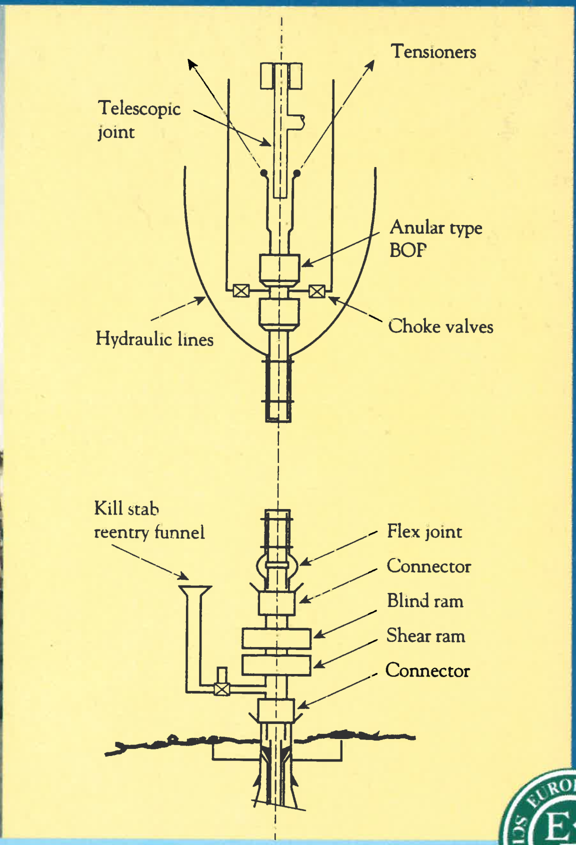
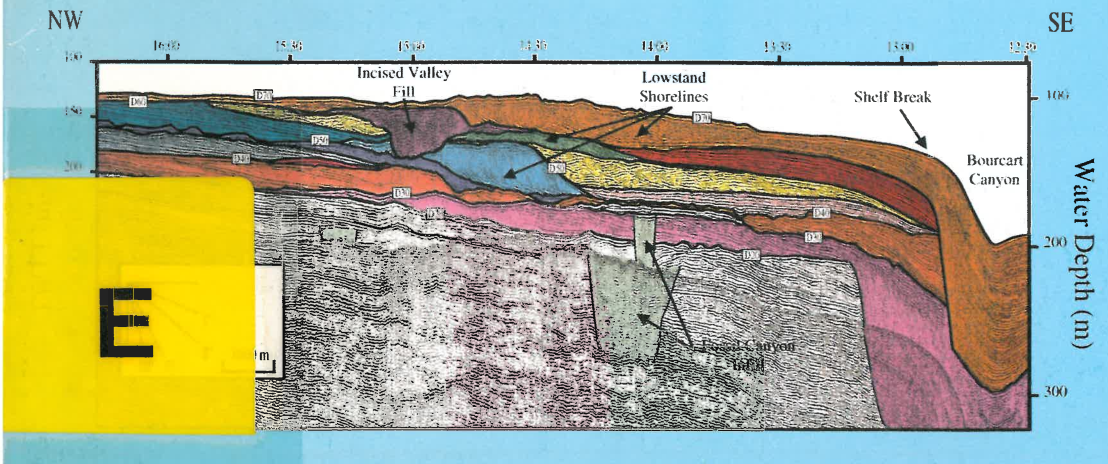
An EMaPS Position Paper

European initiatives in science and technology for deep-sea coring and drilling





European Marine and Polar Science (EMaPS)

European initiatives in science and technology for deep-sea coring and drilling

Contents

Page

Foreword 3

Summary and recommendations 5

Introduction 9
European Marine and Polar Science (EMaPS)
EMaPS statement
EMaPS initiatives
Development of scientific ocean drilling in the world
European marine research and scientific ocean drilling

Scientific and industrial drilling objectives 13
Oceanic lithosphere
Earthquake mechanisms and subduction fluxes
High resolution stratigraphy sequence
    Climate changes
    Sea level changes
    Oil and gas reservoirs
Slope instabilities
Gas hydrates
Deep sub-seafloor biosphere
Oil and gas industrial targets

Technology 23
Marine drilling technologies: state of the art and limits
Near-term developments
Vessel-seafloor links
    Riserless drilling
    Slimline riser
Seafloor-subsurface issues
    Site integrity
    Hole stability

Benefits to Europe: one strategy for science and industry 28

Appendices 29
1. List of acronyms
2. List of the participants in the EMaPS Workshop on European Initiatives for New Deep-Sea Drilling Technologies *(Strasbourg, 14-15 October 1996)*
3. List of the participants in the EMaPS Workshop on European Scientific Strategies for Deep-Sea Drilling *(Southampton, 7-8 November 1996)*

This Position Paper is dedicated to the memory of Professor Robert B. Kidd, a leading European advocate of ocean drilling.

Editors
L. d'Ozouville, C. Jacobs

Contributors
G. Auffret, S. Berné, J.P. Henriet, M. Hovland, H. Kudrass, L. Labeyrie, Y. Lancelot, Y. Le Moign, J. McKenzie, J. Ludden, P. Pezard, J. Parkes, A. Skinner, C. Sparks, G. Wefer

June 1997

Foreword

In creating the European Boards for Marine and Polar Science (EMaPS) back in October 1995, the European Science Foundation and the European Commission shared two main objectives. The first of these was to strengthen the cooperation and coordination between marine and polar institutes in Europe. But, secondly, and just as importantly, EMaPS was established to develop strategies that would help these institutes to make more effective use of their research capacity and collaborate on long-term scientific issues which are beyond the financial reach of individual nations and even, on occasion, of Europe.

Ocean coring and drilling are an important case in point. They are key technologies not only in helping us to answer some fundamental questions about the evolution of the planet, but also in the exploration and exploitation of natural resources. It is an area where there is a clear convergence of interests in the development and use of research resources and techniques amongst both Europe's scientists and industrialists. These shared interests suggest that a coordinated European approach to future developments within the framework of international drilling programmes is now an urgent requirement.

I consider this well-researched and cogently argued position paper, initiated by EMaPS, to be an important contribution towards achieving this objective.

Peter Fricker
Secretary General, ESF

Summary and recommendations

Drilling into the ocean floor for close to 30 years has considerably accelerated our understanding of the dynamics of "Planet Earth", which have become the new paradigm in modern approaches to the study of our planet. Drilling is now to Earth science what large telescopes are to astronomy and large accelerators to particle physicists. Ocean drilling, in particular, is central to resolving the vast majority of fundamental problems posed by the evolution of the planet on a global scale. Furthermore, it has demonstrated a close link between the basic understanding of the dynamics of the Earth and the proper management of its resources. Indeed, ocean drilling is a key technology for the exploration and exploitation of deep-sea oil and gas resources.

Besides the important contribution that European scientists will continue to make in fulfilling the present objectives of the international ocean drilling programmes, they are today in an excellent position to increase their level of participation in solving the most fundamental problems posed by the evolution of the Earth and its environment, and in developing appropriate new technologies.

Science objectives

The two main topics that have recently been recognised as the driving force behind the Ocean Drilling Program are the nature of the deep ocean crust and the dynamics of the lithosphere, and the evolution of the Earth's environment and climate. In both areas, European scientists are important international partners and are capable of defining and proposing major scientific objectives for drilling. In addition, as a result of recent research carried out on behalf of the European Commission and the European Science Foundation, there are many specific science objectives and targets that have been the subject of considerable effort in Europe and have placed our community at the forefront of exploration science. These are centred on the study of continental margins, regions of renewed interest today both in terms of resource exploitation (living and mineral) and natural hazards (slope instability, massive releases of gas, earthquakes), as well as for the high resolution study of climate and sea-level changes.

In many cases, the only method for testing the hypotheses that have arisen from these European research programmes is to drill, but this can not be achieved with only one platform. The European geoscience community urgently requires more frequent utilisation of, as well as more specialised ocean coring and drilling facilities. Ways of accessing platforms other than the JOIDES Resolution, with, as appropriate, long piston coring, geotechnical and drilling capabilities, should be considered.

Technology developments

The present riser technologies used by the oil companies are close to reaching their limits and could not be extrapolated for deeper drilling without difficulty. Developments of new drilling techniques are required before a number of geological and geophysical models and hypotheses, especially those requiring deep drilling, can be solved. In developing any technology, reducing cost and increasing safety are important factors to be taken into account. Ocean exploration technology in Europe is traditionally very strong and often places Europe in a leading position. Yet we have not contributed much so far in technological developments associated with ocean drilling. We should consider two areas in which a European contribution could be highly successful:

- We can contribute to major progress in the construction of the deep penetration tools of the future by developing the "slimline riser" system or an equivalent; we have some advance in the definition of this concept. This might be considered as a European contribution to future international drilling programmes.

- We can contribute a series of down-hole exploration tools, such as new logging sensors, fluid samplers, pressure core samplers, microbiological samplers and in situ laboratories, broad-band seismometers, etc.

A European approach

In order to achieve these scientific objectives and technology developments in ocean drilling, better co-ordination and co-operation have to be developed with all interested partners of private and public sectors in Europe.

- The scientific community needs to improve its organisation around major well-focused international programmes conducted at the European level. This may also entail a better sharing of resources (ships, personnel, and laboratory facilities) and requires a renewed approach in various European

Commission programmes. This would be achieved by establishing a European Scientific Committee on Ocean Coring and Drilling. Such co-ordination would include facilitating the implementation of European scientific programmes requiring coring and drilling technologies, and overseeing technical developments in deep-sea drilling.

- Taking into account the present common interests of Science and Industry, a permanent, active and concrete dialogue should be established between the scientific community and the oil and gas industry in Europe for the identification and the drilling of common targets, and for the development of new technologies.

- The establishment of a permanent European Secretariat for Ocean Drilling is necessary to ensure the implementation of the above recommendations and continuity in the actions taken.

Of course, these European initiatives in science and technology for ocean drilling in Europe have to be undertaken within the framework of the present and future international scientific programmes. In order to achieve this objective, we should seriously consider reorganising our participation in the international drilling programmes with a more unified position. Ways to attain this goal may be to improve the coordination at the executive level in Europe, and to study the possibility of consolidating, step by step, our contribution to international ocean drilling programmes as a major single European partner.

Europe has presently a unique opportunity to benefit from, and to build upon, its long scientific and financial commitments in deep sea coring and drilling, so as to successfully lead the way in tackling a major challenge for the well-being of our Society: the global understanding of the Ocean.

European Marine and Polar Science (EMaPS)

EMaPS forms an informal non-governmental body which was officially created in October 1995 and which is placed under the auspices of the European Science Foundation (ESF). It is composed of a Marine Board and a Polar Board. The Marine Board represents 26 marine research organisations from 18 countries in Europe. EMaPS should aim to provide a focus for concerted action on European marine and polar matters at scientific and policy levels. EMaPS is a source of advice on science policy matters, and examines research issues of strategic importance in close association with the European Commission. EMaPS facilitates the implementation of international research networks and projects and it also promotes the shared use of research facilities and joint activities in the development of new instrumentation and platforms for research.

EMaPS statement

At its meeting of 9-10 May 1996, the EMaPS Marine Board recognised scientific ocean drilling as an area offering a unique opportunity for Europe to take a global lead in technological development, scientific investigation and exploitation. EMaPS agreed to promote constructive approaches to this matter and, more precisely, it decided to focus its efforts on:

- identifying European capabilities in ocean drilling;
- defining long-term pan-European scientific strategies for ocean drilling; and
- promoting European initiatives for the development of new technology, especially in areas where European expertise is well-established.

This should be achieved in close association with those members of the scientific community interested in offshore drilling and with the oil companies. Moreover, all of these initiatives would have to be considered in the framework of the present and future international programmes making use of ocean drilling technologies.

EMaPS initiatives

A first meeting organised by EMaPS on *European Initiatives for New Deep Sea Drilling Technologies* was held in Strasbourg on 14-15 October 1996 and was attended by 26 participants of whom 14 were from oil and contracting companies. The objectives of the meeting were:

- to assess the state of the art and the constraints for deep sea drilling technologies;

- to identify the most likely new deep-sea drilling technologies which could be of common interest to both the scientific community and to the oil companies;
- to draw up a rationale and, if possible, to prepare strategies for the development of these technologies in Europe.

European Scientific Strategies for Ocean Drilling was the topic for a second meeting at the Southampton Oceanography Centre on 7-8 November 1996. From across Europe, 31 delegates from various agencies, industry, research institutes and large scientific programmes discussed European strategies for ocean coring and drilling, addressing major science themes such as the oceanic lithosphere, active margins, paleoclimatology, the high-latitude seas, the deep biosphere and the management of the continental margins (slope stability, gas hydrates and economic development).

Development of scientific ocean drilling in the world

The above-mentioned scientific themes and their technological requirements have already been clearly identified - with varying emphasis - and endorsed by the world-wide Scientific Community in the Long Range Plan of the Ocean Drilling Program (ODP), and also as part of the European Grand Challenges in Ocean and Polar Sciences (EC - ESF Euroconferences on the Deep-Sea Floor and the Arctic) and other major scientific initiatives and programmes (InterRIDGE, IMAGES, NAD, etc.).

Scientific ocean drilling began just over 30 years ago as a project within the USA to explore the geological structure of the seafloor. That initial trial became a fully-fledged international research effort in 1974-76 when Germany, France, Japan, the then USSR and the United Kingdom joined the Deep Sea Drilling Project (DSDP) to begin the International Phase of Ocean Drilling (IPOD).

The succeeding programme to DSDP, the ODP, has been running since 1985 with, currently, 15 European members. France, Germany and the United Kingdom are each full members of ODP, and an ESF consortium, ECOD, made up of Belgium, Denmark, Finland, Iceland, Italy, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and Turkey make up a fourth membership. Other members of ODP are the USA (10 memberships), Japan, and the Australia - Canada – Korea - Chinese Taipei Consortium. ODP operates full time a unique drillship, the JOIDES Resolution (fig. 1), with of a maximum drillstring of 9000 m in length.

The ODP is a proposal driven programme that focuses on global scientific problems. It has recently published an updated Long Range Plan which outlines a number of scientific themes and initiatives that will be followed over the next 5 - 10 years. The ship activity and scientific services are co-ordinated by the Texas A&M University, USA. The acquisition of downhole measurements was the responsibility of Columbia University, USA but since 1992, the latter responsibility has been shared between Columbia University and two groups located in Europe: the Borehole Research Group of Leicester University, UK, and the Laboratoire de Mesures en Forage of CNRS in Aix-en-Provence, France. Shore-based core repositories and data reference centres provide materials for research long after operations at sea are complete. One of the four core repositories is based at the Geosciences Department of Bremen University, Germany. This facility is entrusted with the care of ODP cores recovered from the Atlantic and Southern Oceans, and the Caribbean and Mediterranean Seas beginning with ODP Leg 151. One of the eight micropaleontological reference centres is located in Basel, Switzerland.

Fig. 1: ODP Drillship: JOIDES Resolution. This vessel, registered as SEDCO/BP 471, is 156 metres long and 23 metres wide. The ship's derrick towers 67 metres above the waterline. A computer-controlled dynamic positioning system, supported by 12 powerful thrusters and two main shafts, maintains the ship over a specific location while drilling. A seven-storey laboratory stack and other scientific facilities located fore and aft occupy 1100 square metres. (Photo EMaPS, L. d'Ozouville)

These examples of co-operation show the internationalisation of ODP, not only in terms of scientific participation onboard ship, but also in terms of programme steering and technical contribution.

European marine research and scientific ocean drilling

Over the past decade, the European Commission and the European Science Foundation have encouraged and funded a large number of pan-European marine geology projects, many of which have produced new models and ideas about the formation, evolution and exploitation potential of the ocean floor around Europe. In many cases, the only method for testing the hypotheses that have arisen from European programmes (such as ENAM, QUEEN, STEAM, PONAM and TREDMAR) is to drill. This has been shown by the large number of drill-site proposals collected within a three-week period in January 1995 by the concerted action CORSAIRES (98 well-documented sites). These sites are located alongside Europe in five main areas: Norway – Faeroe - Rockall; Porcupine - Celtic Sea - English Channel; South Portugal; French-Italian Mediterranean Sea; Eastern Mediterranean Sea.

All these drilling requests can not be fulfilled by ODP, and extra capacity for coring and drilling is required around Europe. A European concerted effort should be made to provide this additional capacity to bring EC-funded projects to a successful conclusion and to supplement the international goals of the ODP Long Range Plan.

Indeed, a flexible geotechnical vessel equipped by Europe for excellent core recovery in shallow to mid-depth seas could be a major contribution to the international ODP programme and be of fundamental importance to ocean exploration.

It has to be pointed out that this blockage to accessing drilling facilities has occurred at a time when both industrial exploration and environmental concerns have led to the expression of an urgent need for the definition of base line data for the sustainable exploitation and safe management of our continental margins.

The Science Plans of the world-wide marine geoscience community are expounded in the ODP Long Range Plan and, consequently, these objectives are not repeated here. Instead, using the vision of ODP and taking into account the specific European needs, we have defined a more focused European regional Science Plan as a basis for a Strategic Implementation Plan. In this strategy, the science of which is outlined below, the European specialities and expertise in the respective scientific domains are identified in a global perspective.

Oceanic lithosphere

Some of the requirements for obtaining a detailed understanding of oceanic ridge systems are already pencilled-in as future targets for ODP and the OD21 project: conventional drilling to install ridge axis and intra-plate networks in order to complete the global sea-floor seismic network; deep penetration to 3 km or more involving drilling of telescoped holes off-axis; deep drilling involving a riser or sea-bottom assemblage, for complete penetration of the oceanic crust.

Studies of ridge axes should be integrated with the InterRIDGE programme, and should also be orientated towards instrumentation involving studies of fluid flow, heat fluxes, crustal tectonic stresses, magmatic evolution and biological evolution of ridge systems.

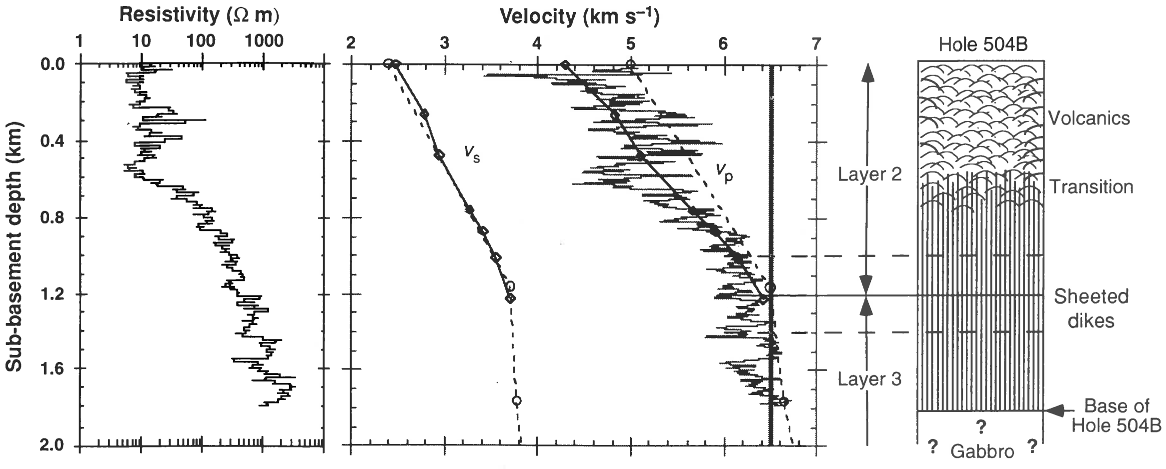


Fig. 2: After Detrick et al., 1995. Nature, 370, 288-290. DSDP/ODP Hole 504B is the only hole ever drilled in the deep ocean penetrating more than 2 km below seafloor. Through a thin sedimentary cover, 1836 m of basalt constitute today the reference section for the geological structure of the upper oceanic crust. This structure was previously described from ophiolites and seismic refraction profiles. Each layer was defined on the basis of seismic velocity values and trend versus depth, and associated to the petrologic layers identified in ophiolites. With seismic layer 3, velocities measured in the sheeted dikes of Hole 504B, at least 400 m above the base of the hole and, consequently, above gabbros (previously thought to correspond to Layer 3), this single hole demonstrated the importance of ground-proofing large-scale geophysical images with drilling, and negated a 30-year-old model.

Drilling the Moho seismic discontinuity was at the origin of scientific ocean drilling in 1967. However, neither DSDP nor ODP have effectively tackled this challenge, since the deepest penetration so far reached a depth of 2111 mbsf while a Mohole is expected to extend 5.0 to 6.0 km into the crust. An initiative involving the deep penetration and characterisation of the oceanic crust should be started as soon as possible. A penetration of 3.0 to 3.5 km appears feasible with the present drillship and technology if sufficient planning and time is devoted to this operation. Specific planning phases and plans for drilling operations, especially regarding the use of telescopic casing strings and real-time borehole stability studies should be implemented. The latter are twofold, with the thermo-mechanical modelling of drilling operations on the one hand, and the monitoring of tectonic instabilities (active faults) with time-lapse acoustic images of the borehole surface on the other. When a riser system or sea-floor based bottom hole assembly is available, entire penetration of the crust should become a priority for drilling the oceanic crust.

Active margins: earthquake mechanisms and subduction fluxes

Drilling in active, accretionary margins, such as that of Japan and the mid-Mediterranean Ridge, should be orientated towards understanding the tectonic processes involved in the formation and deformation of accretionary prisms and, in particular, towards a better comprehension of the distribution of stress in the subducting system in order to model the mechanisms of earthquake development. This research should involve a series of deep holes in active margins and some, or at least one instrumented deep hole through the plate boundary (décollement zone).

Drilling in both accretionary and non-accretionary margins will include representative sections of subducting sediments and oceanic crust, with the aim of evaluating the mass fluxes in active margins. These fluxes include the rates and mechanisms of arc development and back arc formation, as well as the cycling of elements of environmental and economic significance. Drilling will also be used to investigate hydrothermal processes in arc and back-arc crust, with particular emphasis on analogues for the large economic sulphide deposits found on land, many of which were formed in subduction-related settings.

High resolution stratigraphy sequence

Climate changes

There has been a dramatic increase in the international participation and in the study of climate change. Many international and national research programmes focus their studies on the marine environment, using, as proxies for the signal of climate changes, the biological and chemical tracers within the marine sediment column. These proxies can also be geophysical, such as electrical images of the boreholes (fig. 3). In all cases, the highest possible resolution is required for the proxies. The high deposition rates and largely complete (non-eroded) sections of marine sediments (fig. 4) make them ideal repositories for such climatic variation proxies, far superior to all but very few land (actually lake) - based sites. The rapid rise in climate-related research reflects the political importance of this subject. A number of inter-related international initiatives and groups have been formed to act as co-ordinating bodies for this type of research (e.g. CLIVAR, PAGES, IMAGES).

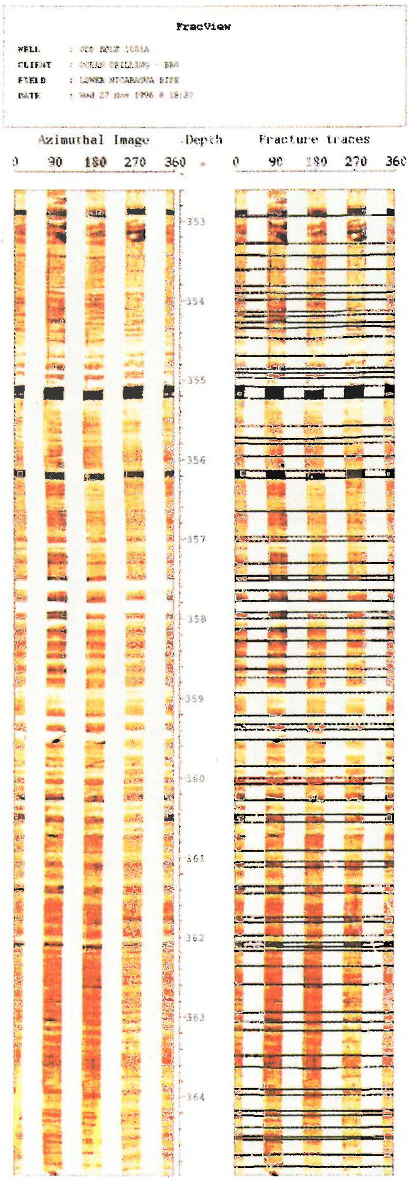


Fig. 3: Electrical images of the borehole surface in ODP Hole 1001A, in the Caribbean Sea. Four antipodal images are presented versus geographical orientation and depth. Dark intervals correspond to clay-rich, more conductive levels and, in some instances, to ash layers (355.15 and 356.20 mbsf). Alternating dark and light intervals correspond to sedimentological changes associated with high-frequency climatic cycles. (CNRS, P. Pezard)

Such programmes and initiatives allow and encourage the use of results from ESF-coordinated and EC- funded projects such as ENAM, PONAM, STEAM, etc., to be synthesised as part of an overall package. The science issues of many of these programmes are complimentary to each other and focus on areas such as quantifying climate and chemical variability of the ocean on time scales of oceanic and cryospheric processes; determining the oceans' sensitivity to given internal and external forcings, and determining its role in controlling atmospheric CO_2.


Fig. 4: ODP Leg 160, Mediterranean Sea. Sapropel. (Photo V. Diekamp)

Progress in resolving these major issues can only be achieved through the examination of the records preserved in ocean sediments under a well-designed and well-coordinated effort of sampling, analysis, and data assimilation. Complete high quality records in areas of high sedimentation are needed. At least 30 dedicated oceanographic expeditions (over 1000 cores approximately 50 m in length) will be needed within the next decade to collect appropriate sediment samples and supporting data. So far, the R/V Marion Dufresne (fig. 5) with a core record of 54 m is the only recognised platform available to collect these IMAGES giant cores.

An important need for drilling to depths of 100 to 300 mbsf into a number of targets in the Mediterranean and North Atlantic is also being assessed. These longer cores would serve to (i) improve the resolution of the correlatable signals from cores of 50 mbsf,


Fig. 5: R/V Marion Dufresne. She is a multipurpose vessel for logistics and oceanographic research. This vessel launched in 1995 is 120 metres long and 21 metres wide. She is operational in all oceanographic fields and, in particular, she is equipped with handling gear for high length core sampling of up to 60 metres. (Photo IFRTP, M. Le Coz)

(ii) improve the time period under study back to 200 000 – 500 000 years (or longer), (iii) act as local reference points for correlation of a suite of regional 50 mbsf cores. All cores should be multiple sites (triple cored) and should be accompanied by a supporting high-resolution geophysical mapping programme (seismic and sonar).

Sea level changes

During the "icehouse" interval (i.e. the last 35 my), global sea-level varied with different magnitudes and frequencies, in relation to climate changes and the evolution of ice-sheets. Of particular relevance is the Quaternary period, because climate and glacio-eustatic sea-level changes were very important, and because of the interest for predicting what might happen in the future. For instance, the rate and pattern of the last deglacial sea-level rise (stepped or continuous) is important to assess the possibility of very fast changes (a few metres over a few hundred years) in the future, which is a major issue for most of the European countries.

Oil and gas reservoirs

In addition, integrated (from the alluvial plain to the deep sea) studies of sedimentation on European margins, in relation to Quaternary sea-level changes, would provide "ground truth" for understanding the controls on sequence architecture and depositional facies. The development of "sequence stratigraphy" has been one of the major outcomes for Earth Sciences in the late 80's, with several implications for the oil industry. Incised valley fills, lowstand shorelines, offshore sand ridges, turbidites, and contourites are major targets in the stratigraphic record. Their recent analogues may all be studied along European margins.

To date, very detailed geophysical investigations (fig. 6) have been carried out in most European waters, indicating that many sites are very favourable to the interpretation of sea-level and climate changes, and the formation of oil and gas reservoirs. In contrast, no, or very few, boreholes are available for providing the ground truthing. In comparison to the projects carried out in America, such as in the Gulf of Mexico, on the Amazon deep sea fan or across the New Jersey margin, it is important that European teams involved in such studies propose targets in areas where a high scientific background has been acquired through national and/or European programmes.

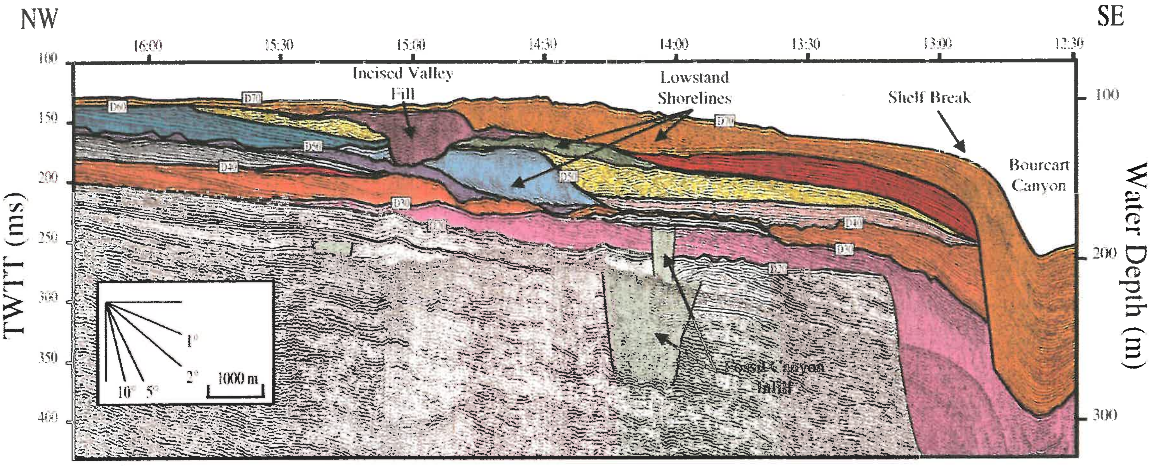


Fig. 6: Very high resolution dip section across the outer continental shelf and upper slope in the Gulf of Lions (Western Mediterranean Sea) showing several lowstand shorelines (steep cliniforms) corresponding to Late Quaternary glacial periods. To note the very thick sedimentary infill within the Bourcart canyon, probably corresponding to Last Glacial Maximum. D 40 is a major seismic discontinuity related to one of the sea level falls. (IFREMER Cruise BASAR; S. Berné)

The successful drilling of recent sediments on continental margins implies the development of new techniques for better penetration and recovery of unconsolidated sediments (especially sandy sediments), as well as the improvement of logging techniques (of particular importance when recovery is poor).

Slope instabilities

The magnitude and aerial extent of giant slope instabilities along the world's oceanic margins has only recently been fully recognised. Large European research projects like PONAM, ENAM, STEAM, TREDMAR, and numerous industrial ventures and regional investigations by Geological Surveys and Scientific Institutions have also demonstrated how common such giant slope failures are along large areas of Europe's continental margins, both in the Atlantic and the Mediterranean.

Mass wasting on continental slopes is not only a major process of sediment transport from the slope to the deep sea, profoundly affecting benthic life, but it also forms a major hazard to human settlements along European coasts. Large slide-induced flood waves or tsunamis can devastate vast stretches of coastal plains. In addition, a direct threat to the exploitation of Europe's offshore energy resources arises from potential failures in the newest frontier area: the Northwest European continental slope.

The causes, triggering and driving processes of giant submarine slides are still poorly understood. Sediment loading pulses through the waxing and waning of ice sheets on the continental shelves and sea-level changes are important factors to be considered. Seismicity almost certainly plays a significant role, as do the nature of the sediments, fluid and gas content, and the interaction between fluid and solid through both diagenetic and biogenic processes.

A striking example of major slides and possible impact on the human environment is offered by the sequence of giant Storegga Slides, which destabilised over 100 km of Norway's continental slopes and transferred about 6.000 km^3 of sediments downslope towards the abyssal plain. The most recent of the Storegga Slides seems to correlate with an 11 m-high tsunami wave which left its scars on the coasts of Norway and Scotland about 7,000 years BP. Also the recently-discovered Great Anaximander Slide (fig. 7), in the Eastern Mediterranean, south of Turkey, raises the issue of the possible impact of giant submarine slides and associated tsunamis on coastal civilisations and Man's early development.

Gas hydrates

The accumulation of free gas at the lower boundary of the hydrate stability zone in marine sediments, usually a few hundred metres below seabed, dramatically decreases the shear strength of the sediment. This may be a significant factor in slope failures, including those with vast aerial extents as described above. In areas of gas hydrates, the process of slope destabilisation may be enhanced by the decay of the hydrate layers in periods of sea level lows (glacial maxima) and, perhaps more significantly, in periods of global warming.

Perhaps one of the most remarkable hypotheses formulated in recent years is the possible active role of giant slope instabilities on the atmosphere and the climate system. The sudden destabilisation of thousands of km^3 of hydrate-bearing sediments would release enormous quantities of methane into the ocean and - most probably in such voluminous transient discharges - into the atmosphere. Methane is widely recognised as a strong greenhouse gas, and can

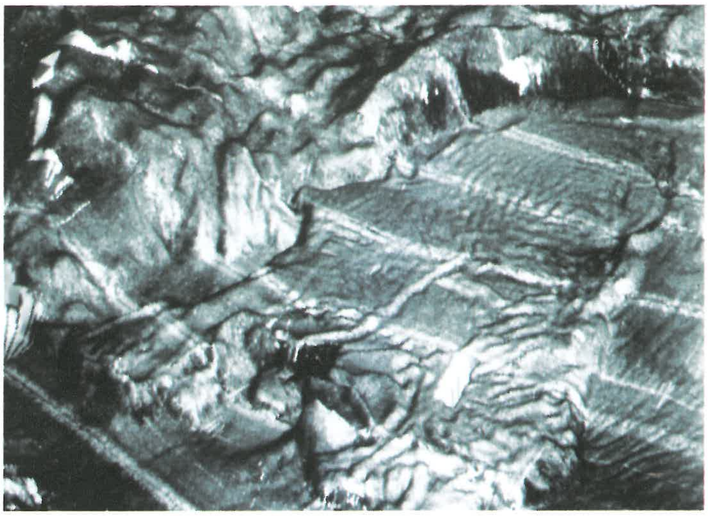


Fig. 7: The Great Anaximander Slide in the Eastern Mediterranean. The flow comes from the upper right and probably was generated from the 1.3 km and 40 km long dark scar in the crescent-shaped mountains. The width of the flow in its front part is about 65 km. This image was made by Dr. J.M. Woodside using Simrad EM12D data obtained during the ANAXIPROBE Project funded by the Netherlands Foundation for the Earth Sciences. (GOA Project 750.195.02)

contribute to global warming, if such discharges are sustained over significant time spans. In periods of global warming, the thermal destabilisation of oceanic gas hydrates may generate a positive feedback loop, hence accelerating climate warming.

New challenging questions, along with clues for these hypotheses have been accumulating rapidly in recent years, requiring serious testing, on a world-wide scale. Ground-truthing by drilling should not only shed light on the basic processes of slope failure, in particular in hydrate-bearing sediments, but should also, in regions which have witnessed sequences of giant slides, define the time frame of the sequences and the lead-lag relationship between giant slides and climatic signals. Drilling through hydrates will also allow scientists to derive the parameters necessary to estimate the concentration of gas and hydrates in sediments. This step is fundamental for the assessment and quantification of the regional (and extrapolation to the global) occurrence of oceanic gas hydrates.

A better understanding of these processes and properties will enable geoscientists to determine the present and model the future links between global warming, slope failure and seabed degassing. In addition, a systematic sampling of hydrates would shed more light on the potential hazard of massive gas releases, especially in near-shore areas or manned offshore fields, and with additional due regard paid to the recent discovery that gas hydrates may frequently contain large concentrations of the highly toxic hydrogen sulphide gas.

Deep sub-seafloor biosphere

Bacteria deep within marine environments play an important role in both the deep ocean biosphere and in geochemical reactions within the ocean crust and marine sediments. The very recent discovery of living bacteria in sediments 500 m below the seabed, many species of which have no known near-surface relations, has great implications for marine science as a whole, and marine biology and geology in particular.

Bacteria have been known to live in the hostile environments around mid-oceanic ridge hydrothermal vent areas and in the upper few metres of marine sediments for some time, but the discovery of bacteria that can survive in the high pressures and temperatures that occur deep within the sediment column demonstrates the presence of a deep marine biomass, possibly accounting for up to 10% of the total organic carbon on Earth. Work on understanding how bacteria can tolerate these natural elevated pressures and temperatures is still in its infancy.

Some of the deep bacterial populations appear to have been surviving on buried organic matter for millions of years, whereas others may have adjusted over time to the changing environment during deep burial. It is thought that in deep ocean sediments the bacteria probably survive in a dormant stage until some external force (such as fluid migration) raises nutrient levels and therefore improves environmental conditions so that the bacteria commence metabolism, probably at very low rates. It may be that the ability of bacteria to enter and leave states of dormancy is a key to successful exploitation of the deep marine environment.

The links between the deep marine bacteria and biogeochemical change have also to be directly demonstrated. Bacteria isolated from hydrothermal environments are already being studied and used in biotechnological processes. The new ubiquitous deep biosphere represents a larger and more diverse source of bacteria that could be exploited for all kinds of uses, such as bio-remedioration, waste treatment, microbial enhanced oil recovery, and exploiting biominerals.

Bacterial activity is intimately linked with the production of gas hydrates, the importance of which around the European margin is outlined above. The whole domain of deep marine microbial research is a new and exciting field, and Europe is well placed to take the lead in this potentially vital area of science.

Oil and gas industrial targets

Over the past five years, within Europe, there has been increasing exploration activity and a good measure of success in both finding and developing hydrocarbon in water depths of up to 800 m. Ongoing activity in ever-increasing water depths has led to the requirement for new technology and a revision of operational techniques within the oil industry in order to promote the progress of these developments in a safe and cost-effective manner. Science has a major part to play in those developments, as there is a willingness to look at new and novel techniques, which can be funded by consortia of oil companies and research institutes. Additionally there is a willingness to look at the funding required in the light of eventually becoming less dependent on Middle East Countries for hydrocarbon supply.

More than 300 oil and gas discoveries have already been made in water depths of more than 200 m, which, in early 1995, represented more than 3.3 TOE for oil, and 6.8 TOE for natural gas. In the year 2000, it is estimated that 15% of the total offshore oil production will be located in water depths of more than 200 m, which will be three times the present production levels. It should be the same ratio for gas production.

Two records to be noted:

- Brazil will soon start oil production at a water depth of 1709 m;
- the record water depth for drilling exploration is 2400 m in the Gulf of Mexico.

The European margin is one of the most important areas for further oil and gas exploration and exploitation. In offshore Norway on the continental slope, the exploration for hydrocarbons in deep water is targeted on large, potential hydrocarbon reservoirs located 1) beneath the Storegga slide scar, 2) beneath apparently undisturbed continental slope sediments, and 3) below a seabed with large sediment diapirs on the Vøring Plateau. The water depths range between 1200 and 2000 m.

In the Norwegian Sea, the zero degree Celsius isotherm is located at a water depth of between 600 and 800 m water depth. Some of the deep-water challenges facing exploration offshore Norway are, however, not only restricted to high-relief seafloor topography, sediment diapirism, and sub-zero temperatures, but also to slope stability, and the action of seeping excess light hydrocarbons and gas hydrates. The areas for co-operation with the scientific community should be all aspects of regional geology, including reconstruction of the prerift sequences in deep petroleum basins. Specific common interests are also most probably within the study of seafloor stability, gas hydrates, and gas-associated processes in the upper seafloor sediments and hole stability.

The oil and gas industry is just starting a new exploration period of the deep part of continental margins off Europe. The scientific community in Europe should be involved in this initiative, both in the development of drilling technology and in the understanding of the tectonic evolution, sedimentation and fluid history of the margin.

Marine drilling technologies: state of the art and limits

Feasibility and costs of deep-sea drilling depend mainly on the drilling target, the water depth, and the local oceanographic/ meteorological conditions. The international geoscientific community forming ODP has successfully operated in water depths as great as 6000 m, and drilled into the ocean crust with a penetration of 2100 mbsf. Sea water was used to transport the cuttings to the upper end of the drill hole. This kind of "riserless" drilling is operated without Blow-Out Preventors (BOP) and controlled mud circulation, which excludes areas with potential gas and oil resources from geoscientific drilling. Furthermore, the stability of deep holes is poor, especially in over-pressurised clays and rocks under tectonic or thermal stresses. A unique feature of the ODP drillship is the very efficient recovery of undisturbed cores of unconsolidated or semi-consolidated sediments by hydraulic piston coring. Short core samples of gas hydrates have just been successfully recovered under ambient hydrostatic pressure. Recovery rates should be improved in firm sediments.

The hydrocarbon industry employs a wide variety of platforms for deep-water exploration and development of oil and gas reservoirs. In most cases, exploration drilling is performed with a standard riser (21-inches or 53 cm) in combination with a BOP system for controlled mud circulation and strict well control for safety and environmental protection. In calm conditions, without strong winds, and with a fair wave climate (e.g. Gulf of Mexico), risers have been used to drill in water depths of up to 2328 m. In areas with harsh environments, strong wind/wave climates and surface and/or deep water currents (e.g. the north east Atlantic), a technical limit is now reached at a water depth of about 1300 m. In these current-afflicted areas, large fairings have to be used to reduce drag on the riser, which adds additional weight, and considerably increases the drilling costs through equipment and deployment. Drilling for the development of a gas/oil reservoir is restricted to even shallower water depths, as heavy and complex components have to be installed at the seafloor.

Near-term developments

The oil industry has increasing interest in drilling in water depths down to 2500 m. The prime motivation in developing any new deep drilling technology is to reduce costs while maintaining or increasing safety. The science community drills at present in open holes (no well control) with sea water circulation (no mud). Acquiring new technology to drill in water depths (down to 4000 m) in areas which are inaccessible at present because of safety reasons and hole stability is the main objective of the latter. The science community has limited funds and, therefore, is also cost-conscious. Technological developments related to the vessel-seafloor link that will allow the oil industry to drill more cheaply (in water depths down to 2500 m), and allow the science community to drill economically with mud and well control (in water depths to 4000 m) should find support in both communities.

Vessel-seafloor links

Two new types of vessel-seafloor link could answer the requirement of both communities: riserless drilling (including mud circulation), and slimline riser drilling.

Riserless drilling

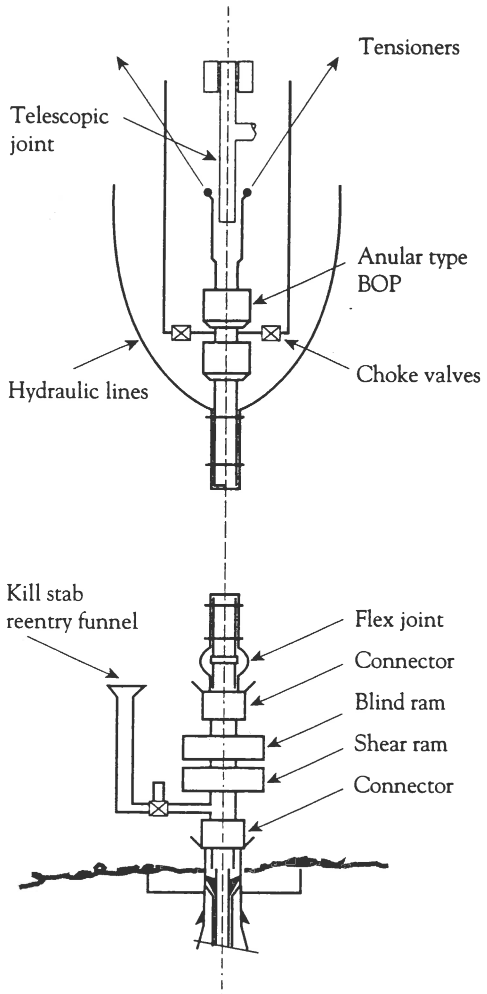
The objective here is to design a system with a rotating Blow-Out Preventor (BOP) located on the seabed, sealing around the drillstring, hence eliminating the need for a riser. Mud would be circulated down the drill-string, up the annulus to the seafloor, from where it would return to the vessel via an independent, possibly flexible, line. Ideally, a mud reservoir would be installed at the seafloor at hydrostatic pressure, to improve borehole stability. This would require mud to be pumped from the seafloor to the vessel. The project is ambitious, very expensive, and success is not guaranteed at this point.

A joint industrial project has already been launched by Conoco to study such a design in detail. It is supported by numerous oil companies (including Exxon, BP, Saga, Statoil, Japex, Shell, Elf, Amoco, Chevron), as well as drilling companies such as Sedco (ODP), Sonat, Foramer, Hydril, Diamond, and also ODP.

Slimline riser

A slimline riser is a small diameter high-pressure pipe (about 10 inches or 25 cm in diameter) without kill and choke lines. The safety device constituted by the BOP is split into two parts: an annular BOP below the vessel, and a ram type BOP at the seafloor. In the case of a formation "kick" occurring, the upper BOP is closed and mud can be circulated down the drill-string, up the well and riser annulus and out through a choke valve just below the annular BOP. The lower BOP is only used in emergency "drive-off" situations.

Fig. 8: Slimline riser



Because of the small diameter, large drill-bits and casings cannot pass through the slimline riser, and under-reaming is used to enlarge the upper sections of the hole. Large diameter casing strings are run with the riser removed. A slimline riser can be designed to operate in water depths of the order of 3000 - 4000 m. Even at such great depths, buoyancy modules are not necessarily required. Compared to a standard oil industry riser, a slimline riser is very light (one tenth the weight or less on the vessel deck) and compact (about one twentieth the volume), and much cheaper. Hence a slimline riser can be carried by a far smaller (and therefore also cheaper) vessel than one with riser capabilities. A slimline riser should also be built in such a way that it could be easily installed in any vessel equipped with drilling capabilities.

The absence of kill and choke lines, and buoyancy units reduces the natural period of axial vibrations of the riser, hence reducing the dynamic amplification of axial loads induced by ship heave. This and the reduced riser mass, lead to a greatly reduced dynamic load in the hung-off riser, and therefore increase safety in this critical design condition. A slimline riser also requires a smaller volume of mud than a standard oil industry riser. Total potential cost savings for the riser, BOP, and operating vessel are very large and are expected to be greater than an order of magnitude over standard systems.

Compared to 'riserless drilling' (with seabed BOP and independent mud return), the principal advantage is reduced complexity and increased safety. One further advantage is that the riser annular fluid serves as thermal insulation and hence reduces the cooling effect of the ocean on the mud descending the drill-string. This reduces thermal fracture effects that have been observed in deep holes.

Seafloor-subsurface issues

The need for new developments covers both the water column and a requirement for better knowledge of the geological structure penetrated below seafloor. At the seafloor and in the subsurface, the main question is that of site and hole integrity, both during and after drilling.

Site integrity

For deep-water oil and gas production, drilling in the deep ocean can only be successful if part of the equipment can be installed at the seafloor, which in itself represents a major technological achievement. At present, to operate in just 1500 m of water requires the launch of very heavy instruments (e.g. BOP's). There are also geotechnical questions to be answered pertaining to the nature of the seafloor and the stability of the equipment at this, sometimes poorly defined, interface. This requires basic research based on both drilling and marine geophysics, and the development of monitoring devices (physical, chemical, seismological) to be placed on the seafloor for safety issues, in relation to the short and long-term behaviour of such structures.

Such stability problems are complicated by the presence of gas hydrates, which also might become unstable due to drilling. A fundamental understanding of the nature and dynamic behaviour of gas hydrates is consequently requested prior to drilling through deep water in continental shelves.

Hole stability

Any borehole with a deep penetration below seabed (>2000 mbsf) experiences hole instability which can cause failure of the programme. In some geological formations this can happen at much shallower depths. Successive Ocean Drilling Programs which, to date, can only use limited casing sections and spot mud circulation within a riserless system have difficulty below this depth in all but hard igneous formations. A joint industry and science approach to the development of novel riser and casing techniques has obvious benefits for both parties. Industry can benefit from the Ocean Drilling Program's experience of deployment of long drillstrings in water, while scientific drilling can benefit from industry's experience in setting casings and riser circulation.

However, a closed-loop system might not be sufficient to solve the overall problem. Recent simulations have shown that the injection of a cold fluid into the subsurface (the mean ocean temperature below 600 m depth is about 2°C), was leading to mechanical instabilities from thermal stresses. Either a restriction of fluid-circulation to the subsurface during the drilling phase, or the design of a thermally-insulated system through the deep ocean appears necessary. This is an area for joint industry and science research on the fluid circulation regime.

Benefits to Europe: one strategy for science and industry

As demonstrated, in particular by the recent meetings of scientists and industrial delegates convened under the auspices of EMaPS in Strasbourg and Southampton, there is a lack of coring and drilling capabilities in Europe to meet the requests of the scientific community. The meetings also demonstrated that a true opportunity is opening for a partnership between European science and industry to advance at a steady pace, on a topic of both prime fundamental and applied interest. This is an opportunity for real synergy, which has to be exploited now, because industry cannot wait, and because environmental safety cannot be allowed to lag behind.

Industrial ventures on the continental slope will soon add an additional stress to these instability-prone areas, and the exploitation industry must be able to build upon better insight into the fundamental processes and risks of slope destabilisation. Furthermore, European science can benefit enormously from unique industrial geophysical data sets, and geotechnical expertise, to move forward in a quest to understand and explain the fundamentals of oceanic slope stability.

The strategy must be to seize this opportunity and encourage collaboration between science and industry in this emerging domain. The European Commission must support a mechanism for integrated multidisciplinary European teams to have access to both deep coring and drilling vessels. These vessels may include both proven large-scale facilities such as the "JOIDES Resolution" for accessing, in particular, the deep-water areas, and the flexible use of specialist geotechnical vessels for water depths of up to 2000 m.

A co-ordinated access scheme to large-scale ocean-going facilities such as coring and drilling vessels, which no single European country could afford or sustain on its own, meets the Principle of Subsidiarity of the European Union in an exemplary way and will strongly contribute to strengthening the European cohesion, competitiveness and identity, within a mainstream of global research. It is through this strategy on oceanic "Grands Chantiers" of European interest and global relevance, that Europe can succeed, in a dynamic way, the challenging art of balancing economic development, environmental concern, and fundamental scientific expertise. This strategy will also ensure that Europe forges a new breed of young, multidisciplinary teams capable of facing the global oceanic challenges of the 21st century.

Appendix 1 – List of acronyms

BOP	Blow-Out Preventors
BP	Before present
CLIVAR	Climate Variability and Prediction Research Programme
CNRS	Centre National de la Recherche Scientifique
CORSAIRES	Coring Stable and Instable Realms in European Seas
DSDP	Deep Sea Drilling Project
ECOD	ESF Consortium for Ocean Drilling
EMaPS	European Marine and Polar Science
ENAM	European North Atlantic Margins
ESF	European Science Foundation
InterRIDGE	Inter-Mid Ocean Ridge Experiment
IMAGES	International Marine Global Change Study
mbsf	Metres below seafloor
NAD	Nansen Arctic Drilling Programme
OD 21	Ocean Drilling in the Twenty-First Century
ODP	Ocean Drilling Program
PAGES	Past Global Environmental Changes
PONAM	Polar North Atlantic Margins Programme
QUEEN	Quaternary Environment of the Eurasian North
STEAM	Sediment Transport in European Atlantic Margins
TOE	Ton Oil Equivalent
TREDMAR	Training and Education in Marine Sciences

Appendix 2

List of participants - European Initiatives for New Deep-Sea Drilling Technologies

ESF, Strasbourg, 14-15 October 1996

Dr. Hermann Kudrass (Chairman)
Bundesanwalt für Geowissenschaften und Rohstoffe
Stilleweg 2, Postfach 510 153
30631 Hannover
Germany
Tel: (49) 511 643 2782
Fax: (49) 511 643 3663
Email: kudrass@gate1.bgr.d40.de

Professor Hans Amann
c/o VWS
Schleuseninsel
10625 Berlin
Germany
Tel: (49) 30 311 84 220
Fax: (49) 30 311 84 200
Email: amann@vws.tu-berlin.de

Mr. Trond Henrik By
DSND Survey
Rådhusgt 23, P.O. Box 752 Sentrum
0106 Oslo
Norway
Tel: (47) 22 41 21 50
Fax: (47) 22 41 06 50

Mr. Claus Chur
Managing Director
Deutsche Tiefbohr Betriebsgesellschaft
Deilmannstrasse 1
48455 Bad Bentheim
Germany
Tel: (49) 5922 72569
Fax: (49) 5922 72457

Appendix 2

Mr. Jean Courjault
GEP
45 rue Louis Blanc
92038 Paris La Défense
France
Tel: (33) 1 4717 6864
Fax: (33) 1 4717 6747

Mr. Chris Drew
BP Exploration Operating Company Limited
Farburn Industrial Estate, Dyce
Aberdeen, AB2 0PB
United Kingdom
Tel: (44) 1224 832625
Fax: (44) 1224 833444

Mr. Vic Estes
Mobil North Sea Limited
Grampian House-Union Row
Aberdeen AB10 1SA
United Kingdom
Tel: (44) 1224 855798
Fax: (44) 1224 855300

Dr. Tim Francis
Ocean Drilling Program
1000 Discovery Drive, College Station
Texas, 77845
United States
Tel: (1) 409 845 8480
Fax: (1) 409 845 1026
Email: tim_francis@odp.tamu.edu

Mr. André Goffart
Drilling R & D Coordinator - TOTAL
Tour TOTAL
92069 Paris La Défense Cedex 47
France
Tel: (33) 1 41 35 36 43
Fax: (33) 1 41 35 37 22

Professor Jean-Pierre Henriet
Renard Centre of Marine Geology
University of Gent
Krijgslaan 281, SP
9000 Gent
Belgium
Tel: (32) 9 264 4585
Fax: (32) 9 264 4967
Email: jeanpierre.henriet@rug.ac.be

Mr. Sigbjorn Hoyland
c/o STATOIL A/S
4035 Stavanger
Norway
Tel: (47) 51 80 98 29
Fax: (47) 51 80 43 60

Mr. Yves Kerbart
FORAMER
16 bis rue Grange Dame Rose
78143 Velizy-Villacoublay
France
Tel: (33) 1 30 70 58 58
Fax: (33) 1 39 46 39 25
Email: kerbart@forasol.edt.fr

Mr. Yves Le Moign
Vice-président, SEDCO FOREX
50 Avenue Jean Jaurès
P.O. Box 599
92542 Montrouge Cedex
France
Tel: (33) 1 47 46 60 60
Fax: (33) 1 47 46 72 88
Email: lemoign@montrouge.sedco-forex.slb.com

Dr. John Ludden
Centre de Recherches Pétrographiques et Géochimiques, CNRS
15 rue N.D. des Pauvres
54520 Vandoeuvre-les-Nancy
France
Tel: (33) 3 83 59 42 13
Fax: (33) 3 83 51 17 98
Email: ludden@crpg.cnrs-nancy.fr

Mr. Marangoni
AGIP S.p.A.
Drilling and Completion Department
P.O. Box 12069
20120 Milan
Italy
Fax: (39) 2 520 22104

Mr. Andy Moore
GEOS
Hargreaves Road
Groundwell Industrial Estate
Swindon SN2 5AZ
United Kingdom
Tel: (44) 1793 706 604
Fax: (44) 1793 462 409
Email: Moore@geos.co.uk

Mr. Daniel Moyne
CSTJF Elf Aquitaine Production Deepwater Development
Avenue Larribau
64018 Pau Cedex
France
Tel: (33) 5 59 83 49 42
Fax: (33) 5 59 83 42 14
Email: Moyne_Daniel/pau@com-pau.elf=p.fr

Dr. Philippe Pezard
CEREGE, Laboratoire de Pétrologie Magmatique , B.P. 80
13545 Aix-en-Provence Cedex 4
France
Tel: (33) 4 42 97 15 53
Fax: (33) 4 42 97 15 59
Email: pezard@cerege.fr

Dr. Peter Seifert
EUROMAR Office
GKSS Research Centre
Max-Planck-Strasse
21502 Geesthacht
Germany
Tel: (49) 4152 87 1991
Fax: (49) 4152 87 1913
Email: peter.seiffert@gkss.de

Mr. Charles Sparks
European Commission, DGXVII, D-3
Rue de la Loi
1049 Bruxelles
Belgium
Tel: (32) (2) 299 2147
Fax: (32) (2) 296 6016
Email: Charles.Sparks@bxl.dg17.cec.be

Mr. Jean-Claude Vasseur
FORAMER
16 bis rue Grange Dame Rose
78143 Velizy-Villacoublay
France
Tel: (33) 1 30 70 58 58
Fax: (33) 1 39 46 39 25
Email: vasseur@forasol.edt.fr

Dr. Marco Weydert
European Commission, DG XII-D3
200 rue de la Loi
1049 Bruxelles
Belgium
Tel: (32) 2 296 2145
Fax: (32) 2 296 3024
Email: marco.weydert@dg12.cec.be

Mr. Bolie Williams
CAMERON
Houston, Texas
United States
Tel: (1) 713 939 2030
Fax: (1) 713 939 2953

Mr. Lothar Wohlgemuth
Geoforschungszentrum Potsdam
Telegrafenberg C9, 14473 Potsdam
Germany
Tel: (49) 331 288 1806
Fax: (49) 331 288 1810
Email: wohlgem@gfz-potsdam.de

EMaPS Marine Board Chairman

Dr. Daniel Cadet
CNRS, Direction des Relations Internationales
3 rue Michel-Ange
75766 Paris Cedex 16
France
Tel: (33) 1 44 96 50 05
Fax: (33) 1 44 96 49 10
Email: daniel.cadet@cnrs-dir.fr

EMaPS Marine Board Scientific Secretary

Dr. Laurent d'Ozouville
EMaPS Secretariat
European Science Foundation
1 quai Lezay Marnésia
67080 Strasbourg Cedex
France
Tel: (33) 3 88 76 71 44
Fax: (33) 3 88 25 19 54
Email: dozouville@esf.org

Apologies for absence

Dr. Guy Crauser
European Commission
Directorate-General III - Industry
Task Force "Maritime Systems of the Future"
Rue de la Loi 200
1049 Bruxelles
Belgium
Tel: (32) 2 299 4129
Fax: (32) 2 296 7014

Mr. Paul R. Erb
Conoco Inc.
P.O. Box 2197
Houston, Texas 77252
United States
Tel: (1) 713 293 2895
Fax: (1) 713 293 4668

Appendix 3

List of participants - European Scientific Strategies for Ocean Drilling

Southampton, 7-8 November 1996

Dr. John Ludden (Co-chairman)
Centre de Recherches Pétrographiques et Géochimiques - CNRS
15 rue Notre Dame des Pauvres
54501 Nancy Cedex
France
Tel: (33) 3 83 59 42 13
Fax: (33) 3 83 51 17 98
Email: ludden@crpg.cnrs-nancy.fr

Professor Gerold Wefer (Co-chairman)
Fachbereich 5 - Geowissenschaften
Univeristät Bremen
Postfach 33 04 40
28334 Bremen
Germany
Tel: (49) 421 218 3389
Fax: (49) 421 218 3116
Email: GWefer@zfn.uni-bremen.de

Dr. Belen Alonso
Instituto de Ciencias del Mar
C.S.I.C.
Paseo Joan de Borbo s/n
08039 Barcelona
Spain
Tel: (34) 3 221 6416
Fax: (34) 3 221 7340
Email: belen@icm.csic.es

Dr. Dennis A. Ardus
British Geological Survey
Murchison House
West Mains Road
Edinburgh
EH9 3LA, Scotland
United Kingdom
Tel: (44) 131 667 1000
Fax: (44) 131 668 4140

Dr. Gérard Auffret
IFREMER
DRO/GM
B.P. 70
29280 Plouzané
France
Tel: (33) 2 98 22 42 57
Fax: (33) 2 98 22 45 70
Email: gauffret@ifremer.fr

Dr. Ulrich Bleil
Fachbereich Geowissenschaften
Universität Bremen
Postfach 33 04 40
28334 Bremen
Germany
Tel: (49) 421 218 3366
Fax: (49) 421 218 7008
Email: bleil@geomarin.uni-bremen.de

Dr. Jean Boissonnas
European Commission
DG XII/D3 - MAST programme
200 rue de la Loi
1049 Bruxelles
Belgium
Tel: (32) (2) 295 6787
Fax: (32) (2) 296 3024

Dr. Petter Bryn
Norsk Hydro ASA
Exploration and Production
Postboks 200
1321 Stabekk
Norway
Tel: (47) 22 738298
Fax: (47) 22 739756
Email: petter.bryn@nho.hydro.com

Dr. Angelo Camerlenghi
Osservatorio Geofisico Sperimentale
P.O. Box 2011
34016 Trieste
Italy
Tel: (39) 40 214 0253
Fax: (39) 40 327 521
Email: angelo@macant.ogs.trieste.it

Dr. Dan Evans
British Geological Survey
West Mains Road
Edinburgh, EH9 3LA, Scotland
United Kingdom
Tel: (44) 131 650 0404
Fax: (44) 131 668 4140
Email: dan.evans@bgs.ac.uk

Dr. David Falvey
ODP, 1755 Massachussetts Avenue, NW
Suite 800
Washington, DC 20036-2102
United States
Tel: (1) (202) 232 3900 X217
Fax: (1) (202) 232 8203
Email: dfalvey@brook.edu

Dr. Rainer Gersonde
Alfred-Wegener-Institut
für Polar- und Meeresforschung
Columbusstrasse, Postfach 12 01 61
25568 Bremerhaven
Germany
Tel: (49) 471 4831 203
Fax: (49) 471 4831 149
Email:rgersonde@AWI-Bremerhaven.de

Professor Jean-Pierre Henriet
RCMG / CORSAIRES Office
University of Gent, Marine Geology
Krijgslaan 281, S8
9000 Gent
Belgium
Tel: (32) 9 264 4585
Fax: (32) 9 264 4967
Email: jeanpierre.henriet@rug.ac.be

Dr. Martin Hovland
STATOIL
4035 Stavanger
Norway
Tel: (47) 51 807 130
Fax: (47) 51 805 670
Email: mhovland@ln.statoil.no

Dr. Susan E. Humphris
JOIDES Office
Woods Hole Oceanographic Institution
Woods Hole
MA 02543
United States
Tel: (1) (508) 289 3451
Fax: (1) (508) 457 2150
Email: shumphris@whoi.edu

Dr. Colin L. Jacobs
Southampton Oceanography Centre
Empress Dock
Southampton
SO14 3ZH
United Kingdom
Tel: (44) 1703 596576
Fax: (44) 1703 596554
Email: Colin.L.Jacobs@soc.soton.ac.uk

Professor Yngve Kristoffersen
Institute of Solid Earth Physics
University of Bergen
Allègaten 41
5007 Bergen
Norway
Tel: (47) 55 58 34 07
Fax: (47) 55 58 96 69
Email: yngve.kristoffersen@ifjf.uib.no

Dr. Laurent Labeyrie
Centre des Faibles Radioactivités
Laboratoire Mixte CNRS-LEA
91198 Gif sur Yvette Cedex
France
Tel: (33) 1 69 82 35 36
Fax: (33) 1 69 82 35 68
Email: labeyrie@cfr.cnrs-gif.fr

Dr. Judith A. McKenzie
Geologisches Institut
ETH Zentrum
Sonneggstrasse 5
8092 Zürich
Switzerland
Tel: (41) 1 632 3828
Fax: (41) 1 632 1080
Email: sediment@erdw.ethz.ch

Dr. Catherine Mével
Laboratoire de Pétrologie
Université Pierre et Marie Curie,
Case 110
4 Place Jussieu, Tour 26, 3me étage
75252 Paris Cedex 05
France
Tel: (33) 1 44 27 51 93
Fax: (33) 1 44 27 39 11
Email: cam@ccr.jussieu.fr

Dr. José Hipolito Monteiro
Instituto Geológico e Mineiro
R. Academia das Ciências, 19-2
1200 Lisboa
Portugal
Tel: (351) 1 346 3915
Fax: (351) 1 342 4609
Email: h-mont@individual.puug.pt

Professor John Parkes
Department of Geology
University of Bristol
Bristol
United Kingdom
Tel: (44) 117 928 9000
Fax: (44) 117 925 3385
Email: J.Parkes@Bristol.ac.uk

Appendix 3

Dr. Julian A. Pearce
Department of Geological Sciences
University of Durham
South Road
Durham DH1 3LE
United Kingdom
Tel: (44) 191 374 2528
Fax: (44) 191 374 2510
Email: J.A. Pearce@durham.ac.uk

Dr. Philippe Pezard
CEREGE
Laboratoire de Pétrologie Magmatique
B.P. 80
13545 Aix-en-Provence Cedex 4
France
Tel: (33) 4 42 97 15 53
Fax: (33) 4 42 97 15 59
Email: pezard@cerege.fr

Professor David G. Roberts
B.P. Exploration Operating Company Ltd
Building 200, Chertsey Road
Sunbury-on-Thames
Middlesex, TW16 7LN
United Kingdom
Tel: (44) 1932 764550
Fax: (44) 1932 764552
Email:robertsdg@txpcap.hou.xwh.bp.com

Mr. Alister Skinner
British Geological Survey
Murchison House, West Mains Road
Edinburgh EH9 3LA, Scotland
United Kingdom
Tel: (44) 131 667 1000
Fax: (44) 131 668 4140
Email: acsk@bgs.ac.uk

Dr. Edith Vincent
Laboratoire de Géologie du Quartenaire/CNRS, CEREGE
B.P. 80
13545 Aix-en-Provence Cedex 4
France
Tel: (33) 4 42 97 15 89
Fax: (33) 4 42 97 15 95
Email: evincent@cerege.fr

Dr. Phil Weaver
Southampton Oceanography Centre
Challenger Division
Empress Dock
Southampton SO14 3ZH
United Kingdom
Tel: (44) 1703 596563
Fax: (44) 1703 596554
Email: ppew@soc.soton.ac.uk

EMaPS Marine Board Chairman

Dr. Daniel Cadet
CNRS
Direction des Relations Internationales
3 rue Michel-Ange, B.P. 287
75766 Paris Cedex 16
France
Tel: (33) 1 44 96 46 90
Fax: (33) 1 44 96 49 10
Email: daniel.cadet@cnrs-dir.fr

EMaPS Marine Board Scientific Secretary

Dr. Laurent d'Ozouville
EMaPS Secretariat
European Science Foundation
1 quai Lezay Marnésia
67080 Strasbourg Cedex
France
Tel: (33) 3 88 76 71 44
Fax: (33) 3 88 25 19 54
Email: dozouville@esf.org

EMaPS Assistant

Ms. Jane Swift
EMaPS Secretariat
European Science Foundation
1 quai Lezay Marnésia
67080 Strasbourg Cedex
France
Tel: (33) 3 88 76 71 41
Fax: (33) 3 88 25 19 54
Email: JSwift@esf.org

Unable to attend:

Mr. John H. Barwis
Shell Research and Technical Services
Postbus 60
2280 AB Jijswijk
The Netherlands
Tel: (31) 70 311 2388
Fax: (31) 70 311 3064
Email: J.H.BARWIS@siep.shell.com

Impression: IREG Strasbourg - Dépôt légal: juin 1997 - N° d'ordre: 971550

The European Science Foundation is an association of its 62 member research councils, academies and institutions devoted to basic scientific research in 21 countries. The ESF assists its Member Organisations in two main ways: by bringing scientists together in its Scientific Programmes, Networks and European Research Conferences, to work on topics of common concern; and through the joint study of issues of strategic importance in European science policy.

The scientific work sponsored by ESF includes basic research in the natural and technical sciences, the medical and biosciences, the humanities and social sciences.

The ESF maintains close relations with other scientific institutions within and outside Europe. By its activities, ESF adds value by cooperation and coordination across national frontiers and endeavours, offers expert scientific advice on strategic issues, and provides the European forum for fundamental science.

EMaPS Secretariat
European Science Foundation
1 quai Lezay-Marnésia
67080 Strasbourg Cedex France
Tel.: + 33 (0)3 88 76 71 41
Fax: + 33 (0)3 88 25 19 54
WWW Home Page: http://www.esf.org/emaps

EMaPS receives financial support from its Member Organisations and the EC, and is under the auspices of the ESF.