characterized by the occurrence of pyrite. In the lower part of the core, around 3.10m bsf the carbonate fragments (corals and shells) increase again. Carbonate sediments presently accumulate on the mounds, mixing with quartz and lithic pebbles and cobbles of glacial origin. The non-carbonate mud fraction consists of quartz and smaller amounts of feldspar, mica, kaolinite, pyrite, dolomite, heavy minerals, glauconite and clays minerals. In general the carbonate mineralogy of deep-water carbonate sediments are largely controlled by the environment, his faunal assemblage, and by the selective dissolution of the more soluble carbonate minerals. Biota found in the deep-water carbonate sediments are dominated by planktic foraminifera, calcareous nannofossils (coccoliths, LMC) and pelagic molluscs which provided the calcite. Corals seem to be the only source of aragonite. In the studied system it is obvious that 2 major sediment sources are involved: pelagic and detrital sedimentation. Detrital sediments have probably been transported from the Irish Continent during the Pleistocene glacial time by floating ice (Belderson et al., 1973). Isotopic analyses of 21 bulk carbonate samples through the core showed a large variation in $\delta^{18}O$ (-3.6 to 2.6‰ PDB) and a rather stable $\delta^{13}C$ values (mean values of -0.02‰ s 0.73‰ PDB). $\delta^{13}C$ values shows clearly a marine isotopic signature. Variations downcore are possibly due to different contributions in faunal assemblage. The fluctuations in $\delta^{18}O$ can be due to variations in temperature through time. Out of the correlation of the bulk carbonate $\delta^{18}O$ values and the standard planctonic $\delta^{18}O$-curve (SPECMAP) 4 isotopic stadia (up to isotopic stadia 5) have been distinguished. However the inferred temperature variation calculated from the data set shows that the $\delta^{18}O$ values are not only dependent of temperature. A close correlation could be observed between levels with accumulation of corals and isotopic heavier stages. It is well known that the ahermatypical corals are enriched in ^{18}O relative to equilibrium precipitators of calcium carbonate from sea water (Land and Lang, 1977). The positive overprint in $\delta^{18}O$ and negative in $\delta^{13}C$ can be explained by the contamination of aragonitic coral fragments. Coral free zones show more negative values in $\delta^{18}O$ which is interpreted in terms of the absence of corals during warmer periods. The latter seem to grow preferentially during glacial times. This hypothesis supports also the stable $\delta^{13}C$ data which during warmer periods reflect an increase in coral and other faunal assemblage. Variations in $\delta^{18}O$ are, however also function of the composition of seawater. At the present time the mounds occur at the boundary between East North Atlantic Water and Mediterranean Water layers (Rice et al., 1991). A diverse fauna, consisting of forams, coccoliths, shells and corals downcore indicate a variation in source of marine water. Changes in water stratification triggered by glaciation excluded some sources and caused other water circulations, with an other isotopic composition. Therefore the $\delta^{18}O$ values are probably related to the combined effect of water temperature, composition and presence of coral fragments and other bioclasts. The 5 sampled corals in the core are enriched in the lighter carbon isotope ^{12}C, except one anomaly. The latter has a more or less similar value as the bivalve shells. Out of the isotopic data is believed that the fine-grained carbonate originated from autochtonous marine-precipitation.

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MODELLING OF ACOUSTIC BACKSCATTER FROM CORALS: AWAY TO MAP CORAL FIELDS

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A set of deep-towed O.R.E.tech sidescan sonar lines was acquired during the TTR-7 Cruise of the RV *Professor Logachev* in the Porcupine Basin. The study area is known for carbonate mud mounds with coral accumulations. This presentation is focuses on the possibility of using deep-towed sidescan sonar data for the recognition and mapping of deep-water coral fields. This issue has been examined by means of comparison of the high-resolution sonographs with the results of computer modelling. At the first stage of the investigation, the seafloor sonographs were analyzed. In order to distinguish areas with corals, the underwater TV and sampling information was plotted on the sonographs according to the underwater navigation data. Spectral analysis of areas with corals and without corals did not give any systematic characteristic criteria, since the spectra were quite similar. However, coral containing areas were found to be marked by stronger backscattering relative to non-coral ones, which made the modelling possible.

Subsequently, a mathematical model to process the backscatter signal from corals has been developed. The model calculates acoustic energy backscattered from a single coral thicket approximated by an object of a simple shape. The rounded cone of certain height, diameter, and density has been chosen as such an object. A set of such objects positioned in different ways was used as a model for coral sickets, which in their turn can form groups and larger fields. This model, together with the bathymetrical information and physical parameters of the surrounding sediments was used to solve this direct acoustic problem. At the final stage, the comparison of the simulated sonographs and the real data has been established.

The results obtained demonstrate that this method allows the distinguishing and mapping of areas inhabited by corals, however, precise bathymetry information is needed.

TEMPERATURE DEPENDENCE OF ISOTOPIC COMPOSITION FOR THE SCELETAL AHERMATYPIC SLERACTINIAN CORALS

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Often $\delta^{18}O$ of ahermatypic deep-sea corals are used to deduce of calcite precipitation. During the TTR-7 cruise, corals which cover the tops and slopes of carbonate mounds were sampled in the Porcupine Seabight. For geochemical studies, two cores, AT2G and AT16G were chosen from the top of carbonate mounds situated at the waterdepth of 691 and 793m respectively. Carbon and oxygen values of the skeletal aragonite from ahermatypic corals have been measured for 13 separate corals. Additionally, the Cl^- , Mg^{2+}, and Ca^{2+} concentrations in pore water were determined for 16 pore waters amples along the cores recovered.

The sceletons of these corals exhibit a wide range in isotopic composition. Each sample is depleted in ^{13}C and ^{18}O relative to calcium carbonate in isotopic equilibrium with ambient sea water system. Carbon isotope values (from -1.5‰ to -10.2‰) show that sea water is the most possible source of sceletal corals carbon. The results obtained show that $\delta^{13}C$ and $\delta^{18}O$ are closely correlated, indicating that low carbon isotope values are associated with the depletion in ^{18}O isotope. It can be attributed to variations in the relative contributions to skeletal carbonate of metabolically-derived CO_2 and dissolved bicarbonate sources. The studied sediments were ascribed to glacial and interglacial periods on the base of micro-paleontological and mineralogical data. Higher $^{18}O/^{16}O$ ratios in corals and the decrease of C_l^- concentration in pore water can be correlated with interglacial periods. Despite the obvious isotopic disequilibrium, the systematic relationships between isotopic composition and environmental parameters are clearly apparent, permitting the use of stable isotope ratio data for ahermatypic corals and pore water chemical composition in paleoecological interpretations.

DISTRIBUTION AND COMPOSITION OF ORGANIC MATTER IN SEDIMENTS FROM CARBONATE MOUND OF THE PORCUPINE SEABIGHT

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Carbonate mounds were investigated in the Porcupine Seabight during 7-th TTR Cruise of R/V "*Professor Logachev*". One of the aims of the survey was to elucidate the role of the hydrocarbon gases in the origin of these mounds. During the cruise, a total of 248 samples from 17 gravity cores were collected for the following investigations: determination of Total Organic Carbon (TOC); fluorescent analysis of Extractable Organic Matter (EOM); bituminological analysis for determination of type and quantity of bitumen components. The TOC content varies from 0,05% to 0,59%. The average value of TOC in basinal sediments is ~0.35% (35 samples), in the sediments above barrier reefs without corals is ~0.31% (31 samples) and in sediments from carbonate mounds containing corals ~0,19% (44 samples).The EOM data range in values from 0% to 0,005%. The most common values are within 0,00025% to0,0006%. The higher values of EOM (> 0,002%) are noted for the cores taken from an area around a mound(sites AT-07G, AT-11G) and for sediments above barrier reefs (site AT-19G). The lowest values (0% to 0,0001%) are found in core AT-05G with abundant corals; in core AT-18G demonstrating a geochemical front (with strongly oxidized sediment in a layer at 48-100 cm) and rare layers in the cores with low (<0,0006%)background value of EOM (sites AT-02G, AT-16G, AT-17G, and AT-22G).

According to the results obtained on TOC and EOM concentrations, all studied cores can be divided into four groups:

1. The cores with different lithology, but similar along-core distribution of TOC and EOM (AT-03G, AT-05G, AT-09G, AT-18G, AT-19G, AT-20G, and AT-21G). The TOC content ranges from 0,09% to 0,54% and the EOM values range from 0% to 0,0025%. The EOM content is controlled by the TOC content.
2. The cores with intensively bioturbated layers: AT-16G (207-213 cm) and AT-22G (175-185 cm).These layers are characterized by an increase of the TOC content (0,42%-0,45%) and negligible content of EOM(< 0,003%).
3. Cores AT-02G, AT-06G, AT-07G, AT-11G, AT-17G, and AT-23G which were taken from different parts of the mounds: The content of TOC almost does not change along the core (variations are <0,1%), but the EOM concentration increase several times in intervals of 345-350cm (AT-02G), 185-190cm (AT-06G), 100-230cm (AT-07G), 0-40cm and 230-275cm (AT-11G), 47-58cm (AT17G), and 0-10cm (AT-23G).
4. In discrete intervals from cores AT-17G (48-53 cm), AT-19G (122-132cm and 288-295 cm), AT-21G (213-223cm and 247-257 cm), AT-22G (49-59 cm, 238-348cm and 298.5 to 308.5cm) some sulphur was detected. These intervals also have increased values of EOM.

The main results of the studies are:

1. Most of the cores show background values of the TOC and EOM content.
2. In cores AT-07G, AT-11G, and AT-19G, the concentration of EOM is much higher than that in the rest of the investigated cores.
3. The reduced values of TOC and EOM in coral-containing layers are apparently caused by intensification increasing of bottom water circulation or (and) low sedimentation rate.
4. Increase of EOM concentration in the cores is not in relationship with coral layers. Chromatographic analysis of gaseous phase from the cores is in progress.

SUBBOTTOM CURRENTS ON THE PORCUPINE MARGIN STUDY BY SIDE-SCAN SONARS

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A 30 kHz Side-scan sonar survey accompanied with 6.5 kHz subbottom profiler data has been conducted at several areas of the Porcupine Seabight during TTR-7 cruise. The data set shows the seafloor of the northern and eastern parts of the basin is strongly affected by northerly directed subbottom current. The current is mainly localized within the depth interval ranging from 500 to 1000m.Variety of bedforms observed on the sonographs allows suggesting certain zonality within the current. Thus, core of the current has width of about 3.5 km. Smoothed bottom and streaked pattern is observed on the side-scan sonar records within this zone and seafloor beneath the core is mainly affected by erosion. Streaked pattern suggests current's speed up to 1m/s. Peripheral parts of the current could be identified by presence of barchan-like features and sandy wave fields. These bedforms are likely to beformed within less dynamic environment where current's speed allows transportation of relatively coarse sediments. Seabed mounds inhabited with ahermatic corals were found to be located mainly at the peripheral parts of the current and their present shape is controlled by current direction. According to subbottom profiler data development of mounds depends on current behaviour. Normally mounds situated close to the current path reveal inner stratification reflecting several periods of the mound's burial with coarse material and subsequent recovering of the coral draping. Such burials caused by increased input of current-derived sediments significantly restrict the mound's growth.

CHANNEL ARCHITECTURE AND ACTIVITY IN THE GOLLUM CHANNEL, PORCUPINE SEABIGHT

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The Gollum Channel system is one of the very few lengthy, leveed channel systems known from the NW European margin. Previous studies (Berthois & Brenot, 1966; Belderson & Kenyon 1976; Kenyon et al., 1978; Kenyon, 1987; Rice et al., 1991; Kenyon, 1997) have revealed that it is a low sinuosity tributary system with narrow, steep-sided, flat-floored channels. Channel heads are in c.400m depths with the channel gradients being greatest on the upper slope and decreasing down-system to the south-west where at 2300-2500m a few channel meanders are present. In the middle reaches the channels are characteristically 100-280m deep and 1.5km across. The system continues down to a depth of c.3500 where it becomes structurally-controlled. New survey data and core data are presented from the TTR7 cruise of the RV Prof. Logachev. OKEAN side-scan sonar and single-channel high-resolution seismic data from the channel heads reveal seven major channels with a number of successive infills and plugged channels. O.R.E.-Tech side-scan sonar data from the middle reaches of the channel system show a steep-sided, flat-bottom channel with evidence of gullying on the channel walls. The gullies suggest that the system is not fully active at present. Extensive terraces with scallop-shaped edges are present on either side of the channel. Though at first thought to be remnants of former channel meanders, the presence of small parallel ridges is best explained as small rotational fault traces on slump scars. Core data from the overbank, terraces, channel walls and channel floor reveal some evidence for minor turbidity current activity during oxygen isotope stage 2. Recent activity is unlikely with debrites below thin hemipelagic sediments forming the uppermost unit in one channel floor core. Surface sands in the upper channel are believed to be due to strong present day contour currents. Turbidite deposition on the terraces during stage 2 is not recorded, suggesting that the channel was relatively inactive during the last glacial maximum.

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ISOTOPIC CHARACTERISATION OF AHERMATYPIC CORAL ON A "HOVLAND" MOUND

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Recent sampling surveys (Hovland et al. 1994 and TTR-7 cruise) of carbonate mounds in Porcupine Basin (especially the "Hovland" mounds) suggest that the crests and slopes of these mounds are covered with dead and living ahermatypic coral species. TTR-7 sampling (gravity cores and TV grabs) show clearly that the ahermatypic coral *Madrepora occulata* appears to be far more common than *Lophelia Sp.*, which was expected to be the dominating coral. Stable isotope analyses were carried out on ahermatypic corals collected by TV Grab TTR7-24GR and gravity core 16G, both taken on a "Hovland" mound. Detailed sampling of the separated coral compounds (polyps, stem, polychaete tubes, surface layers and encrusted bryozoa) was carried out on 14 M. occulata (1 living species) and 4 *L. species* and on 2 shells and 1 echinoderm needle (as reference) for carbon and oxygen stable isotope investigation. Bulk skeleton $\delta^{13}C$ values vary between +1.7 and -5.4‰(PDB) and values of $\delta^{18}O$ vary between +4.3 and -0.6‰ (PDB). In comparison with the isotope data of shells and the echinoderm needle, the corals are characterized by a higher concentrations of lighter isotopes. The $\delta^{13}C$ and $\delta^{18}O$ values of skeletons show an excellent positive correlation over a wide range of isotopic compositions. Swart (1983) attributes the apparent coupling of the C and O isotopes to the effect of absence of photosynthesis, as photosynthesis only affects the O isotopes. In the ahermatypic corals, respiration and thermodynamic fractionation are the only processes affecting C and O and therefore the overall fractionation of the isotopes will be positively correlated. Within individual specimens large differences in the isotopic composition of separate skeletal elements occur. In general, the variation in $\delta^{18}O$ is less than that in $\delta^{13}C$. The variation in

$\delta^{18}O$ values along stems or different stemparts of the same species could not be explained by fluctuations in temperature and water composition only. Intraskeleton isotopic heterogeneity is explained by differences related to variations in growth rate during the life span of the coral (Emiliani et al., 1978). Those isotopic variations presumably reflect also changes in food supply. We explain the variation in $\delta^{13}C$ (between +1 and -10‰) in our data set by assuming that the isotopic composition of the skeleton is controlled by mixing between inorganic CO_2 (-7‰) and respired CO_2 (-13.5 to -19.45‰). The relative contribution of C and O from inorganic and metabolic sources is thought to be controlled by factors that influence the efficiency of metabolic CO_2 removal via diffusion through coral tissues to the ambient sea water (Swart, 1983). Presence of the polychaete *Eunice sp.* seems to stimulate the coral secreting a surplus of aragonite around the parchment tube of the worm. Those aragonite crossing tubes between coral stems are filled with sediments. $\delta^{18}O$ values of these crossing tubes are close to equilibrium; $\delta^{13}C$ values show a larger variation. This can be interpreted as a vital effect stimulated by changes in the environment. Parts of the living coral that are not protected by mucus, and dead corals are encrusted by bryozoa (Henrich et al., 1996). The honeycomb-like bryozoa sheets attached on *M. occulata* and *L.species* show characteristic isotopic values of $\delta^{13}C$ between +1.36 and +1.56‰ and of $\delta^{18}O$ between +2.4 and +2.33‰. Hydrographic studies in Porcupine Basin it show that the ahermatypic corals accumulate below the thermocline, which exists at 600-1400 m water depth, where the temperature falls from 10°C to 4°C. (Rice et al., 1991). Also, intermediate nepheloid layers, on suspension load currents have been recorded at 700-800 m depth. These currents are probably responsible for the food supply of the coral thickets. It would appear that the corals have settled on these mounds to take advantage of the increased currents present near the bottom, and of the associated suspended material supply. The wide range of isotopic compositions reflects variation in geometry, water temperature, growth rates and even local isotopic regimes (sulphate reduction).

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ADVANCED PROCESSING OF OKEAN LONG RANGE SIDESCAN SONAR DATA

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The raw OKEAN long range sidescan sonar data collected in 1997 during the TTR-7 Cruise of the RV *Professor Logachev* were very noisy. They allowed only recognition of large and contrasting bottom features, while smaller details were hardly visible. In order to improve the quality of the sonographs and digital mosaics, the properties of the signal and noise on the OKEAN records have been analyzed and the advanced processing flow has been developed.

Parameters of the filter which allows to obtain the largest signal-to-noise ratio have been chosen based on the results of the analysis of the signal and noise in the frequency domain, as well as by trial-and-error method. The amplitude spectrum of such a filter has been found to be approximately similar to that of the studied signal with some corrections for higher and lower frequencies. This filter being applied to the data significantly increases signal-to-noise ratio making even small and low amplitude anomalies better resolved.

However, at the same time such a filtering emphasises artifacts caused by variations in the directional pattern of the sidescan sonar transducers. The time-varying gain (TVG) procedure traditionally used to correct these artifacts turned out to be not efficient after filtering. A new algorithm of angle-varying gain in a sliding window has been developed and applied to the data, which efficiently compensates variations of the directional pattern improving significantly the quality of sidescan sonar images.

DISTRIBUTION OF CORALS AND BOTTOM CURRENT IN THE PORCUPINE SEABIGHT AND ON THE PORCUPINE BANK, NE ATLANTIC (FROM UNDERWATER TV AND SIDESCAN SONAR SURVEY)

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During the TTR-7 cruise on board the R/V "*Professor Logachev*", the detailed TV survey of some parts of the sea bottom in the NE Atlantic was carried out. The equipment used consists of 3 modules: module of uninterrupted video recording; module of discrete video recording; and photo module. The TV profiles were run on the basis of preliminary interpretation of seismic and sidescan sonar data (OKEAN long range and O.R.E.tech medium to short-range sonars), as well as bottom sampling.

Three TV records were obtained: from the northern and eastern parts of the Seabight, as well as from the northwestern slope of the Porcupine Bank. All of the TV profiles were run at the upper part of the continental slope of the Ireland margin. The water depth at the survey sites varies between 500 and 900 m. The seafloor in the study areas consists in general of sand/mud and carbonate sediments with dropstones and colonies live and dead corals. Two types of the seafloor surface were observed. The first one is characterized by significant smoothness and flatness, with rear traces of bottom currents. The sea bottom is formed by sand-clay sediments, often rather dense, with small dropstones. The second type of the seafloor surface is notable for the presence of carbonate mounds; the seafloor topography is very rough, and a number large dropstones are present. The seafloor is composed here of clay-carbonate sediments with fragments of dead corals and colonies of live corals. The relative height of the carbonate mounds is not more than 110 m. The corals were observed at each surveyed carbonate mounds, independently of the study areas. The colours of corals were white, light grey and orange/pink. The corals are observed from the base of the carbonate mounds to their tops. The size of coral thickets changes within 0.1 - 1 m.

The analysis of the TV recording shows that the live corals are grouped at that side of the mounds which faces opposite the bottom current direction, at the water depth of 750 to 850 m. According to the sonar survey, the carbonate mounds have both circular and elongate shapes. The size of individual circular mounds is found to be around 1 km across. The areas of the coral development are possibly characterized by stronger backscatter in sonographs.

FINE SEDIMENT FROM DIFFERENT MORPHOLOGICAL FEATURES OF THE PORCUPINE SEABIGHT BASIN FLOOR

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The region of carbonate seabed mounds was sampled during the TTR-7 Cruise. Several cores were taken from tops, flanks and moats of the carbonate mounds and from surrounding areas. Study of these cores allowed us to compare the sedimentary environments on the mounds and in the rest of the basin. Cores AT2G, AT16G (tops of mounds) and AT18G (flank of mound) have been chosen as the most representative for the investigation. Sediments in these cores contain a large amount of detritic material (corals, shells, etc. up to 80% of total volume) which is not presented in pelagic sediments in this basin. Cores AT3G (from a moat) and AT7G (at the distance of the mounds) were taken for the comparison. The mineralogical study included thin-section and X-ray analyses of carbonates and clay minerals sampled from each layer recovered by these cores. The X-ray data shows that hydromica and chloride are dominated clay materials. Small amount of smectite, chlorite and kaolinite was also observed. The rest of fine fraction included such minerals as: quartz, feldspar, calcite, dolomite, siderite, aragonite, magnesia calcite and pyrite. The data obtained show that cores taken from mounds and basinal hemipelagic sediments are represented different lithologies. The oldest recovered sediments belong to Emiliania huxleyi Zone (Saoutkin, this volume). In general, sedimentary succession is composed by interbedded layers, which correspond to glacial and interglacial periods.

The main components of sediments in glacial periods are:
1. On mounds (AT16G): clay material ~45%, terrigenous material ~ 30%, carbonate ~25%.
2. From a moat (AT3G): clay material ~50%, terrigenous material ~ 40% (the size of units increases as a result of sea-bottom currents), carbonate ~10%.
3. In the rest of the basin (AT7G): clay material ~60%, terrigenous material ~25%, carbonate ~15%.
   In interglacial periods:

On the mounds (AT16G, AT2G): bioclastic material -30-80%, terrigenous material ~10%, clay material - 15-60, carbonate ~ 5-10%. At the base and at the distance of the mounds (AT3G, AT7G) interglacial periods in sediments are poor represented or not represented.

Interglacial clays have different ratio of minerals from glacial ones. Normally the first are enriched in hydromica but contain less chlorite.

The layers with the increased amount of sandy grain units (forams, quartz-feldspar, glauconite, etc.) are observed on the boundaries of interglacial and glacial periods (AT2G, AT16G). Good sorting suggests that these layers are the result of sea bottom currents. These layers are mainly composed by fragments of corals, shells etc. ~25%, terrigenous material ~30%, clay material ~15%, forams ~30%. The similar layers are found in cores taken from a moat (AT3G) and at the distance of the mounds (AT7G).

Such minerals as pyrite, dolomite and siderite were found in sediments of carbonate build-ups and basinal hemipelagic sediments in approximately equal proportions. An absence (less than 0.5%) of magnesial calcite in sediments lets it make a guess about the terrigenous origin of dolomite. An absence of aragonite in sediments of glacial periods confirms that there was no coral-derived detritic sedimentation in these periods. Cores from the mounds recovered none extended sedimentary succession then cores from the basin floor.

Reduced thickness and presence of different lithologies suggest more actives sedimentary environment at the mounds. This could by a result of bottom currents activity. Layered succession like describe above formed as a result of continuos supply of biogenic detrital material that is subsequently being re-deposited by bottom current.

Such conditions can be active if amount of coral reef develops from a coral patch of limited size migrating over the mound surface. This coral patch is a source for coral detritic covering mound's surface.

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RECORDS: WHAT IS THEIR PHYSICAL NATURE?

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The main purpose of the TTR -7 cruise of the R/V *Professor Logachev* in the north-eastern Atlantic in 1997 was the investigation of the deep water carbonate mounds. Deep towed O.R.E.tech acoustic complex with 6 kHz subbottom profiler and 30 kHz sidescan sonar was used for the investigation together with seismic profiling, underwater TV and other methods.

There is an option, that carbonate mounds grow due to hydrocarbon gas seepage from deep layers. Thus, any indicators of high gas concentration in sediments or gas venting were searched on the data obtained.

Plum-shaped anomalies in the water column were observed on the subbottom profiles along lines Orat-1 and Orat-8, run across the area of carbonate mounds in the Porcupine Seabight. These anomalies may be interpreted as side reflections, gas plums or schools of fish.

Trying to understand the real nature of these anomalies we thoroughly analysed the acoustic data. If these anomalies are side reflections, they must be well expressed at the same arrival times on one of the sides of the unprocessed sidescan sonar records, with shadowed areas behind them. However, these anomalies happened to be hardly visible on the sonographs, and they were no shadows either.

This suggests that they cannot be caused by the bottom relief. Band-pass filtering has been applied to the data, which provided additional confirmation of this interpretation: after the filtering the bottom and sub-bottom reflections became better resolved while the anomalies maintained their original chaotic pattern. Therefore, they are likely to be scattered waves from acoustic disturbances in the water column, which could be either gas plumes or schools of fish. Although the absence of any disturbance in the layering below these anomalies casts some suspicion on the gas theory, it still cannot be excluded.

HIGH-RESOLUTION SEISMIC INVESTIGATIONS OF THE BELGICA-LOGACHEV MOUND RANGE ON THE EASTERN MARGIN OF PORCUPINE BASIN, SW OF IRELAND

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Within the framework of the EC ENAM II and CORSAIRES project, as well as for testing new technological developments in the framework of the Belgian Antarctic Research Programme, "R/V *Belgica*" has surveyed in May 1997 part of the eastern margin of Porcupine Basin. Students from Lomonosov Moscow State University had joined the cruise as part of the "Floating University - TTR7" exchanges.

The high-resolution sparker profiles revealed surprising features. High, largely buried mounds, towering about 200 m above a transparent and deeply eroded sole layer, seem to fringe a buried shelf edge as barriers of limited lateral extent. The reefs are embedded in a thick and wavy drift sequence. Sediments ponded upslope or between two barriers display moat-like structures on the flanks of the mounds.

The subsequent TTR7/CORSAIRES cruise with R/V "Prof. Logachev" in July 1997 has given evidence of similar features further north. *Lophelia* and *Madrepora* corals were sampled on this range. Such association suggests some possible analogy with shallower and smaller examples of shelf-edge fringing reefs, described e.g. along the Norwegian margin. The "Belgica-Logachev" mound ranges are found at depths of 750 and 1500 m and can have a lateral extent of 20 km. The downslope erosional boundary of the transparent layer could easily be mapped on the few "*Belgica*" profiles, but uncertainty remains about the upslope boundary and the lateral north-south extent of the reefs. The "Porcupine-*Belgica*" campaign in May 1998 should allow to elicit the full extent of this mound range.

The slope deposits can be interpreted in terms of three sequences.

- A "pre-reef" sequence: the sequence below the erosional surface at the base of the transparent sole is characterized by small-scale sigmoidal prograding units, on a slope terminated uphill by a rather well defined palaeoshelf edge. These structures bear striking similarities - though at a much smaller scale - with probably Plio-Pleistocene features found at the Celtic Margin.

- A "syn-reef" sequence: there are two stages of deposition. Firstly the "transparent sole" unit has been deposited on the erosional surface. It has itself been deeply eroded and shows as an "outlier" of a sequence which probably had a wider regional extent. Next the "towering" reefs grew on top of this sole, probably progressively buried by prograding drift sediments.

- The "post-reef" sequence: a cover of prograding drift sequences and a late drape of probably hemipelagic sediments. Rythmic amplitude variations within these drift sequences could call for some climatic control.

The estimated age of these structures is Plio-Pleistocene, though no firm constraints are available yet. Drilling will be necessary if we really want to elucidate the true nature of the reefs and the transparent layer, as well as their age. Very speculatively, the origin of such barrier-like features might be searched within a combination of hydrodynamic controls (internal waves along shelf edge) and high nutrient fluxes in cold, glacial environments. But some acoustic anomalies still argue for possible gas migration features. Further research is required for solving these enigma's.

LITHOLOGY OF MUD BRECCIA CLASTS FROM THE COBBLESTONE AREA (WESTERN PART OF THE MEDITERRANEAN RIDGE)

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Lithological and paleontological investigations were carried out on mud volcanic deposits recovered during the TTR4 expedition to the western part of the Mediterranean Ridge (Cobblestone 3 mud diapiric area) with R/V Gelendzhik in 1994. A total of 150 samples of mud breccia clasts were studied in thin sections and showed big variety of different lithologies represented among mud breccia clasts. 17 main lithological types were identify on the base of structural, textural and compositional peculiarities

Studied mud breccia clast types provide an important information about the composition and genesis of deep-seated formations through which mud volcanoes erupted. The analysis of the contacts and lithological and genetic similarities of the different rocks as well as paleontological data led us to the reconstruction of several packages of rocks which are compositionally similar, genetically related and could be formed as one formation in the same depositional environment.

Pelagic, mostly carbonate sequence contains abundant micrites and fossiliferous micrite intercallated with calcareous claystones and pelsparites. It reflects particle-by-particle sedimentation in deep-sea environments. The sequence seems to have been formed in warm open basin with calm-water hydrological conditions, at a distance from the continental slope. The rocks, which we compiled in this sequence, were dated as Cretaceous and, probably, present the oldest lithologies obtained as mud breccia clasts from the mud volcanoes of the Mediterranean Ridge western sector. Siliciclastic, terrigenous sequence contains subquarzose arenites, siltstones, and mudstones. Compositional similarity of these rocks, presence of transitional lithologies as well as findings of several lithologies in the same mud breccia clast allow to ascribe them definitely to certain sequence. The sequence is interpreted to be regressive, presenting a prodelta progradation as a result of sea-level falling. Thick clastic series has been deposited rapidly. Mostly quartzose, compositionally matured material has been supplied from passive margin provinces. Several fragments of the rocks from this sequence contain reworked Cretaceous species, mostly Campanian-Maastrichtian. We can assume a formation of this sequence as a harbinger of Eocene-Oligocene regression in the region.

Many mud breccia clasts studied were dated as Miocenian deposits. They, probably, present a very complicated pre-Messinian complex. Although they are rather various in composition and genesis, the certain sequence can be devised as well. The succession has been formed in relatively deep-sea environments. There was a prevalence of hemipelagic and biogenic particle-by-particle sedimentation of fossiliferous micrites, micrites, and clay. Periodically local turbidites redeposited just settled material within the basin, forming the detritic biomicrites. It reflects, probably, an active tectonic and complex sea-floor morphology of the basin. Shallow-water biogenic material was supplied periodically by gravity flows as well. We are inclined to ascribe the higher activity of the gravity flows to the uppermost part of the sequence, that corresponds perfectly with the dating results. The high supply of material from shelf area might occur at the Tortonian/Messinian boundary as a results of relatively sea-level fall. Thick series of carbonate clastic deposits represented by calclithites and biocalcarenites might be formed just before Messinian crises. The evolution of the region can be considered very schematically on the base of the depositional sequences defined. In Cretaceous time the studied area presented an open deep-sea basin with pelagic mostly carbonate sedimentation and a relatively passive tectonic regime. In Paleogene the activisation of tectonic processes in the Mediterranean region reflected in gradual sea-level fall and the formation of thick clastic series. On the shelf area the progradation of delta/prodelta has taken place and the siliciclastic sequence has been deposited. Full regression in Oligocene was followed by Miocene transgression and the deposition of pelagic sequences followed by pre-Messinian sea-level fall with deposition of carbonate flyshoid sequence.

Open Session

MIOCENE COLD SEEP CARBONATES AND ASSOCIATED FAUNAS FROM BARBADOS

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Barbados lies on the crestal zone of the Barbados accretionary prism, on the eastern margin of the Caribbean tectonic plate. Eocene to Miocene sediments are found in the northeastern Scotland District, and represent two distinct tectonic units. The structurally lower of the two units is the Basal Complex (imbricated thrust slices of pelagic and hemipelagic sediment accreted at an inner trench wall setting in Late Eocene times, resulting from the westward subduction of the North Atlantic plate beneath the Caribbean plate). Lying above this sequence are the pelagic biogenic oozes of the Oceanic Series, everywhere in fault contact with the Basal Complex.

The Oceanics were emplaced as allochthonous backthrust nappes overriding the accretionary Basal Complex. The tectonic horizon separating these two structural units is the sub-Oceanic Fault Zone (SOFZ), a major detachment surface which concentrated fluid expulsion from the dewatering the accretionary prism during Miocene times.

Such fluid migration was associated with authigenic, methane-de nappes and late intraprism contraction. Authigenic carbonates have been collected from five locations: Bath Cliffs, Windy Hill, Belleplaine, Morgan Lewis and Joe's River. The authigenic carbonates at Bath Cliffs consist mainly of large adjacent blocks and slabs of calcitised radiolarian ooze protolith displaying a distinctive 'spherulitic' fabric. Along the margins of these blocks are preserved 'stands' of cylindrical casts and tubes interpreted as fossilised intertwined pogonophoran tube worms.

The fissures between these blocks are filled with later-stage micritic cements. Bath Cliffs have also yielded several well preserved fossil carbonate 'chimneys' (conduits), again showing the spherulitic fabric and multiple phases of fluid flow and reactivation of the conduits.

The conduits provide an important addition to our knowledge of the morphology, structure, petrology and development of these edifices in areas of focused fluid flow. All of the carbonates are extensively impregnated with hydrocarbons.

Windy Hill, Belleplaine and Morgan Lewis yield ex situ carbonate blocks as surficial clitter (remainé horizons from long-eroded fault zones previously existing at higher structural levels, or eroded from buried fault zones). This material displays much more complex multiphase carbonate microstratigraphies and contains a much more diverse fauna consisting of pogonophoran tubes, serpulid tubes and molluscs.

The bivalves include vesicomyids (Pleurophopsis), thyasirids (?Conchocele), lucinids and Nuculana senni, and a rare solemyid. Gastropods such as Solariella, 'Diastoma', buccinids and possible fissurelliform limpets have also been isolated. Many of these forms are known to have affinities with modern seep (and vent) related taxa, and to have been chemosymbiotic organisms (e.g. the vesicomyids).

The Joe's River Mélange, a grey-green sandy, organic-rich mudstone containing large angular exotic blocks (including rare calcite-cemented sandstone blocks), has previously been interpreted as a massive diapiric structure, continuous over some 20km E-W, extending to several km depth and thought to have been intruded into surrounding strata post-nappe emplacement. However, the discovery of perfectly articulated, chemosynthetic vesicomyid bivalves in 'nests' preserved in virtually life position argues for a revision of this interpretation. It is now believed that the Joe's River Mélange had a submarine expression on the Miocene seafloor as a mud volcano, fluid emissions from which sustained a chemosymbiotic fauna, the whole being subsequently overrun by the Oceanic nappes as they propagated eastwards.

LITHOHERMS IN BLAKE-BAHAMA REGION: CONTROLLED BY BOTTOM CURRENTS NOT METHANE SEEPAGE

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Lithoherms were defined in 1971 as subphotic mounds built by the baffling and trapping action of organisms under the control of bottom currents with concurrent submarine carbonate cementation providing stabilisation. Coral- Zoanthid-Crinoid mounds at 500 to 600m in the Straits of Florida were observed via the submersible, Alvin, and became the studied features that provided the initial definition.

A more recent investigation employing the Johnson Sea-Link I submersible and the US Navy's NR-1 submarine has extended lithoherm occurrence to a wide belt along the Florida-Hatteras Slope and extending from a depth of 440m to over 800m on the inner Blake Plateau. One terrace-margin lithoherm complex is ~400m wide, more than 4.4km long and ~150m high in relief. The configuration of a slope-parallel ridge of lithoherm accretion along the seaward edge of a terrace suggests bedrock control. The marked increase in bottom currents (>100 cm/sec) over these topographic features and the feedback effect on accretion is an integral element of their formation and is reflected in the resultant zonation of filtering organisms. The geometry of this deep water platform-edge build-up, its linear trend and seismic signature mimics a shallow water shelf-edge reef system and could be confused for one in the subsurface.

Other individual lithoherms scattered throughout the region commonly exceed 50m in relief, have steep flanks (30-60°) and exhibit carbonate-cemented crusts which crop out on their flanks. As in the lithoherms of the Florida Straits, the Hatteras Slope features appear to accrete by the baffling and trapping action of deep water corals and become stabilised by early cementation. Coral thickets mantle the crests and up-stream flanks and yield modern ^{14}C ages (700±80 yr. BP), while the aragonitic fine sediments trapped therein give older bulk dates (3,250±100). The crusts yield the oldest dates (17,770±330 - 32,710±570), and contain more high-magnesium calcite which probably reflects cement composition. $\delta^{13}C$ of corals, sediments and crusts all suggest precipitation from normal seawater (1.7 - 2.3‰ PDB) and show no evidence of methane invasion. The deep water coral-bearing lithoherms of the Florida-Bahamas-Blake region all appear to be the result of processes involving normal seawater.

In contrast, crusts from known methane seeps, such as the 3,300m deep base of the West Florida Escarpment, yield extremely light $\delta^{13}C$ values. The calcitic cements observed from methane-charged cold seeps run the spectrum from extremely fine micritic textures to coarse palisade rim cements. The latter mimic the isopachous rinds in ancient rocks that are often referred to as "marine cements." Curiously, methane crusts from the West Florida Escarpment commonly exhibit a smooth base and an irregular top, suggesting an upward flux of cementing agents. The crusts from the lithoherms, however, reveal smooth tops and irregular bases which suggests a downward movement of the cementation front. The implication is that stromatactis from methane mounds may be inverted relative to those structures formed from normal overlying seawater.

LANDSCAPE AND BIOLOGICAL ZONING ON THE HAAKON MOSBY MUD VOLCANO (NORWEGIAN SEA): RESULT OF DEEP-TOW VIDEO AND STILL PHOTOGRAPHY

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The Haakon Mosby Mud Volcano (HMMV) is situated at the continental slope in the Norwegian Sea at the depth of 1250m (Vogt et al., 1997). Sea floor in the HMMV area was studied by deep-tow photo- and video-survey in cruise 15 R/V *Professor Logachev* (1996).

Towed submarine apparatus (TSA) was equipped with two photo-cameras (black-white film and colour film) and the colour video camera. TSA was co-ordinated by satellite-hydro acoustic navigation system; the apparatus location accuracy was 6-8 m. Photo- and video-surveys were conducted on operator's manual command at moments when the apparatus was 2-4m above sea floor. The total length of the profiles is about 18 km. More than 1300 complex images (black-white and colour photo and video images) of sea floor were obtained. The area covered by photo- and video-survey is about 8000 m^2 of which 5000 m^2 were surveyed within the edifice of mud volcano that was some 0.5% of its total area.

The total area of landscapes affected by mud volcano activity (i.e. different from the background) is 0.85 km^2 by photography data. The concentric zoning is observed in the distribution of the landscapes. The contours of landscapes distribution correlate well with morphostructural elements of mud volcano discerned from sonar images (Vogt et al., 1997). Five types of sea floor landscapes discerned from photo images of the HMMV surface are described below.

(i) Slightly shagreen sea floor with digging organisms holes (background sea floor). Rounded holes up to 5cm across are distributed beyond the HMMV and along its periphery at the floor of brown and grey-brown colour. They cover up to 5-10% of photo images.

(ii) Highly shagreen sea floor with tube worms (*Pogonophora*) is common at the external hummocky periphery of the mud volcano and ring its central plane (crater) on each side. The following sea floor types are common mainly within the central plane of mud volcano.

(iii) Sea floor with predominant white matter is located south-west and south of the eruptive zone as patches of irregular shape. White matter cover the floor so widely (up to 80%) that underlying sediments often nearly cannot be seen. These white patches are bacterial mats and/or gas hydrates. It seems impossible to give a clear determination for their nature as long as extra field studies are not conducted.

(iv) Sea floor landscapes with an absolutely flat topography are common along the periphery of the active volcanic part (eruptive zone). Many photo images show widely distributed white-colour patches and stripes very similar to those described above but very scarce and covering much less area of images.

(v) Sea floor with micro relief (extended swells up to 1m long and a few cm high resembling the evidence of ripples) is confined to the active volcanic part. These features are likely small-scale still-non-eroded young extruded mud flows. Sea floor landscapes of the first four types are observed in the area of extensive mud volcano flows distribution.

The relatively limited biological community dominated by tube worms and fish is developed on the mud volcano. Tube worms are common at the external hummocky periphery of HMMV. The density of fish is 0.05-0.84 individuals/m^2. At least 8 fish species were identified which belong to 5 families. Fish of family *Zoarcidae* prevail in quantity in images. All the species are representatives of the demersal ichthyocene of the Arctic abyssal fauna; no specific character is observed in the composition of ichthyofauna species of the mud volcano. The most quantities of fish were noted in the vicinity of the volcanic central plane, in areas where white-colour patches are very common.

DISTRIBUTION AND CLASSIFICATION OF SUBMARINE MUD VOLCANOES

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The research history of subaerial mud volcanoes originates at the last century. Subaerial mud volcanoes are widespread in many regions of the world. However the study of submarine mud volcanoes (SMVs) has become possible only in the last decades mainly as a result of geophysical methods' development and wide use of side scan sonar survey in particular. The importance of SMVs research is defined by the following reasons. Firstly mud volcanoes are the major source of the methane flux from lithosphere to atmosphere. Secondly clasts occurring in volcanic mud can be used for studying sedimentary section. Thirdly mud volcanoes are considered often as the reliable evidence of high petroleum potential of sedimentary basins.

SMV is the expressed on the sea floor structure (edifice) from which the mud volcanic sediments pour out or erupt. Its reliable identification is possible only with the complex of geophysical and geological research. Side scan sonar survey is the most important part of this complex. Only structures with mud flows are mud volcanoes and no others. These mud flows can be distinguished on sonar images or during visual observations from submersible. The world map of SMVs distribution is compiled from the above reasoning. The revealed and assumed SMVs areas are showed on the base of a critical review of published data. SMVs are distributed on the Earth more extensively than subaerial ones. In common with subaerial mud volcanoes, the SMVs form the wide areas often. It seems plausible that the number of SMVs is greater than subaerial ones. SMVs areas can be classified as shallow (shelfy) and deep-water. Shallow SMVs, as a rule, have the spatial connection with areas of subaerial mud volcanoes. Deep-water SMVs do not necessarily have the genetic connection with areas of subaerial mud volcanoes. Besides the revealed SMV areas can be classified as areas on the passive margins, in the submarine fans (including the fans of large rivers) and on the active margins (in front of accretionary prisms and within the limits of accretionary prisms).

The main reason of mud volcanoes formation is the occurrence of relatively plastic overpressured shale layers at some depth as already noted by many researchers (e.g. Hedberg, 1980; Rachmanov, 1987). But the initial reasons of these layers occurrence are different for SMVs. High-speed sediments accumulation is of first importance on the passive margins and in the submarine fans. The lateral tectonic pressure responsible for the fluids migration play a crucial role in mud volcanoes' formation in front of accretionary prisms. The SMVs form within the limits of accretionary prisms as a consequence of combination of high-speed sediments accumulation and lateral tectonic pressure.

The examination of published seismic profiles across SMVs and morphological descriptions of SMVs gives an insight into mechanisms of SMVs formation. The first mechanism is the formation of SMV on the pierced shale diapirs as a consequence of fluids migration along diapirs. The second mechanism (and more frequent) is the formation of mud volcanoes along fracture zones. Both of these mechanism are described for subaerial mud volcanoes (e.g. Barber et al., 1986; Rachmanov, 1987). It is significant that fluids migration plays a decisive role in the mud volcanoes formation.

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Rockall-Faeroe: Cold Water Corals, Mud Mounds, Sedimentology, Stratigraphy and Tectonic setting

DEEP-WATER CORALS AND ASSOCIATED FAUNAS ON CARBONATE MOUNDS, NORTH SLOPE OF PORCUPINE BANK AND THE SOUTH EAST SLOPE OF ROCKALL BANK

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The purpose of the sampling programme undertaken from the RV '*Professor Logachev*' was to investigate the carbonate producing macrofaunas and the composition of the sediments forming the distinctive mounds and knolls on the north slope of Porcupine Bank and the south-east slope of Rockall Bank. The samples were collected using a gravity core, Kasten core (with box area of 40cm by 40cm), box core (with box area of 50 cm by 50 cm) and a Preussag TV grab capable of taking a sample of over one tonne of sediment. Where possible a traverse was undertaken with the Russian Polar Institute underwater TV and camera system. The faunal data from the samples was obtained by initial examination of the samples immediately following collection and afterwards in the laboratory.

Deep water corals especially *L. pertusa* are widely distributed in the north-east Atlantic (Wilson 1979a). The distribution on Porcupine Bank and the Porcupine Seabight was described initially by Duncan (1873). Joubin (1922a,b) published a distribution based on data supplied by French fishermen and further observations were given by Le Danois (1948).

The new observations suggest that the summits and upper slopes of the majority (if not all) of the many carbonate mounds and knolls identified on side-scan sonar and other records of the northern flank of Porcupine Bank and on the southeastern slope of Rockall Bank are covered by a carpet of coral debris which supports a living coral fauna consisting principally of the two colonial species *Lophelia pertusa* and *Madrepora oculata. Desmophyllum cristagalli* and the octocoral *Stylaster* sp are also occasionally present. Amongst the living coral fauna, the relative proportions of *L. pertusa* and *M. oculata* colonies collected or observed were either similar or there was a preponderance of *Lophelia. L. pertusa* dominated the dead coral debris however. Most of the live colonies collected in the samples are up to 15 cm in height. Observations on the underwater TV suggest that many colonies are up to 30 cm in height. Perhaps two or three colonies more than 30 cm high were observed during the TV tow down the northern flank of Porcupine Bank. Specimens showing the attachment of the coral to the substrate are rare (Wilson 1979b). Several specimens were collected using the gravity core, Kasten core and TV Grab which included the point of attachment and which showed in some detail the relationship between the polychaete worm *Eunice* sp and *M. oculata* where the early growth of the colonies was determined by the direction of growth of the worm tube (Wilson & Freiwald in preparation).

There are some faunal differences between the Rockall Bank area and the Porcupine area. The Rockall area has a lower diversity of mollusc species, with fewer cold water species. Some of the species found in the Porcupine area such as the gastropod *Oenopota rufa* are very abundant on Rockall Bank. The presence of the bivalve *Achestes* sp. in the living colonies on Rockall Bank and its absence on Porcupine Bank may be related to either differences in the water quality or simply to the sampling. The presence of this bivalve within the cores indicates that it is a persistent species. The high proportion of coral debris throughout the gravity cores suggests that a coral bank could develop over a considerable period of time. The perceived differences between Rockall Bank and the

Porcupine area may be due to the relatively few samples on which this study is based or to differences in the water movements between the two areas following the last glaciation.
The small size of the living coral colonies in an area with a well developed carpet of dead coral suggests that the conditions were suitable for the growth and development of the coral banks at an earlier stage but now either the current, the temperature or the food supply are less suitable for their sustained development. Another possibility is that fishing activity in the area is intensive and does not allow time for the continual long term growth of the coral colonies.

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NEOGENE SEISMIC PATTERN AND CURRENT PATHWAYS WEST OF FAEROE BANK CHANNEL

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Seismic, subbottom profiling data as well as data from 12 kHz OKEAN and 30 kHz O.R.E.tech sidescan sonars were obtained in order to study sediment pathways associated with the spreading of Norwegian Sea Overflow Water (NSOW) once it leaves the Faeroe Bank Channel. A few comparable studies with similar objectives had been conducted in the immediate surroundings of the present survey area (Dorn & Werner 1993; Kuijpers *et. al.* 1998; Boldreel *et. al.* 1998;. Kuijpers & Shipboard Scientific Party, 1997). The top reflector of the acoustic basement is strong and continuous for the most part, although with a series of escarpments and/or faults. Generally, the basement reflector dips from NE to SW, from 1175 ms TWT to 2500 ms TWT, with a basement high in the central part of the survey area. The basement high is similar in shape and size to the banks to the south and is thought to be subaerially extruded basalt. Basement outcrops in the NE part of the area, in depressions possibly covered with a thin layer of coarse lag sediments. High resolution sidescan data from this part of the area shows the presence of longitudinal bedforms indicative of strong (NSOW) bottom water flow with maximum flow speed occasionally >0.9 m/s. Around the central high the Neogene surface unit infills and smoothes the acoustic basement topography, except where cut by several channels with a variety of forms and depths. The topography of the surface unit is hummocky on top of the central high. On a more regional scale, five seismic facies have been identified in this surface unit from high resolution sleevegun records (Boldreel *et al.*, 1998).

The channels enter the region from the east, flow around all sides of the basement high, and exit to the west. Low backscattering from the banks of most of the channels suggests the accumulation of sandy material, whereas sand waves locally cover the channel floor. Flow within the channels sometimes exceeds 0.4 m/s. There are also overbank mud waves flanking some channels. The interpretation of flow of the core of the NSOW through the channels from sonar data fits well with the seismic information, and has been confirmed by hydrographic (CTD) measurements and by the coarse sediments obtained in cores.

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CARBONATE MOUNDS AND REEFS AT THE ROCKALL TROUGH AND PORCUPINE MARGINS.

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Seismic and side-scan sonar survey with ground-truthing by coring conducted in three different areas of the Rockall Trough margin and Porcupine Seabight within several years revealed the presence of carbonate mounds and reefs at the seabed between depths of 500-1000 m. Distinct mounds of different morphology of up to 100 m high and 5 km in diameter are present. Some of these mounds have been successfully cored. They were found to be covered by living cold-water corals *Lophelia pertusa* and *Madrepora oculata* and to be composed mainly of carbonate-rich clay with abundant coral debris. Comparative analysis of carbonate mounds from the areas studied shows that they are of rather similar morphology. They are associated with subbottom currents, as shown by side-scan sonar and seismic surveys as well as by coring data. Particular attention was paid to southwestern Rockall Trough margin where a new area of carbonate reefs was discovered. The mounds are localized within a narrow (8-9 miles) zone ranging in depth from 500 to 1000 m parallel to the margin. A number of seismic lines shot in this area by NIOZ in 1987 and ENAM and TTR-7 lines recorded in 1996-97 shows the presence of elongated reef-like structure, formed by several groups of carbonate mounds which were found growing mainly above relatively elevated acoustic basement. The nature of the acoustic basement cannot be derived from the present data. However, volcanic domes could be invoked. Southeasterly directed currents that are sufficiently strong to transport coarse-grained sediments are indicated in the area of the reef by side-scan sonar data and by samples and also supported by short-term current measurements. Cores collected from different parts of the reef system contained different carbonate facies that may reflect a complex history of reef development. Results of underwater TV trawling during the TTR-97 cruise show indeed abundant living corals and organisms at the reefs. The recent hypotheses (see Hovland et al., 1994, Hovland and Thomsen, 1997) that the origin of such carbonate mounds or possibly reefs is related to thermogenic gas seeps on the seafloor cannot be directly supported by results of this study. However, the role of thermogenic gases in the early stages of the carbonate mound development remains still unclear.

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A MULTY-DISCIPLINARY STUDY OF LOPHELIA PERTUSA IN THE FAEROE-SHETLAND CHANNEL

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A major project has been initiated under the Natural Environment Research Council's MIME programme (Managing Impacts on the Marine Environment) to examine the sensitivity of cold water corals and other large benthic biota to oil, gas and fishing activities west of Shetland. It includes biologists and geologists from several academic and industrial groups.

The project's objectives are:

1) To assemble a map of the present day distribution of *Lophelia* along the U.K. area of the Faeroe-Shetland Channel. This will collate the available information on coral distribution from previous studies, fishermen's reports and oil industry rig site surveys. Some sea-bed features, identified by the latter's high resolution side scan sonar surveys, have been interpreted as coral colonies and this interpretation will be investigated by imaging a representative selection of the features.

2) Contribute to understanding the environmental sensitivities of *Lophelia,* and other large epifauna, such as sponges, by relating organism health to well emissions and drill cuttings history. This will be considered against an improved background knowledge of organism occurrence in relation to local hydrographic conditions, bed flow and suspended particle load.

3) Decode a record of the chemical environment by means of precision elemental analysis of the coral skeleton in relation to the natural growth pattern studied using isotopic and other markers.

4) Investigate the reproductive strategy of *Lophelia* to help understand its capacity to grow and reproduce, especially in the event of any environmental impact.

5) Clarify the ecological role of Lophelia and sponge fields as important reservoirs of regional marine biodiversity and the occurrence and importance of these and other larger epifaunal organisms in the ecology of the wider community, including fish stocks.

Opportunities to sample living coral west of Shetland are being sought to provide material for geochemical analyses and molecular genetics.

SEISMIC INVESTIGATIONS OF CARBONATE MOUNDS IN THE NORTH ATLANTIC TO THE WEST OF IRELAND

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The presence of carbonate mounds in the North Atlantic to the west of Ireland was known from previous multi-channel and single channel seismic investigations[1]. The aim of the single channel seismic investigations during the TTR7 cruise on board R/V *Professor Logachev* was the more detailed study of the known carbonate mounds together with the dip towed acoustic systems, underwater TV and geological sampling and, possibly, the discovery of other carbonate mounds in this area.

The research team could distinguish here 3 areas according to the distribution pattern of carbonate mounds:
1) Eastern flank of the Porcupine Seabight - in this area we found only one carbonate structure, consisting of some mounds, situated very close to each other;
2) northern flank of the Porcupine Seabight and the Porcupine bank - it is in this area that the Hovland mounds are situated - and more of them were found. In general the mounds resemble each other, though their size varies;
3) southern flank of the Rockall bank - the large field of almost continuos growing carbonate mounds was discovered here during the TTR-97 cruise. According to the seismic and side scan sonar data the forms, the sizes and the distribution pattern of the mounds in the latter area are rather chaotic.

The carbonate, coral origin of these structures was confirmed during the cruise by geological sampling and underwater TV records.

There are different characteristic features of these carbonate mounds on seismic records:
1) the carbonate mounds may be recognised on seismic time sections as dome like structures on the seafloor, with chaotic reflections inside them;
2) most part of the carbonate mounds seem quite transparent for seismic waves however underlying reflectors are well visible on the seismic time sections;
3) up-doming effect or velocity pull-up is visible on underlying reflectors, which is caused by the higher seismic velocity in the body of carbonate mounds;
4) At the bottom of these structures possibly higher velocity and higher seismic impedance bodies occur at least in some seismic profiles. This corresponds with a smooth reflector of negative reflection coefficient 100-200 m below the surface of the carbonate mounds. This is interpreted in terms of a cemented coral dominated carbonate body which is situated on comparatively softer sediments with lower seismic impedance.

Some authors explain the origin of the carbonate mounds in this region by the hydrocarbon gas seepage from deep sources through the faults in sediment layers[1]. We also looked for evidence of such explanation on our seismic records. However we did not find in the vicinity of the investigated carbonate mounds direct hydrocarbon indicators as bright spots or dim spots. Neither did we find bottom simulating reflections - indicators of gas hydrates. This does not mean that the possible influence of hydrocarbon gas or gas hydrates for the origin of these carbonate mounds should be categorically rejected. It means however that the quantity of gas seepage may be moderate now, and it's worth to take into account other possible sources feeding corals today, for example the strong deep sea currents existing in this area.

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SAMPLING CORALS WEST OF SHETLAND

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Seabed studies west of Shetland, whether for environmental or geotechnical considerations, need to consider the possible presence of coral on the seafloor. There have been many reports on the occurrence of coral, initially by fishermen concerned at damage caused to their nets. Subsequently geophysical features imaged on the seafloor have been interpreted as corals, carbonate mounds or small reefs. These reports have been used to suggest extensive occurrence of coral on the slope west of Shetland and as such would provide a major environmental sensitivity to those operating in the area, even claims of a "Great Barrier Reef" have been made by the media. It is necessary to provide ground truthing to such claims. Towed ocean bottom instrument (TOBI) imaging of the seabed in some of the areas associated with hydrocarbon exploration of the West Shetland Slope has not observed large reef like structures above 25 m in diameter. There is a major discrepancy between the abundance claimed by some agencies and the physical observation or recovery of coral samples.

Fragments of coral have been recovered from samples collected by the British Geological Survey as part of its regional mapping programme. These include fragments of corals collected from the seabed by use of Shipek grabs and from tops of cores. Buried fragments have also been found within cores up to 3.5 m below seabed. Within the area of 59 30' N to 62 N and between 0 and 7 W there are 3803 seabed samples collected by BGS. A search of computerised summary sample descriptions, computerised sample station geological descriptions and a visual search of the shipboard sample description sheets for the terms "coral" and/or "Lophelia" identified 55 sites where coral had been reported. Additional reported sampling by other agencies of coral exists in the area which when combined with the BGS dataset suggests that a range of corals occur on the shelf and slope to approximately 600 m water depth. The colonial coral *Lophelia pertusa* seems to be most common close to the Wyville-Thomson Ridge where the presence of rock outcrop may assist the provision of a firm substrate to allow coral growth to occur.

Fossil Mounds

FRASNIAN MUDMOUNDS FROM BELGIUM

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Three calcareous mud mound levels succeed in the Frasnian shales from the south of the Dinant Synclinorium. A detailed sedimentological study of more than 2000 thin sections from some ten buildups allowed to define a composite biohermal sequence starting from below the photic and storm wave base zones and progressing toward subexposed environments (Boulvain, 1993; Boulvain & Herbosch, 1996). The sequence consists of spiculitic wackestones with stromatactis (S3), becoming progressively enriched in crinoids and corals (S4), then in peloids and cyanobacteria (S5). These three facies are red coloured by microaerophilic iron-bacteria *Sphaerotilus-Leptothrix* and *Siderocapsa* (Bourque & Boulvain, 1993); the sequence is then continued with grey stromatoporoid and stromatactis floatstones and rudstones (S6); algal-peloids wackestones and packstones with green algae and thick algal coatings (S7); algal and cryptalgal bindstones (S8); branching stromatoporoids rudstones (S10) and loferites (S11). All buildups and peri-biohermal sections are biostratigraphically correlated by conodonts and rugose corals (Boulvain & Coen-Aubert, 1992).

The transition from aphotic to cyanobacteria photic zone is reflected by sequence S4-S5; the transition from cyanobacteria to green algae photic zone by sequence S6-S7. The storm wave base is reached with S5 and fair-weather wave base with S7. The evolution S7-S8 indicates an ecologically dominated process rather than a bathymetric evolution. The paleobathymetric interpretation reveals a hundred of metres for the pioneer community S3 and about 70 m for the base of the photic zone.

The 30 to 40 m thick "Les Bulants" bioherms are catch-up buildups (Neumann & Macintyre, 1985) displaying only a vertical facies succession (S3-S4-S5-S7-S8) and a low relief. The 60 to 80 m "Les Wayons" mounds possess a relatively high relief with steep flanks and bioclastic talus (S9). These catch-up-give-up mounds present the same sequence as the former, but their relief is responsible for the lateral differentiation. "St-Rémy" mounds are smaller buildups growing in deeper parts of the ramp: they are almost totally constituted by S3 and S4. "Lion" type mounds are 150 m thick buildups developing in a relatively shallower environment, forming a keep-up (S6), followed by a catch-up-give-up sequence (S7-S8-S10-S11-S6).

The "Les Wayons", "Les Bulants" and "St-Rémy" buildups developed during a period of major eustatic fluctuations while the "Lion" type mounds grew during a time of relatively minor sea-level fluctuations. On a large scale, this difference is reflected by the evolution from a rimmed shelf during the Middle Frasnian into a ramp during the Upper Frasnian. For each of the mounds, it is evident that the scale of facies variation depends on the initial bathymetry of the beginning of buildup growing. The sequence begins below the photic zone with S3 and S4 for "Les Bulants", "Les Wayons" and "St-Rémy" mounds and within the cyanobacteria photic zone for the "Lion" type buildups (S6). Except for the back-reef facies (S10, S11), all these bioherms nearly display the same ecological succession, confirming the bathymetry control and/or the community maturation. This is not the case for the size and morphology of the buildups, suggesting a eustatic control, by means of the interrelation of bioherm growing rate and the rate of sea-level change. A slow rate of sea-level change permits a keep-up growing for "Lion" bioherms, covering the transgressive system tract, high system tract and shelf margin system tract. On the other hand, the rapid sea-level rise during the Upper Frasnian only permits a development of catch-up bioherms, which are then restricted to the high system tract and shelf margin system tract. The low relief of "Les Bulants" type bioherms, contrasting with the high relief of "Les Wayons" buildups is a result of respectively high and low rates of peri-biohermal sedimentation.

THE TAPHONOMY OF A WAULSORTIAN CARBONATE BUILDUP

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Recent work has suggested that parts of the surface of Waulsortian buildups were covered by a mucillage-rich, microbial film, which stabilised the surface sediment to the extent that depositional dips of up to 40° were maintained. The taphonomy of a diverse assemblage of crinoids, bryozoans, brachiopods and molluscs in a Waulsortian carbonate buildup of late Tournaisian age at Mullawornia, County Longford, Ireland has been investigated in order to establish the physical conditions on the surface of the mound.

The fauna is parautochthonous. The brachiopods and bivalves are mostly preserved as conjoined valves and show little evidence of transport. However, their orientation is random and they are rarely preserved in life position. There is no evidence of bioturbation; the re-orientation of shells must have resulted either from currents or through the collapse and settlement of the semi-coherent sediment as organisms such as sponges decayed. The component parts of crinoids in many cases do not appear to have been dispersed very far. Fenestrate bryozoans, in contrast, are commonly comminuted, suggesting that at least at some times current energy levels on the bank surface were high. Sorting ratios of conodont elements may provide some information as to what extent currents were an important feature of the surface of a buildup.

GEOMETRY AND STRUCTURES OF DANIAN BRYOZOAN MOUNDS, FAKSE QUARRY, DENMARK

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Fakse quarry is situated in eastern Zealand 80 km south of Copenhagen in Denmark. Different coarse grained chalky limestone types of Middle Danian age are here being excavated for agricultural and industrial use. Deposition took place in the relatively shallow parts of the Danish Basin as a termination of the Late Cretaceous-Early Palaeocene cool-water carbonate deposition in North-West Europe (Surlyk, 1997). Two mound building limestone facies are composed of bryozoan wackestone-packstone and hexacoral limestone of ahermatypic scleratinians. Both are seen as 10-30 m high mounds with a lateral extent on a 100 m scale. Hexacoral mounds are steeper and more lithified than bryozoan mounds. Structures and facies of the coral mounds at Fakse have been described previously (Floris, 1980; Bernecker and Weidlich, 1990). Strongly variable thicknesses of soft octocoral limestone facies are deposited in the troughs between bryozoan mounds. The bryozoan limestone is composed of 95-100% pure Calcite beds alternating with more or less pure chert. Limestone beds are thinning upwards from about 2 m below mounds to about 0.5 m in the upper part of the mounds. The chert form beds of 5-30 cm which enhance the bedding. The purpose of this study is to provide documentation on the depositional structures of the bryozoan limestone mounds at Fakse. The bryozoan limestone was chosen for this study because of its regional significance compared to the locally occurring coral limestone. Comparable bryozoan mounds from early Danian times were studied at Stevns close to Fakse by Surlyk (1997) and in a more distal part of the Danish basin (Thomsen, 1976).

Geometrical data were collected by ground penetrating radar (GPR), outcrop photos, and measurements of dip and strike. The GPR is an electromagnetic geophysical tool to record shallow reflection images which primarily indicates differences in water content. Mound geometry is outlined by GPR-reflectors caused by the changes in porosity between chert and limestone. Field work was primarily carried out in the southern part of the quarry because excavation had exposed quarry walls suitable for a geometrical study. Depositional structures seen in the quarry walls were documented by camera and by GPR-profiles. A comparison of GPR-images recorded along the quarry walls with photos of the same walls served as a basis for interpretation of GPR-profiles recorded in the ground. Chert layers in the ground were subsequently seen in newly excavated areas and used in structural mapping of the bryozoan limestone.

An example of the development of depositional structures is shown in four steps. GPR-reflectors interpreted as time lines define the stacking pattern of depositional limestone units. Mound development is apparent at 160 m, 280 m, and 340 m where differential thickening of bryozoan limestone is seen. Line 6 defines the upper boundary of the bryozoan limestone on which a unit of octocoral limestone is deposited. Line 7 defines the base of a unit of hexacoral limestone interfingering with bryozoan limestone. Note the condensed zones at the top of the two western bryozoan mounds. Other data show that the bryozoan limestone also form large low angel build-ups with prograding flanks. The typical bryozoan mounds are found to be primarily aggrading build-ups with eliptical bases striking NNE-SSW. Their heights are 10-15 m and their lateral dimensions are 50-100 m along the short axis and between 1 and 2 times longer along the long axis.

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LATE DEVONIAN - EARLY CARBONIFEROUS DEEP WATER CORAL ASSEMBLAGES AND SEDIMENTATION ON A DEVONIAN SEAMOUNT: IBERG REEF, HARZ MTS., GERMANY

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Growth of the middle to late Devonian Iberg Reef, a small atoll in the Variscan Geosyncline of central Europe, ceased towards the end of the Frasnian. During the Famennian and Dinantian, the reef continuously subsided relative to sea level. In the latest Dinantian the reef was eventually covered by clastic sediments.

Five deep-water organism assemblages colonised the Famennian - Dinantian seamount successively. They are well comparable to recent organism communities on deep-water coral banks. In the Famennian, abundant crinoids and ancillary rugose corals and brachiopods colonised the reef top. During the late Tournaisian, a coral-crinoid assemblage established on the reef. It developed into a varied fauna of corals, crinoids, trilobites, brachiopods, bivalves, gastropods, and goniatites in the early and middle Visean. The late Visean assemblage was dominated by goniatites and pseudoplanktonic bivalves. In the latest Visean, a monospecific brachiopod fauna and small microbial buildups thrived in extreme environmental conditions on the reef top.

The skeletal debris of the organisms was eroded *post-mortem* and only accumulated in current-protected depressions of the reef surface, along with carbonate mud. Local depressions include hollows on the reef top, neptunian dikes, and pore space of a breccia that formed due to intensive shattering of the reef top during nearby volcanic activity. During most of the Famennian and Tournaisian, there is a hiatus caused by non-deposition. Only reworked Famennian and Tournaisian conodonts, recovered from upper Tournaisian - middle Visean limestones, give evidence of marine conditions on top of the reef. The sedimentary environment on the drowned atoll compares well to that on recent guyots, including hiatuses, slow and patchy sedimentation, erosion and redeposition.

Both the aftermath of the Frasnian/Famennian extinction event that drastically reduced metazoan reef builders and a trend towards lower temperatures in the Famennian and Dinantian are believed to have prevented the re-establishment of a shallow water reef on the drowning Devonian atoll.

SEDIMENTOLOGY AND DIAGENESIS OF THE MID-FAMENNIAN BAELEN MUD MOUNDS

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Block faulting has been proposed as a major mechanism to account for important lithofacies changes on the Famennian shelf South of the Old Red Continent (Thorez & Dreesen, 1986). The sudden appearance of Mid-Famennian (late Upper Devonian) algal-sponge-crinoid mud mounds in an essentially siliciclastic shelf setting, is very striking. The mounds are located in the eastern part of the Verviers Synclinorium, which is the eastern extension of the Dinant Nappe, South of the Variscan front. Although the occurrence the mounds apparently coincides with a world-wide transgressive pulse (Dreesen et al, 1989), their location is rather controlled by the presence of a deep-seated structural lineament, the Verviers-Trier dislocation. The mud mounds of Baelen accumulated during one single 4th-order eustatic cycle, the duration of which is less than 0.5 my (the Late *marginifera* Conodont Zone pro parte) (Thorez & Dreesen, 1997). Thus far, the Baelen mounds represent the first known mud mounds in the Famennian of the Ardenno-Rhenish realm and the first reefoid structures after the mass extinction of colonial reefs at the end of the Frasnian (Dreesen et al, 1985). The initial triggering mechanism of the Baelen mounds is uncertain: a temporary lull in the afflux of siliciclastics and possible methane seeps along the above faults may well have initiated the carbonate production. Initially, crinoids, dasyclads (Issinellids) and hexactinellid sponges lowered the current velocity (by baffling) and trapped the lime mud. Subsequently (cyano)bacteria and encrusting non-calcified and porostromate algae produced lime mud and/or fixed skeletal grains in place, so that the lime mud banks developed as a self-propagating system. Sedimentological and palaeoecological evidences point to an open shelf setting, below or near wave base but still within the photic zone (Dreesen et al, 1985). The dominant microfacies consists of algal, cryptalgal (*stromatactis*-bearing) and spiculitic mudstones or wackestones, with subordinate algal bindstones and floatstones. Lenticular crinoidal-foraminiferal packstones, grainstones and even rudstones intermittently interrupt the mudstones. The former are affected by graded, reverse graded bedding, cross bedding and even slumping, suggesting that the mounds had reached wave base or that they had been affected by storm wave activity. The Baelen mound complex displays a conspicuous cyclic aspect, reflecting changes in carbonate microfacies and in detrital content. Both the basalmost and topmost lithological units consist of nodular or lenticular bioclastic wackestones, embedded in calcareous micaceous sandstones. The core of the complex consists of sand-free red-stained cryptalgal-spiculitic mudstones with numerous stromatactis and LF-fabrics. The transitional units to the core are composed of algal mudstones and wackestones enclosing numerous crinoidal packstone/grainstone/rudstone lenses. Due to strong pressure solution the actual grainstone / mudstone ratio is exaggerated with respect to the original mud mound composition. The original thickness of the individual mounds may well have exceeded 150m. The diagenetic history is complex (Dreesen et al, 1985; Belmans, H., 1992) and reveals succeeding marine phreatic, mixed water, meteoric phreatic as well as burial diagenetic conditions, all subsequently overprinted by Variscan tectonics. Stable carbon and oxygen isotope data for different bioclasts and individual diagenetic phases (e.g. radiaxial fibrous marine cements in stromatactis, etc.) all plot within the same field ($\delta^{18}O$ of -6.6‰ ± 0.8‰ and $\delta^{13}C$ of +1.5‰ ± 0.7‰). The carbon signature clearly suggests that the system has been buffered by the host rock, while the oxygen signature points to a resetting of the oxygen isotope signal by hot late diagenetic fluids.

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Topics Related to Previous TTR-Cruises

SEISMIC MANIFESTATIONS OF GAS IN THE SOROKIN TROUGH (BLACK SEA): ANALYSIS OF VELOCITY MODEL OBTAINED BY INVERSION OF THE SEISMIC DATA

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Single-channel seismic data collected in 1996 during the TTR-6 Cruise on the south-eastern continental margin of the Crimea (northern part of the Black Sea) have been analyzed. The study area is known for clay diapirism. On the cruise, several mud volcanoes and numerous gas seeps were discovered. Gas hydrates were sampled from several mud volcanoes.

Wide-spread manifestations of gas occurrence and migration through the sediments, such as bright spots, acoustic voids and acoustically transparent columnar disturbances, have been recognized on the seismic records. Inversion algorithms have been applied to the seismic data in order to estimate velocity variations in zones of probable free gas occurrences. Bright spots on the flanks of diapirs were found to associate with a velocity decrease of 200-300 m/sec. This suggests at least 5-8 % of the pores in the sediments being occupied by free gas.

HYDROCARBON GAS IN THE ANAXIMANDER MOUNTAINS REGION. EASTERN MEDITERRANIAN SEA

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The investigations of the Anaximander Sea-mountains were carried out during the first Leg of the ANAXIPROBE/Training Trough Research expedition in 1996. During this cruise a new mud volcano area was discovered. The mud volcanoes seem to be associated with cross-cutting faults defining individual blocks in this mountain complex. The latter may permit overpressured fluids from thrusts in this compression zone to be expelled at the surface (Woodside, 1996). Mud breccia was recovered from six new mud volcanoes in order to study hydrocarbon gas and organic matter. Moreover, gas hydrates from the Kula mud volcano were recovered for the first time from the Mediterranean Sea. A study of the hydrocarbon gas from the hosting sediments was carried out.

Three different sampling sites MS-213G, MS-224G and MS-233G were chosen for the geochemical investigations.

MS-213G was placed in the Kula mud volcano. The mud breccia from this site was intensively gas-saturated and contained gas hydrates. Based on the gas chromatography data, methane is predominant over its homologues and ranges from 99.07% to 99.66% of total hydrocarbons. The C_2^+ components are mainly represented by ethane (0.27% - 0.77%). The ratio C_1/C_2^+ corresponds to values 59.49-298, which indicates that gas is sourced a mixture of thermogenic and biogenic hydrocarbons.

At site MS-224G the longest pelagic core was recovered from the topographic high on the northernmost part of the Anaximander Mountain (Neotectonics and fluid flow). This core differs in its hydrocarbon composition of hydrocarbons from all other investigated cores. Here methane is also predominant. Its content varies from 75.27% to 93.55%. The C_1/C_2^+ ratio is 14.50 in the uppermost part and decreases to 3.56-7.61 towards the bottom of the core. It could be suggested that this gas was brought from a deeper part which would imply a thermogenic origin.

The site MS-233G was taken near the edge of flow from the Amsterdam mud volcano (Neotectonics and fluid flow). The mud breccia from this core was saturated with H_2S. Its hydrocarbon gas composition was similar to MS-224G. The gas analysis revealed that methane content ranges from 85.22 % to 98.56 %. The C_1/C_2^+ ratio varies between 5.77 and 65.27, a range which suggests the involvement of thermogenic gas.

The determination of Total Organic Carbon (TOC) content in all investigated sites ranges between 0.34% and 1.60%. The higher values correspond to pelagic sediments from site MS-224G. The distribution of TOC in all studied cores is the same. There is no significant variation along the sediment cores.

In conclusion, the results of the geochemical investigations support the possibility of involvement of thermogenic sourced gases.

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ORGANIC MATTER OF MUD BRECCIA CLASTS FROM THE ANAXIMANDER MOUNTAINS MUD VOLCANO AREA COMPARED WITH THAT FROM THE OLIMPY AND UNITED NATIONS RISE AREAS (EASTERN MEDITERRANEAN)

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Mud volcanoes are common in thick sedimentary basins and accretionary complex environments. They are often associated with oil and gas fields and seeps. Geochemical investigations, such as 1) fluorescent analysis, 2) determination of Total Organic Carbon content (TOC), 3) Rock-Eval pyrolysis, 4) chromatography of the Extractable Organic Matter (EOM), allow to assess the amount, quality, and thermal maturity of Organic Matter (OM) in source rocks. This helps to find out the source of the hydrocarbons and the evaluation of oil/gas potential in sedimentary basins.

This paper presents the results of a geochemical study of mud breccia samples, taken in 1996 and 1997 during the TTR-6 and TTR-7B cruises in the Anaximander Mountains mud volcano area in the Eastern Mediterranean Sea (Woodside et al., 1997). This investigation follows the previous studies of the Mediterranean mud volcanism carried out in the Olimpy and United Nations Rise mud volcano areas.

The content of TOC of the major part of the samples is less than 0,5% (source rock with no oil but possibly with some gas potential). According to the results of pyrolysis, the OM belongs to immature kerogen of types II and III (humic/sapropel mixed and humic matter, Tissot & Welte, 1984).

Few samples are characterised as a source rock with moderate oil potential (TOC content is 0,69-2,54%). They belong to kerogen of type II, located at the beginning of "oil window" zone.

There are also two samples with small amounts of TOC, but related to the post stage of "oil window" zone. These rocks can produce only gas.

By source rock properties, mud breccia clasts from the Anaximander Mountains area differ from those from the Olimpy and United Nations Rise mud volcano areas (Cronin et al., 1997). Rocks represented by these clasts have lower maturity level and less oil/gas potential.

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BIOTURBATION IN PELAGIC SEDIMENTS AS PALAEOENVIRONMENTAL INDICES, DESCRIPTION AND INTERPRETATION OF TRACE FOSSILS IN CORES

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Trace fossils are common in pelagic sediments and are usually simply noted in field descriptions and core logs. In the last decade, a number of authors have explored the possibility to use trace fossils as indicators of bottom water oxygenation. Trace fossils are common in pelagic sediments, are almost always found in-situ, ichnospecies occur in a wide range of environmental conditions and are sensitive to environmental changes. These factors illustrate the advantages of trace-fossil studies over the analyses of skeletal fossils.

The development of trace fossils is controlled by the environment just above and below the sediment-water interface. The oxygenation and salinity of the bottom water are limiting factors. Within the sediment, the amount of nutrients, the oxygenation of the pore water and the amount of toxic substances control the development of trace fossils.

Ichnospecies are distributed in different levels in the sediment, so-called 'tiers'. These tiers are defined by different environmental conditions. The uppermost sediment interval is relatively oxygen- and nutrient-rich, while deeper levels are depleted of these. The tiering relationship of ichnospecies can be reconstructed by cross-cutting relationships and the preservation of the burrows, as well as direct observation on 'frozen' profiles.

Four ichnospecies are described, as these are common and their environmental demands and their tiering-relationships are relatively well known. 'Vague burrow mottling' is a collection term for poorly preserved burrows. This type of trace fossil is formed in the top layer of the sediment and is indicative for relatively high concentrations of oxygen and nutrients. *Thallassinoides* sp. occupies the second tier and this species demands relatively less oxygen and nutrients. *Chondrites* sp. occupies the deepest tier and this species was adapted to low concentrations of oxygen and nutrients and high concentrations of toxins. Under optimal environmental conditions, all tiers will be present. As the conditions deteriorate, the uppermost tiers will disappear and the lower tiers will move up in the sediment. By comparing the tiers present at different levels of a section of a sedimentary column, changes in the palaeoenvironment can be reconstructed.

The methods and potentials of trace fossil analyses are illustrated by a case study from the Cenomanian of the Crimea. The Middle Cenomanian sediments are characterized by a rhythmic alteration of dark and light-grey lime mudstone. This alteration is believed to be caused by the precession cycle inducing temporal bottom water disoxia. This facies is comparable to the sapropel facies of the Mediterranean. Corresponding couplets at two different sections show differences in the sediment composition and the corresponding trace fossil tiers. This variation made it possible to single out environmental factors. The main controlling environmental factors are the nutrient content of the sediment, the oxygenation of the pore water and the toxicity of the sediment caused by anaerobic breakdown of organic matter.

A new method for the description of trace fossils is proposed. This includes a description of ichnospecies, the preservation of the burrows, in terms of colour of the burrow fill and compaction, and cross-cutting relationships. Noted in this way, it is possible to reconstruct trace fossil generations that can be compared to evaluate palaeoenvironmental changes in a stratigraphic section. Previously published methods are critically reviewed. This paper is meant to stimulate further research on this subject and not as a final statement. Data on the occurrence of other ichnospecies and their environmental niche is needed for a wide and successful application.

GAS-DERIVED AUTHIGENIC CARBONATES IN SEDIMENTS OF THE MEDITERRANEAN AND BLACK SEAS

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Large varieties of authigenic carbonates were obtained during the TTR-7 cruise from gas-saturated sediments of the Black Sea and Eastern Mediterranean. Carbonates in the form of thin crust, irregular concretions and fragile inclusions were subjected to microscope study and X-ray powder analysis.

Carbon and oxygen stable isotope measurements in carbonates and pore water geochemical investigations were also carried out. Authigenic carbonates appear to have been formed inside significant intervals, were the measurements of Ca, Mg and Alk contents indicate the removal of these ions from pore water through carbonates precipitation.

A resistant assemblage of carbonate minerals, which comprises calcite, aragonite, high-Mg calcite, and dolomite with the prevalence of the latter, was revealed in both Black Sea and Mediterranean samples. The authigenic carbonates are characterised by negative $\delta^{13}C$ values ranging from -2.0‰ to -50.90 PDB and $\delta^{18}C$ from -3.29‰ to -6.7 PDB.

Carbonates strongly depleted with ^{13}C (from -27.60 to -50.90 PDB) occur inside distinct intervals where an increasing gas concentration has been noted.

The samples enriched with dolomite (48-89 wt %) taken in the Black Sea revealed heavy carbon isotopic composition indicating the precipitation of carbonate under the normal conditions.

On the basis of the geochemical investigations pore water and stable carbon composition, it is suggested that recrystallization of calcite to dolomite took place in these sediments where sulphate-ion depletion in pore water has been observed.

THE OCCURRENCE OF GAS HYDRATES IN AN AREA OF EXTENSIVE FLUID FLUX AND GAS VENTING. NORTH-EASTERN PART OF THE BLACK SEA

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A new area where extensive fluid flux and gas venting occurred was studied during the 6th Training-Through-Research expedition in 1996. This area is located within the Sorokin Trough on the NE continental margin of the Black Sea. The Sorokin Trough is known by Oligocene-Under Miocene mud diapiric structures. Some of the diapirs are crowned by mud volcanoes. One of the remarkable features of the mud volcanoes in this Trough is that some of the mud breccia contain accumulation of gas hydrates. During the expedition, a total of 15 cores was taken from this area. Twelve of them were noted for gas saturation and five cores included gas hydrates. The gas hydrates were recovered from patches of high backskatter on MAK-1 sidescan sonar lines. Accumulation of gas hydrates was encountered here at water depths ranging from 1850 to 2100 m within the interval of 0.3-2.4 m bsf. This paper is aimed to solve the problem why not all of the gas-saturated sediments from the sampling sites in the area contained gas hydrates. An attempt will be made to extract conclusions for three sampling sites BS-284G, BS-288G and BS-293G, in which sediments are characterized by similar lithology and gas-saturation. Core BS-288G contains gas hydrates, but the measurements of gas content revealed that Core BS-284G has similar gas concentrations. At both sites the methane content predominates over other gases. It accounts for 97.37%-99.99% of the total amount of hydrocarbons.

Gas from the gas hydrates appeared to be mostly methane (97.7%-99.7%). However, some gas hydrate samples also contained an admixture of heavy hydrocarbons up to i-hexanes. $\delta^{13}C$ shows that CH_4 and CO_2 from gas hydrates have a biogenic origin, $\delta^{13}C$ (CH_4) ranging from -61‰ to 65‰, and $\delta^{13}C(CO_2)$ from 31‰ to 34‰.

All the sites mentioned above are characterized by variation of Total Organic Carbon (TOC) content from 0.30% to 2.44% and its distribution along the cores does not display any relation with the gas content.

In the sediments from Site BS-284G many of Policyclic Aromatic Hydrocarbons (PAH) were detected. Their amounts are rather high: perylene - 58.6%, homologues of naphtalene - 19.1%, etc. In these cores, numerous authigenic carbonate inclusions were found. In Core BS-284G, at the interval of 30-55 cm, a limestone clast consisting of a large number of cemented Pleistocene bivalve shells was observed. The value of $\delta^{13}C(CaCO_3)$ for this clast is -27.6‰. The interval around 2.2-2.8 m shows the range of $\delta^{13}C$ from +1.81‰ to -33.32‰. In Core BS-288G a carbonate-cemented layer above gas hydrates has a value of $\delta^{13}C(CaCO_3)$ = -2.05‰, which is normal for marine carbonates. In the upper part of this core, fragment of carbonate crusts with bacterial mats were found which had a $\delta^{13}C$ value of -40.12‰. (Belenkaya, 1997). By contrast, at Site BS-293G (Kazakov mud volcano) the methane concentration decreases downcore from 92.2% to 1.5%, while the content of

C^{2+} increases with the depth up to 98.5%. The homologues of methane are represented by all spectrum of hydrocarbons up to i-hexanes.

According to the all above, the reasons of the absence/presence of gas hydrates at these cores are the following. First of all, the lack of correlation between the distribution and the composition of hydrocarbon gas and TOC content is evidence for fluid inflow at these sampling sites. Site BS-284G is possibly characterized by a fluid inflow from deeper part of the sedimentary sequence with rather high temperature. This fact is confirmed by presence of significant amounts of a PAH's. Gas found in mud breccia could be supplied simultaneously with breccia eruption and then trapped in underlying hemipelagic sediments. This gas had a thermogenic origin and this is corroborated by isotopic composition of carbonates. These carbonates were obviously formed under the influence of hydrocarbon gas which was oxidized in a sulphate-reduction zone due to microbial activity (Belenkaya, 1997). At Site BS-288G, the gas hydrates and the carbonate-cemented layer overlaying them have a different origin. Probably, the carbonate-cemented layer formed earlier and served as a caprock for hydrocarbons that came up from the deeper sources to form gas hydrate accumulations. Gas from Site BS-293G is likely to be thermogenic, according to its composition. The lack of methane in relation to its homologues could explain the absence of gas hydrates at this site.

References:

Belenkaya I., 1997. Carbonate Nodules: Mineralogical and Isotopic Characteristics of the Authigenic Carbonates (Black Sea). In: Intergovernmental Oceanographic Commission Workshop Report No. 129, Gas and Fluids in Marine Sediments: Gas Hydrates, Mud Volcanoes, Tectonics, Sedimentology and Geochemistry in Mediterranean and Black Seas, fifth post-cruise meeting of the Training Through Research Programme and International Congress, Amsterdam, The Netherlands, 27-29 January, 1997, pp. 8-9.

ANAXIMANDER MOUNTAINS MUD VOLCANIC AREA RE-VISITED - RESULTS OF BOTTOM SAMPLING

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The Anaximander Mountains, located at the northeastern part of the Mediterranean Sea, were re-visited in the summer of 1997 with the Russian R/V *Akademik Boris Petrov* during the ANAXIPROBE/TTR-7B cruise. Previous marine expeditions carried out in 1991, 1995 and 1996 led to the discovery of several mud volcanic structures in this area. In 1996 mud volcanic breccia was recovered from six of them. Besides gas-hydrates were raised for the first time in the Mediterranean from the structure named the Kula mud volcano (Woodside et al., 1997). The ANAXIPROBE/TTR-7B cruise was aimed to sample of assumed mud volcanic deposits in places which were characterized by high reflectivities. Twelve gravity core stations, two grab stations, and two dredging stations were chosen on the basis of the bathymetric and bottom reflectivity data obtained in 1995 during the multibeam echosounder EM-12D survey and from the acoustic images of the MAK-1 deep-towed sonar system obtained during the TTR-6 cruise in 1996.

Most of the cores obtained during the cruise reflect the pelagic sequence of Late Pleistocene to Holocene age. These are likely to cover mud volcanic. Observed pelagic sequences consisted mainly of: (i) light brown and brown marls, often bioturbated, or stuctureless, rich in forams and pteropod remains; (ii) clayey, light grey and grey marls of the lower part of the sequences, structureless, with forams, sometimes with bioturbation structures; (iii) marker layers of sapropel S1 and tephra Z2, Y4, and Y5. The sedimentation rates calculated for Holocene (starting from bottom of sapropel S1 layer) vary in most cores from 5 to 7.5 cm/kyrs, marking rates of Holocene sedimentation to be higher in the area of investigation than average rates for the Eastern Mediterranean. Only core TTR-7B-252G taken from the top of a small hill to the south of the Anaximander Mountain shows normal Eastern Mediterranean sedimentation rate of 2.5 cm/kyrs.

Two of the cores recovered contained grey, very stiff, structureless muds with millimetric subangular fragments of different rocks. These muds had a characteristic H2S smell and may correspond to mud volcanic deposits.

Five very angular rock fragments up to 7 cm in diameter were found in the core catcher of TTR-7B-248G with a mixture of grey mud and brown soupy marl with pteropod fragments. The lithologies of the rock fragments are as follows; two clasts of light heading

Brownish-grey micritic limestone, one clast of light grey micritic limestone with a small number of forams, one very light grey chert clast and one fragment of micritic rock with a small white elongated spot (basalt?). This core did not penetrate the sediment, instead it fell horizontally onto the sea floor. However, the presence of rock fragments in the core catcher may imply the occurrence of mud breccia exposed at the seafloor or covered only by a thin veneer of pelagic sediment in the crater of the mud volcanic structure named later the Ottawa mud volcano. Core TTR-7B-251 was taken on the slope of the Ottawa mud volcano and demonstrated typical slumping structures as well as mud breccia at the bottom.

Dredge 249D recovered carbonate crusts and flysch sequence. Whilst the carbonate crusts are formed on the sea floor, the fragments of the flysch formation have been ripped off outcropping strata. The flysch formation in question may be correlated with the Beyddaglari Miocene flysch outcropping in southern Turkey. The pelagic sediments recovered with the dredge TTR-7B-254D are typical of the uppermost part of the Quaternary sequence in the Eastern Mediterranean.

Bottom sampling carried out during the cruise led to the discovery of at least one new mud volcano and showed a big diversity of types of sediments and depositional environments (pelagic sedimentation, slope processes, mud volcanic activity) in the region under investigation, reflecting a complex morphology and active new tectonic.

ANNEX I

CONFERENCE PROGRAMME

Saturday 7 February
19:30 REGISTRATION AND ICE-BREAKER

Sunday 8 February
09.00-18.00 FIELD TRIP : "WAULSORT AND FRASNIAN REEFS IN BELGIUM"
Excursion leader : **R. Swennen**

Monday 9 February

Carbonate Mud Mounds and Cold Water Corals : are they methane related ?

*Chairman: **B. De Mol***

09.00-09.25	Opening : **Prof. Dr. De Leenheer** Vice-Rector (UG), **Prof. Dr. Van Damme** Flemish Government, **Prof. Dr. Ivanov** TTR
09.25-09.50	**P. Croker & O. O'Loughlin** : A CATALOGUE OF IRISH OFFSHORE CARBONATE MUD MOUNDS
09.50-10.15	**M. Hovland** : DO CARBONATE REEFS FORM DUE TO FLUID SEEPAGE ?
10.45-11.10	**J. Greinert & G. Bohrmann** : CARBONATE PRECIPITATES AT THE OREGON ACCRETIONARY MARGIN : THEIR RELATIONSHIP TO VENT FLUIDS AND THE INFLUENCE OF GAS HYDRATES
11.10-11.35	**T. van Weering & J.-P. Henriet** : FLUID MIGRATION, GAS HYDRATES AND BIOGENIC CARBONATE MOUNDS : FUNDAMENTAL QUESTIONS AND OUTLOOK ON RESEARCH ACTIONS.
11.35-12.30	**Debate** : Deep Biosphere-Geosphere Coupling (with Delegates of IOC/UNESCO, EC DG XII, Governmental Departments, Industry and Universities)
12.30 - 12.45	**Signature of a Bilateral Agreement** between Universiteit Gent and Lomonosov Moscow State University : Prof. Dr. ir. J. Willems, Rector Universiteit Gent, and Prof. Dr. V. T. Trofimov, Vice-Rector Lomonosov MSU, representing Prof. Dr. V. A. Sadovnichiy, Rector MSU

*Chairman: **R. Swennen***

14.00-14.25	**S. Cavagna, P. Clari & L. Martire** :THE FOSSIL COLD SEEP CARBONATES OF MONTFERRATO (NW ITALY) : AN EXAMPLE OF LOCALIZED CARBONATE PRECIPITATION INDUCED BY METHANE-DEGRADING BACTERIA.
14.25-14.50	**B. Kaufmann, J. Wendt & Z. Belka** : THE DEVONIAN CARBONATE MUD MOUNDS OF THE AHNET BASIN (ALGERIAN SAHARA) - ANCIENT ANALOGUES OF MODERN DEEP WATER BUILDUPS ?
14.50-15.15	**Z. Belka** : THE ORIGIN OF THE EARLY DEVONIAN KESS-KESS MUD MOUNDS OF THE EASTERN ANTI-ATLAS (MOROCCO) : EVIDENCE FOR SUBMARINE VENTING OF METHANE-RICH FLUIDS
15.15-15.40	**J. Peckman, J. Reitner & F. Neuweiler** : SEEPAGE RELATED OR NOT ? COMPARATIVE ANALYSES OF PHANEROZOIC DEEP-WATER CARBONATES.

*Chairman: **T. van Weering***

16.25-16.50	**J. Wilson & A. Freiwald** : HOW ICEBERGS SHAPE DEEP-WATER REEFS

16.50-17.15 **M. Hovland** : SUB-SURFACE RELATED LOPHELIA REEFS OFF NORWAY.

17.15-17.40 **P.B. Mortensen, M. Hovland, J.H. Fossa & D.M. Furevik** : SIZE AND ABUNDANCE OF LOPHELIA BANKS IN MID-NORWEGIAN WATERS

17.40-18.05 **A. Freiwald & J. Wilson** : THE FATE OF A LOPHELIA REEF OR HOW TO CONVERT A CORAL FRAMEWORK INTO A SKELETAL MUD MOUND?

18.05-18.25 **A. Freiwald & J. Wilson** : SUBMERSIBLE DIVES TO THE GIANT LOPHELIA REEFMOUNDS ON THE SULA RIDGE, NORWEGIAN SHELF

19.00u **TTR Executive and Scientific Committees Meeting : Discussion on TTR Plans**

<u>Tuesday 10 February</u>

Porcupine : Cold Water Corals, Mud Mounds, Sedimentology, Stratigraphy and Tectonic setting

*Chairman: **M. Hovland***

09.00-09.25 **M. Ivanov, N. H. Kenyon, J.-P. Henriet, R. Swennen, A.Limonov, and TTR-7 Shipboard party** : CARBONATE MUD MOUNDS AND COLD WATER CORALS IN THE PORCUPINE SEABIGHT AND ROCKALL BANK : ARE THEY METHANE RELATED ?

09.25-09.45 **A. Mc Donnell & P. Shannon** : THE GEOLOGICAL DEVELOPMENT OF THE PORCUPINE BASIN

09.45-10.05 **N. H. Kenyon, M. Ivanov, A. Akhmetzhanov & A. New** : THE CURRENT SWEPT CONTINENTAL SLOPE AND GIANT CARBONATE MOUNDS TO THE WEST OF IRELAND

10.05-10.25 **S. Pillen, M. Vanneste & J.P. Henriet** : CELTIC RING REEFS : A GENETIC HYPOTHESIS

*Chairman: **P. Croker***

10.45-11.05 **A. Saoutkine** : INFLUENCE OF SURFACE-WATER TEMPERATURE OSCILLATIONS ON THE DEVELOPMENT OF DEEPWATER CORAL BUILD-UPS IN THE PORCUPINE SEABIGHT (NORTH ATLANTIC)

11.05-11.25 **B. De Mol, R. Swennen & J.P. Henriet** : SEDIMENTOLOGY AND GEOCHEMICAL CHARACTERISTICS OF A CORE TAKEN FROM A "HOVLAND" MOUND

11.25-11.45 **N. Amelin & A. Almendinguer** : MODELING OF ACOUSTIC BACKSCATTER FROM CORALS : A WAY TO MAP CORAL FIELDS.

11.45-12.05 **I. Belenkaia** : TEMPERATURE DEPENDENCE OF ISOTOPIC COMPOSITION FOR THE SCELETAL HERMATYPIC SCLERACTINIAN CORALS.

12.05-12.25 **A.U. Saprykina, A. Egorov & A.N. Stadnitskaya** : DISTRIBUTION AND COMPOSITION OF ORGANIC MATTER IN SEDIMENTS FROM CARBONATE MOUNDS OF THE PORCUPINE SEABIGHT.

*Chairman: **M. Ivanov***

14.00-14.20 **P. Chachkine & A. Akhmetzhanov** : SUBBOTTOM CURRENTS ON THE PORCUPINE MARGIN. STUDY BY SIDE-SCAN SONARS.

14.20-14.40 **A. J. Wheeler, B. Cronin, N. Kenyon, N. Satur & R. J.N. Devoy** : CHANNEL ARCHITECTURE AND ACTIVITY IN THE GOLLUM CHANNEL, PORCUPINE SEABIGHT

Open Session

14.40-15.00 **I. C. Harding** : MIOCENE COLD SEEP CARBONATES AND ASSOCIATED FAUNAS FROM BARBADOS

15.00-15.20 **A.C. Neumann & C.K. Paull** : LITHOHERMS IN THE BLAKE-BAHAMA REGION : CONTROLLED BY BOTTOM CURRENTS NOT METHANE SEEPAGE.

15.20-15.40 **A. Milkov, P. Vogt, G. Cherkashev, N. Chernova & A. Andriashev** : LANDSCAPE AND BIOLOGICAL ZONING ON THE HAAKON MOSBY MUD VULCANO (NORWEGIAN SEA) : RESULTS OF DEEP-TOW VIDEO AND STILL PHOTOGRAPHY.

Rockall-Faeroe: Cold Water corals, Mud Mounds, Sedimentology, Stratigraphy and Tectonic Setting

Chairman: J. B. Wilson

16.25-16.50 **J. B. Wilson & C. V. Herbon** : DEEP-WATER CORALS AND ASSOCIATED FAUNAS ON CARBONATE MOUNDS, NORTH SLOPE OF PORCUPINE BANK AND THE SOUTH EAST SLOPE OF ROCKALL BANK

16.50-17.10 **N. H. Kenyon, A. Kuipers, T. Nielsen & J. Taylor** : NEOGENE SEISMIC PATTERN AND CURRENT PATHWAYS WEST OF FAEROE BANK CHANNEL

17.10-17.30 **A. Akhmetzhanov, T. C.E. van Weering, N. H. Kenyon & M. Ivanov** : CARBONATE MOUNDS AND REEFS ON THE ROCKALL TROUGH AND PORCUPINE MARGINS

17.30-17.50 **D. Long** : A MULTI-DISCIPLINARY STUDY OF LOPHELIA PERTUSA IN THE FAEROE-SHETLAND CHANNEL.

17.50-18.10 **V. Gainanov** : SEISMIC INVESTIGATIONS OF CARBONATE MOUNDS IN THE NORTH ATLANTIC TO THE WEST OF IRELAND.

<u>Wednesday 11 February</u>

Fossil Mud Mounds

Chairman: F. Neuweiler

9.00-9.20 **F. Boulvain** : FRASNIAN MUD MOUNDS FROM BELGIUM

9.20-9.40 **J. Lord** : THE TAPHONOMY OF A WAULSORTIAN CARBONATE BUILDUP

9.40-10.00 **J.M. Hvid** : GEOMETRY AND STRUCTURES OF DANIAN BRYOZOA MOUNDS, FAKSE QUARRY, DENMARK

10.00-10.20 **E. Gischler** : LATE DEVONIAN - EARLY CARBONIFEROUS DEEP WATER CORAL ASSEMBLAGES AND SEDIMENTATION ON A DEVONIAN SEAMOUNT: IBERG REEF, HARZ MTS., GERMANY

Chairman: N. Kenyon

10.50-11.10 **R. Dreesen & R. Swennen** : THE BAELEN BUILDUPS : SEDIMENTOLOGY AND DIAGENESIS

Results of Previous TTR-cruises

11.10-11.30 **S. V. Bouriak** : SEISMIC MANIFESTATIONS OF GAS IN THE SOROKIN TROUGH (BLACK SEA): ANALYSIS OF VELOCITY MODEL OBTAINED BY INVERSION OF THE SEISMIC DATA.

11.30-11.50 **A. Stadnitskaia** : HYDROCARBON GAS IN THE ANAXIMANDER MOUNTAINS REGION EASTERN MEDITERRANIAN SEA.

11.50-12.10 **E.V. Kozlova** : COMPARISON OF ORGANIC MATTER OF MUD BRECCIA CLASTS FROM THE ANAXIMANDER MOUNTAINS, MUD VOLCANO AREA THE OLIMPY AND UNITED NATIONS RISE AREAS (EASTERN MEDITERRANEAN)

12.10-12.30 **van den Bosch** : BIOTURBATION IN PELAGIC SEDIMENTS AS PALAEO-

ENVIRONMENTAL INDICES, DESCRIPTION AND INTERPRETATION OF TRACE FOSSILS IN CORES
14.00-17.30 Geological-Historical Excursion in Gent

Poster presentations

G. Akhmanov, I. Premoli Silva, E. Erba, and M.B. Cita LITHOLOGY OF MUD BRECCIA CLASTS FROM THE COBBLESTONE AREA (WESTERN PART OF THE MEDITERRANEAN RIDGE)

I. Belenkaia : GAS-DERIVED AUTHIGENIC CARBONATES IN SEDIMENTS OF THE MEDITERRANEAN AND BLACK SEAS

B. De Mol , E. Keppens, R. Swennen & J.P. Henriet : ISOTOPIC CHARACTERISATION OF AHERMATYPIC CORAL ON A "HOVLAND" MOUND

Gaynanov, S. Bouriak, and P. Chachine : ADVANCED PROCESSING OF OKEAN LONG RANGE SIDESCAN SONAR DATA

B. Kaufmann, J. Wendt & Z. Belka : THE DEVONIAN CARBONATE MUD BUILDUPS OF THE AHNET BASIN (ALGERIAN SAHARA) - ANCIENT ANALOGUES OF MODERN DEEP WATER BUILDUPS?

O.V. Krylov : DISTRIBUTION OF CORALS AND BOTTOM CURRENT IN THE PORCUPINE SEABIGHT AND ON THE PORCUPINE BANK, NE ATLANTIC (FROM UNDERWATER TV AND SIDESCAN SONAR SURVEY)

D. Long : SAMPLING CORALS WEST OF SHETLAND

L.L. Mazurenko : FINE SEDIMENT FROM DIFFERENT MORPHOLOGICAL FEATURES OF THE PORCUPINE SEABIGHT BASIN FLOOR

A. Milkov : DISTRIBUTION AND CLASSIFICATION OF SUBMARINE MUD VOLCANOES

A.V. Morozov and V. G. Gainanov : RECORDS: WHAT IS THEIR PHYSICAL NATURE?

S. Pillen, M. Vanneste & J.-P. Hentriet : CELTIC RING REEFS: A GENETIC HYPOTHESIS

A. Stadniskaya : THE OCCURRENCE OF GAS HYDRATES IN AN AREA OF EXTENSIVE FLUID FLUX AND GAS VENTING. NORTH-EASTERN PART OF THE BLACK SEA

D. Van Rooij, J.-P. Henriet & The Porcupine-Belgica '97 Shipboard Party : HIGH-RESOLUTION SEISMIC INVESTIGATIONS OF THE BELGICA-LOGACHEV MOUND RANGE ON THE EASTERN MARGIN OF PORCUPINE BASIN, SW OF IRELAND

J.B. Wilson & C.V. Herbon : DEEP-WATER CORALS AND ASSOCIATED FAUNAS ON CARBONATE MOUNDS, NORTH SLOPE OF PORCUPINE BANK AND THE SOUTH EAST SLOPE OF ROCKALL BANK

J.M. Woodside, G.G. Akhmanov, E.V. Kozlova, and Shipboard Scientific Party of ANAXIPROBE/TTR-7B cruise : ANAXIMANDER MOUNTAINS MUD VOLCANIC AREA RE-VISITED - RESULTS OF BOTTOM SAMPLING

ANNEX II

LIST OF PARTICIPANTS

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46	Reunión de Trabajo para Desarrollo del Programa "Ciencia Oceánica en Relación a los Recursos No Vivos en la Región del Atlántico Sud-occidental"; Porto Alegre, Brazil, 7-11 de abril de 1986.	S
47	IOC Symposium on Marine Science in the Western Pacific: The Indo-Pacific Convergence; Townsville, 1-6 December 1966.	E
48	IOCARIBE Mini-Symposium for the Regional Development of the IOC-UN (OETB) Programme on 'Ocean Science in Relation to Non-Living Resources (OSNLR)'; Havana, Cuba, 4-7 December 1986.	E, S
49	AGU-IOC-WMO-CPPS Chapman Conference: An International Symposium on 'El Niño'; Guayaquil, Ecuador, 27-31 October 1986.	E
50	CCALR-IOC Scientific Seminar on Antarctic Ocean Variability and its Influence on Marine Living Resources, particularly Krill (organized in collaboration with SCAR and SCOR); Paris, France, 2-6 June 1987.	E
51	CCOP/SOPAC-IOC Workshop on Coastal Processes in the South Pacific Island Nations; Lae, Papua-New Guinea, 1-8 October 1987.	E

No.	Title	Languages
52	SCOR-IOC-UNESCO Symposium on Vertical Motion in the Equatorial Upper Ocean and its Effects upon Living Resources and the Atmosphere; Paris, France, 6-10 May 1985.	E
53	IOC Workshop on the Biological Effects of Pollutants; Oslo, 11-29 August 1986.	E
54	Workshop on Sea-Level Measurements in Hostile Conditions; Bidston, UK, 28-31 March 1988	E
55	IBCCA Workshop on Data Sources and Compilation, Boulder, Colorado, 18-19 July 1988.	E
56	IOC-FAO Workshop on Recruitment of Penaeid Prawns in the Indo-West Pacific Region (PREP); Cleveland, Australia, 24-30 July 1988.	E
57	IOC Workshop on International Co-operation in the Study of Red Tides and Ocean Blooms; Takamatsu, Japan, 16-17 November 1987.	E
58	International Workshop on the Technical Aspects of the Tsunami Warning System; Novosibirsk, USSR, 4-5 August 1989.	E
58 Suppl.	Second International Workshop on the Technical Aspects of Tsunami Warning Systems, Tsunami Analysis, Preparedness, Observation and Instrumentation. *Submitted Papers*; Novosibirsk, USSR, 4-5 August 1989.	E
59	IOC-UNEP Regional Workshop to Review Priorities for Marine Pollution Monitoring Research, Control and Abatement in the Wider Caribbean; San José, Costa Rica, 24-30 August 1989.	E, F, S
60	IOC Workshop to Define IOCARIBE-TRODERP proposals; Caracas, Venezuela, 12-16 September 1989.	E
61	Second IOC Workshop on the Biological Effects of Pollutants; Bermuda, 10 September-2 October 1988.	E
62	Second Workshop of Participants in the Joint FAO-IOC-WHO-IAEA-UNEP Project on Monitoring of Pollution in the Marine Environment of the West and Central African Region; Accra, Ghana, 13-17 June 1988.	E
63	IOC/WESTPAC Workshop on Co-operative Study of the Continental Shelf Circulation in the Western Pacific; Bangkok, Thailand, 31 October-3 November 1989.	E
64	Second IOC-FAO Workshop on Recruitment of Penaeid Prawns in the Indo-West Pacific Region (PREP); Phuket, Thailand, 25-31 September 1989.	E
65	Second IOC Workshop on Sardine/Anchovy Recruitment Project (SARP) int he Southwest Atlantic; Montevideo, Uruguay, 21-23 August 1989.	E
66	IOC *ad hoc* Expert Consultation on Sardine/Anchovy Recruitment Programme; La Jolla, California, U.S.A., 1989.	E
67	Interdisciplinary Seminar on Research Problems in the IOCARIBE Region; Caracas, Venezuela, 28 November-1 December 1989.	E (out of stock)
68	International Workshop on Marine Acoustics; Beijing, China, 26-30 March 1990.	E
69	IOC-SCAR Workshop on Sea-Level Measurements in the Antarctica; Leningrad, USSR, 28-31 May 1990.	E
69 Suppl.	IOC-SCAR Workshop on Sea-Level Measurements in the Antarctica; *Submitted Papers*; Leningrad, USSR, 28-31 May 1990.	E
70	IOC-SAREC-UNEP-FAO-IAEA-WHO Workshop on Regional Aspects of Marine Pollution; Mauritius, 29 October - 9 November 1990.	E
71	IOC-FAO Workshop on the Identification of Penaeid Prawn Larvae and Postlarvae; Cleveland, Australia, 23-28 September 1990.	E
72	IOC/WESTPAC Scientific Steering Group Meeting on Co-Operative Study of the Continental Shelf Circulation in the Western Pacific; Kuala Lumpur; Malaysia, 9-11 October 1990.	E
73	Expert Consultation for the IOC Programme on Coastal Ocean Advanced Science and Technology Study; Liège, Belgium, 11-13 May 1991.	E
74	IOC-UNEP Review Meeting on Oceanographic Processes of Transport and Distribution of Pollutants in the Sea; Zagreb, Yugoslavia, 15-18 May 1989.	E
75	IOC-SCOR Workshop on Global Ocean Ecosystem Dynamics; Solomons, Maryland, U.S.A., 29 April-2 May 1991.	E
76	IOC/WESTPAC Scientific Symposium on Marine Science and Management of Marine Areas of the Western Pacific; Penang, Malaysia, 2-6 December 1991.	E
77	IOC-SAREC-KMFRI Regional Workshop on Causes and Consequences of Sea-Level Changes on the Western Indian Ocean Coasts and Islands; Mombasa, Kenya, 24-28 June 1991.	E
78	IOC-CEC-ICES-WMO-ICSU Ocean Climate Data Workshop Goddard Space Flight Center; Greenbelt, Maryland, U.S.A., 18-21 February 1992.	E
79	IOC/WESTPAC Workshop on River Inputs of Nutrients to the Marine Environment in the WESTPAC Region; Penang, Malaysia, 26-29 November 1991.	E
80	IOC-SCOR Workshop on Programme Development for Harmful Algae Blooms; Newport, U.S.A., 2-3 November 1991.	E
81	Joint IAPSO-IOC Workshop on Sea Level Measurements and Quality Control; Paris, France, 12-13 October 1992.	E
82	BORDOMER 92: International Convention on Rational Use of Coastal Zones. A Preparatory Meeting for the Organization of an International Conference on Coastal Change; Bordeaux, France, 30 September-2 October 1992.	E
83	IOC Workshop on Donor Collaboration in the Development of Marine Scientific Research Capabilities in the Western Indian Ocean Region; Brussels, Belgium, 12-13 October 1992.	E
84	Workshop on Atlantic Ocean Climate Variability; Moscow, Russian Federation, 13-17 July 1992.	E
85	IOC Workshop on Coastal Oceanography in Relation to Integrated Coastal Zone Management; Kona, Hawaii, 1-5 June 1992.	E
86	International Workshop on the Black Sea; Varna, Bulgaria 30 September - 4 October 1991.	E
87	Taller de trabajo sobre efectos biológicos del fenómeno «El Niño» en ecosistemas costeros del Pacífico Sudeste; Santa Cruz, Galápagos, Ecuador, 5-14 de octubre de 1989.	S only (Summary in E, F, S)
88	IOC-CEC-ICSU-ICES Regional Workshop for Member States of Eastern and Northern Europe (GODAR Project); Obninsk, Russia, 17-20 May 1993.	E
89	IOC-ICSEM Workshop on Ocean Sciences in Non-Living Resources; Perpignan, France, 15-20 October 1990.	E
90	IOC Seminar on Integrated Coastal Management; New Orleans, U.S.A., 17-18 July 1993.	E
91	Hydroblack'91 CTD Intercalibration Workshop; Woods Hole, U.S.A., 1-10 December 1991.	E
92	Réunion de travail IOCEA-OSNLR sur le Projet « Budgets sédimentaires le long de la côte occidentale d'Afrique » Abidjan, Côte d'Ivoire, 26-28 juin 1991.	F
93	IOC-UNEP Workshop on Impacts of Sea-Level Rise due to Global Warming. Dhaka, Bangladesh, 16-19 November 1992.	E
94	BMTC-IOC-POLARMAR International Workshop on Training Requirements in the Field of Eutrophication in Semi-Enclosed Seas and Harmful Algal Blooms, Bremerhaven, Germany, 29 September - 3 October 1992.	E
95	SAREC-IOC Workshop on Donor Collaboration in the Development of Marine Scientific Research Capabilities in the Western Indian Ocean Region; Brussels, Belgium, 23-25 November 1993.	E
96	IOC-UNEP-WMO-SAREC Planning Workshop on an Integrated Approach to Coastal Erosion, Sea Level Changes and their Impacts; Zanzibar, United Republic of Tanzania, 17-21 January 1994.	E
96 Suppl. 1	IOC-UNEP-WMO-SAREC Planning Workshop on an Integrated Approach to Coastal Erosion, Sea Level Changes and their Impacts; *Submitted Papers* 1. Coastal Erosion; Zanzibar, United Republic of Tanzania 17-21 January 1994.	E
96 Suppl. 2	IOC-UNEP-WMO-SAREC Planning Workshop on an Integrated Approach to Coastal Erosion, Sea Level Changes and their Impacts; *Submitted Papers* 2. Sea Level; Zanzibar, United Republic of Tanzania 17-21 January 1994.	E
97	IOC Workshop on Small Island Oceanography in Relation to Sustainable Economic Development and Coastal Area Management of Small Island Development States; Fort-de-France, Martinique, 8-10 November, 1993.	E
98	CoMSBlack '92A Physical and Chemical Intercalibration Workshop; Erdemli, Turkey, 15-29 January 1993.	E
99	IOC-SAREC Field Study Exercise on Nutrients in Tropical Marine Waters; Mombasa, Kenya, 5-15 April 1994.	E
100	IOC-SOA-NOAA Regional Workshop for Member States of the Western Pacific - GODAR-II (Global Oceanographic Data Archeology and Rescue Project); Tianjin, China, 8-11 March 1994.	E
101	IOC Regional Science Planning Workshop on Harmful Algal Blooms; Montevideo, Uruguay, 15-17 June 1994.	E
102	First IOC Workshop on Coastal Ocean Advanced Science and Technology Study (COASTS); Liège, Belgium, 5-9 May 1994.	E
103	IOC Workshop on GIS Applications in the Coastal Zone Management of Small Island Developing States; Barbados, 20-22 April 1994.	E
104	Workshop on Integrated Coastal Management; Dartmouth, Canada, 19-20 September 1994.	E
105	BORDOMER 95: Conference on Coastal Change; Bordeaux, France, 6-10 February 1995.	E
105 Suppl.	Conference on Coastal Change: Proceedings; Bordeaux, France, 6-10 February 1995	E
106	IOC/WESTPAC Workshop on the Paleographic Map; Bali, Indonesia, 20-21 October 1994.	E
107	IOC-ICSU-NIO-NOAA Regional Workshop for Member States of the Indian Ocean - GODAR-III; Dona Paula, Goa, India, 6-9 December 1994.	E
108	UNESCO-IHP-IOC-IAEA Workshop on Sea-Level Rise and the Multidisciplinary Studies of Environmental Processes in the Caspian Sea Region; Paris, France, 9-12 May 1995.	E
108 Suppl.	UNESCO-IHP-IOC-IAEA Workshop on Sea-Level Rise and the Multidisciplinary Studies of Environmental Processes in the Caspian Sea Region; *Submitted Papers*; Paris, France, 9-12 May 1995.	E
109	First IOC-UNEP CEPPOL Symposium; San José, Costa Rica, 14-15 April 1993.	E
110	IOC-ICSU-CEC Regional Workshop for Member States of the Mediterranean - GODAR-IV (Global Oceanographic Data Archeology and Rescue Project) Foundation for International Studies, University of Malta, Valletta, Malta, 25-28 April 1995.	E

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111	Chapman Conference on the Circulation of the Intra-Americas Sea; La Parguera, Puerto Rico, 22-26 January 1995.	E
112	IOC-IAEA-UNEP Group of Experts on Standards and Reference Materials (GESREM) Workshop; Miami, U.S.A., 7-8 December 1993.	E
113	IOC Regional Workshop on Marine Debris and Waste Management in the Gulf of Guinea; Lagos, Nigeria, 14-16 December 1994.	E
114	International Workshop on Integrated Coastal Zone Management (ICZM) Karachi, Pakistan; 10-14 October 1994.	E
115	IOC/GLOSS-IAPSO Workshop on Sea Level Variability and Southern Ocean Dynamics; Bordeaux, France, 31 January 1995.	E
116	IOC/WESTPAC International Scientific Symposium on Sustainability of Marine Environment: Review of the WESTPAC Programme, with Particular Reference to ICAM Bali Indonesia, 22-26 November 1994.	E
117	Joint IOC-CIDA-Sida (SAREC) Workshop on the Benefits of Improved Relationships between International Development Agencies, the IOC and other Multilateral Intergovernmental Organizations in the Delivery of Ocean, Marine Affairs and Fisheries Programmes; Sidney B.C., Canada, 26-28 September 1995.	E
118	IOC-UNEP-NOAA-Sea Grant Fourth Caribbean Marine Debris Workshop; La Romana, Santo Domingo, 21-24 August 1995.	E
119	IOC Workshop on Ocean Colour Data Requirements and Utilization; Sydney B.C., Canada, 21-22 September 1995.	E
120	International Training Workshop on Integrated Coastal Management; Tampa, Florida, U.S.A., 15-17 July 1995.	E
121	Atelier régional sur la gestion intégrée des zones littorales (ICAM); Conakry, Guinée, 12-22 décembre 1995.	F
122	IOC-EU-BSH-NOAA-(WDC-A) International Workshop on Oceanographic Biological and Chemical Data Management Hamburg, Germany, 20-23 May 1996.	E
123	Second IOC Regional Science Planning Workshop on Harmful Algal Blooms in South America; Mar del Plata, Argentina, 30 October - 1 November 1995.	E, S
124	GLOBEC-IOC-SAHFOS-MBA Workshop on the Analysis of Time Series with Particular Reference to the Continuous Plankton Recorder Survey; Plymouth, U.K., 4-7 May 1993.	E
125	Atelier sous-régional de la COI sur les ressources marines vivantes du Golfe de Guinée ; Cotonou, Bénin, 1-4 juillet 1996.	F
126	IOC-UNEP-PERSGA-ACOPS-IUCN Workshop on Oceanographic Input to Integrated Coastal Zone Management in the Red Sea and Gulf of Aden Jeddah, Saudi Arabia, 8 October 1995.	E
127	IOC Regional Workshop for Member States of the Caribbean and South America GODAR-V (Global Oceanographic Data Archeology and Rescue Project); Cartagena de Indias, Colombia, 8-11 October 1996.	E
128	Atelier IOC-Banque Mondiale-Sida/SAREC-ONE sur la Gestion Intégrée des Zones Côtières ; Nosy Bé, Madagascar, 14-18 octobre 1996.	E, F
129	Gas and Fluids in Marine Sediments, Amsterdam, the Netherlands; 27-29 January 1997.	E
130	Atelier régional de la COI sur l'océanographie côtière et la gestion de la zone côtière ; Moroni, RFI des Comores, 16-19 décembre 1996.	F
131	GOOS Coastal Module Planning Workshop; Miami, USA, 24-28 February 1997.	E
132	Third IOC-FANSA Workshop; Punta-Arenas, Chile, 28-30 July 1997	S/E
133	Joint IOC-CIESM Training Workshop on Sea-level Observations and Analysis for the Countries of the Mediterranean and Black Seas; Birkenhead, U.K., 16-27 June 1997.	E
134	IOC/WESTPAC-CCOP Workshop on Paleogeographic Mapping (Holocene Optimum); Shanghai, China, 27-29 May 1997.	E
135	Regional Workshop on Integrated Coastal Zone Management; Chabahar, Iran; February 1996.	E
136	IOC Regional Workshop for Member States of Western Africa (GODAR-VI); Accra, Ghana, 22-25 April 1997.	E
137	GOOS Planning Workshop for Living Marine Resources, Dartmouth, USA; 1-5 March 1996.	E
138	Gestión de Sistemas Oceanográficos del Pacifico Oriental Conceptión, Chile, 9-6 Abril 1996.	S
139	Sistemas Oceanográficos del Atlántico Sudoccidental, Taller, TEMA. Furg, Rio Grande, Brazil, 3-11 Noviembre 1997.	S
140	IOC Workshop on GOOS Capacity Building for the Mediterranean Region Valletta, Malta, 26-29 November 1997.	E
141	IOC/WESTPAC Workshop on Co-operative Study in the Gulf of Thailand: A Science Plan, Bangkok, Thailand, 25-28 February 1997.	E
142	Pelagic Biogeography ICoPB II. Proceedings of the 2nd International Conference. Final Report of SCOR/IOC Working Group 93. Noordwijkerhout, The Netherlands, 9-14 July 1995.	E
143	Geosphere-biosphere coupling: Carbonate Mud Mounds and Cold Water Reefs. Gent, Belgium, 7-11 February 1998.	E