ECORD
European Consortium for
Ocean Research Drilling

ECORD
Evaluation Report

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Printed by Vagner graphic

Front cover: *World map credit is http://histgeo.ac-aix-marseille.fr*

ECORD Evaluation Report

October 2011

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Period covered: from 1/1/2004 to 6/7/2011

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Executive summary

Seventy percent of the Earth's surface is covered by oceans that have highly significant geological and biological systems, yet large areas of both our continental shelves and deep oceans are still largely unexplored. The Deep Sea Drilling Project (DSDP), its successor the Ocean Drilling Program (ODP) and the current phase, the Integrated Ocean Drilling Program (IODP) have been tremendously successful in improving our knowledge of these systems, partly due to the programmes' drilling facilities and partly because of the rigorous process of development and selection of projects.

The IODP drilling facilities are provided by the US drillship, the *JOIDES Resolution*, the Japanese drilling vessel *Chikyu* and mission-specific platforms (MSPs). MSPs are made available to the global scientific community through the European Consortium for Ocean Research Drilling (ECORD) funded by 16 European countries and Canada. Several of the projects would have been impossible without the international partnerships created by IODP and ECORD. ECORD in particular has provided the opportunity for some of the smaller European nations to participate in this global science programme.

The current phase of IODP ends in 2013 and plans are in place to continue the collaboration for a further 10 years. In 2010, the executive authority of ECORD, the ECORD Council, therefore commissioned an independent evaluation of the role of ECORD in the scientific achievements of IODP. The ECORD Evaluation Committee were asked to pay particular attention to the role and impact of ECORD scientists in proposal submission, expedition participation and publications, as well as the efficiency and impact of mission-specific platform expeditions. Secondly, the Committee was asked to assess the new science plan for the future of ocean drilling after 2013, including the need for a strong programme of MSP activities. This report presents the conclusions of the ECORD Evaluation Committee. Their key findings are summarised as follows.

ECORD has been a great success, and has provided ECORD members with the opportunity to contribute to scientific research of global importance and to access major operational infrastructures and data that would have otherwise been impossible as individual countries.

ECORD scientists have been very active in many aspects of IODP science. They have contributed to a large number of proposals (40 of the 105 currently under evaluation or ready to be implemented) and have participated in a large number of expeditions, providing about one-third of IODP expedition Co-chief Scientists. ECORD scientists have also contributed to more than 2600 peer-reviewed papers, many of which have been published in high ranking journals such as *Nature* and *Science*.

The mission-specific platform concept has shown, through their work on four expeditions to the Arctic, Tahiti, New Jersey (USA) and the Australian Great Barrier Reef, that these flexible platform facilities provide scientists with the facilities to solve specific problems. For example, the ECORD-led Arctic Coring Expedition (ACEX), which aimed at deciphering the paleoceanographic evolution of the Arctic Ocean in relation to the tectonic history of the Arctic basin, as well as constraining the formation of Arctic sea-ice, was an enormous scientific success. The impact of the project is clearly shown by the number of papers published in *Nature* and other journals. The discovery of the freshwater fern, *Azolla*, is both important for the understanding of the paleoclimate during a period some 55 million years ago, and for estimating the petroleum potential of the Arctic Region.

MSP operations are, therefore, a valuable contribution to IODP ocean-drilling and monitoring operations that complement the *JOIDES Resolution* and *Chikyu*. Providing IODP with the capability to drill in the Arctic and other challenging environments clearly demonstrates the value of MSP operations and the enormous scientific and societal benefits that ECORD contributes to the programme. The exploration of the Arctic, in particular, should continue as a high-priority activity within ECORD.

Even in a successful organisation such as ECORD, the ECORD Evaluation Committee recognises that some aspects can be improved, and individual recommendations are made where appropriate. The effort made by the **ECORD Science Operator (ESO)** to apply efficient, timely and less costly procedures is acknowledged, given the boundary conditions, both in terms of scientific requirements and the unique character of each MSP operation. The Bremen

Core Repository (BCR), one of three IODP core repositories worldwide and a part of the ESO consortium, is well-organised and effective. In all of the contributing organisations within ESO there are highly specialised scientific and technical staff ready to provide the required services.

The new Science Plan, elaborated by the international community for the next phase of ocean drilling, introduces new scientific methods and models that clearly identify cutting-edge research opportunities in the future. The scientific and societal challenges are enormous, emphasing the need for more Earth-system science as societies become increasingly vulnerable to changes in our natural environment. It is very promising to see that efforts will be made to develop relationships with other organisations, although how this collaboration will work is still to be detailed. The future research goals may also open up collaboration with industry as innovative drilling, sensor and sampling technology will be needed to successfully fulfill some of the objectives described. To rapidly progress toward implementation, we recommend to identify the scientific priorities for the next five years and the related challenges.

Between 2013 and 2023 mission-specific platform expeditions will be crucial, and it is expected that MSP approach will include sea-bed drills and long-piston coring. Only MSPs will be able to access shallow shelves and most of the Arctic which are key areas for studies of climate and sea-level changes

The ECORD Evaluation Committee recommends that ECORD continues with a funding and activity level higher than the present programme. There are still many areas to be explored and many Earth system models to be tested.

1 - Introduction

1.1 - Background

The European Consortium for Ocean Research Drilling (ECORD) is a collaboration of 17 countries *(see back cover)* that participates as a unit in the Integrated Ocean Drilling Program (IODP), the international scientific programme that investigates the ocean floors and sub-seabed environments through drilling. Ocean drilling for scientific purposes began in 1968 as a major American programme which quickly developed into the international Deep Sea Drilling Project (DSDP), then the Ocean Drilling Program (ODP) and finally, from 2003, into the current IODP. During more than 40 years of drilling, these successive projects have revolutionised our understanding of the ocean floor. Scientific drill holes have penetrated deep into the volcanic basement beneath the ocean floor, unravelling the complex history of its origin and modification by high-temperature fluids such as those seen in black smokers. The holes drilled into the sedimentary cover have revealed global patterns of changing environments, of oceanic chemistry and of geological environments. The results from drilling provide crucial ground-truthing information for computer models of climate change. Recently, drilling has revealed an unexpected sub-seafloor biosphere that is a radically new form of life on Earth. Fresh avenues for science are developing as unexpected results emerge and as new technology is developed for use within drill holes. Participants in scientific drilling include many of the most talented earth scientists of the last decades. The quality of the science arising from ocean drilling is as high as ever.

1.2 - IODP current science plan highlights and implementation

In the years before 2003 a single drill ship was active, first the *Glomar Challenger* and then the *JOIDES Resolution*. Since IODP started in 2003, there have been three different ways of conducting ocean drilling expeditions *(photo 1)*. The US-run ship, the *JOIDES Resolution*, totally renovated in 2009, continues to drill many of the sites in deep water using open holes. The Japanese vessel *Chikyu* drills sites that require very deep penetration and the use of a 'riser' system that includes a casing that surrounds the drill pipe to return drilling fluids to the vessel and maintain pressure balance within the borehole. Targets that cannot be reached by either of these ships, because of shallow water depth, ice cover or other factors, are drilled using mission-specific platforms (MSPs). The MSP operations for IODP are the responsibility of ECORD.

The current phase of IODP runs until 2013. The drilling during this phase has been based on a science plan that arose from an international workshop in which the ECORD science community played an important role. This 'Initial Science Plan' addressed three major topics:

- Deep Biosphere & Sub-Seafloor Ocean
- Environmental Change, Processes & Effects
- Solid Earth Cycles & Geodynamics

The plan also emphasised eight initiatives of high scientific priority: the deep biosphere, gas hydrates, extreme climates, rapid climate change, continental breakup and sedimentary



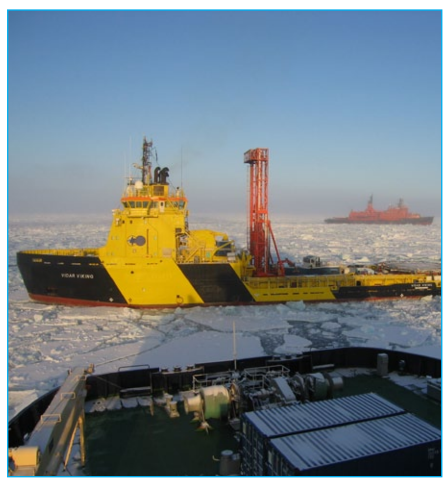


Photo 1: The three IODP drilling platforms. From left to right, the JOIDES Resolution (William Crawford, IODP/TAMU), Chikyu (©IODP/JAMSTEC) and the mission- specific platform the Vidar Viking used during the Arctic Coring Expedition in 2004 (D. McInroy ©ECORD/IODP).

basin formation, large igneous provinces, 21st century Mohole and the seismogenic zone.

The major partners in IODP are the USA and Japan, who together provide typically 80% of the total annual costs of $120-200M per year. As the main contributors to IODP, the USA and Japan are called the Lead Agencies *(Figure 1)*. ECORD is a contributing member and currently pays $21.5M per year, 10-15% of the total cost and in return plays a very important role in planning and in participation on all IODP expeditions and activities. Other countries (China, Korea, India, and an Australia-New Zealand consortium (ANZIC)) are associate members, contributing around $4M per year in total.

Within the current structure of IODP, ECORD plays a significant part. The IODP scientific and engineering committee structure is made up of a web of panels that evaluate new proposals for drilling, plan future expeditions, review site surveys, take care of safety aspects and so on. ECORD is well represented on all of these panels and is also entitled to nominate three governors to the IODP Board of Governors. ECORD has the right to nominate an average of eight shipboard participants from its member countries on each drilling expedition - and often exceeds that number.

Planning is well advanced for another ten-year phase of drilling from 2013-2023. The new Science Plan is based on a meeting held in Bremen in 2009, following which the plan was written by a team of fourteen scientists with four from ECORD, including the Chair. The proposed new programme will be known as the International Ocean Discovery Program (still IODP).

1.3 - ECORD's role in IODP

During the ODP phase of drilling before 2003, individual European countries took part in the programme as separate members. At the start of IODP, the European members of ODP decided to form a consortium to join the new programme as a single member and play a major role as a platform operator. Initially composed of 12 countries, the European Consortium for Ocean Research Drilling (ECORD) has now expanded to 17 members (16 from Europe and

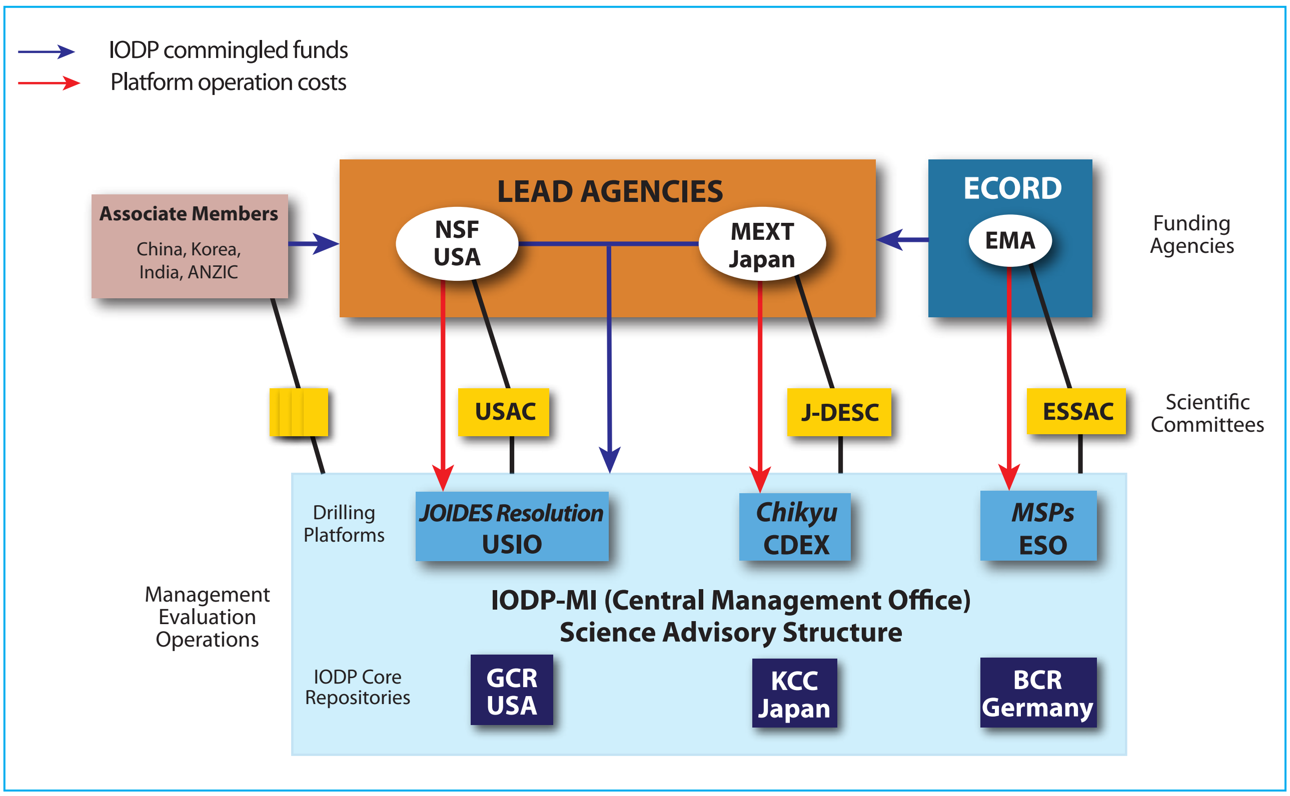


Figure 1: The organisational and funding structure of the Integrated Ocean Drilling Program. See Annex, page 35 for explanation of acronyms.

Canada). The setting up of ECORD was supported by an EC-funded ERA-Net (ECORD-Net, 2004-2008), but ECORD funding (*i.e.* the international contribution to IODP and the operations of MSPs) now comes entirely from its member country contributions.

ECORD was created with strong ambitions:

- To speak with one voice to the Lead Agencies of the programme and therefore be more visible,
- To play a major role as platform operator by providing access to MSPs, and expand the scope of scientific drilling to areas previously inaccessible,
- To develop a strong and coordinated drilling community in Europe and Canada.

The ECORD Memorandum of Understanding (MoU), signed in December 2003, specifies the structure and functioning of the consortium. The ECORD Council is the executive authority of the consortium. The ECORD Managing Agency (EMA) pools the funds of ECORD member countries. Administered by CNRS (France), it implements ECORD Council's decisions and interacts with the Lead Agencies *(Figure 1)*. The ECORD Science Operator (ESO) is the "Implementing Organization" of ECORD, which operates mission-specific platforms within the frame of IODP. ECORD also hosts one of the three major repositories for IODP, the Bremen Core Repository, which curates and stores cores from any of the IODP expeditions that take place in the Atlantic and Arctic oceans and the Mediterranean Sea. The ECORD Science Support and Advisory Committee (ESSAC) is responsible for the coordination of activities related to scientific ocean drilling in ECORD member countries. To fulfill this role, ESSAC has developed a number of supporting activities such as the summer schools, the Distinguished Lecturer Programme and ECORD grants. A mid-term review of ECORD was conducted in 2005, as part of the EC-funded ECORD-Net project. This first review focused on the ECORD structure and the overall outcome was very positive. The report is available at http://www.ecord.org/enet/ecord-midterm-review.pdf

The cost of IODP has gradually increased as the programme has developed and become much higher than initially estimated. The cost increases arose through the rapid rise in the price of fuel oil and also through the resulting increase in demand for drillships throughout the world, leading to higher shipyard costs. In the current situation, the US National Science Foundation (NSF) funds 7-8 months of drilling per year with the *JOIDES Resolution*, the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT) funds an average of 5 months of drilling per year with the *Chikyu*, and ECORD aims to fund one expedition every second year.

1.4 - Terms of Reference and organisation of the evaluation

As the plans for the new phase of IODP developed, the ECORD Evaluation Committee was set up to evaluate from the point of view of ECORD the results to date of the first phase of IODP and the plans for the new phase.

ECORD Council set up the Committee with the following terms of reference.

> The "ECORD Evaluation Committee" will undertake two tasks:
>
> 1) The **first task** is to conduct an evaluation of the role of ECORD in the scientific achievements of IODP (2004-present). This will cover three aspects:
>
> - the analysis of IODP scientific achievements with a particular emphasis on the role and impact of ECORD scientists: proposal submission, cruise participation (including co-chiefs), post-cruise scientific publications,
> - the analysis of the impact of mission-specific platform (MSP) expeditions on the IODP scientific accomplishments. MSP expeditions are funded by ECORD and operated by the ECORD Science Operator for the whole IODP scientific community.,
> - an overall assessment of the efficiency of MSP operations, building upon the IODP Operation Review Task Force reports.
>
> 2) The **second task** is to assess the new science plan for the future ocean drilling programme, post 2013, and in particular the need for a strong MSP programme to address the scientific objectives.

The Committee held three meetings, one of which was a visit to the Bremen Core Repository and completed most of its work by e-mail.

In this report we first examine the achievements of the first phase of IODP and then look forward to the possible next phase of drilling.

2 - Evaluation of the Scientific Achievements

In this chapter we review IODP's scientific achievements so far. These were presented to the Evaluation Committee as seven themes: Arctic Drilling (ACEX), Climate Variability, Sea-Level Change, Fluid Flow, Deep Biosphere, Ocean Lithosphere and the Seismogenic Zone. It is important to note that it takes several years for the science from an expedition to be complete enough for publication. The science for expeditions 301 to 316 is available as IODP report volumes and as refereed publications in the open literature. For expeditions later than 316 the information available depends on informal articles and unrefereed reports, with very little for drilling later than late-2009. Accounts of the science achieved on the seven themes are concluded with our remarks on the impact of the research and of the ECORD scientists' contributions. These sections are followed by an overall evaluation of the science.

2.1 - Arctic Drilling (ACEX)

The Arctic Ocean plays a major role in ocean circulation and is critical in the investigation of climate change. The history of Arctic sea-ice is archived in the sediments on the floor of the Arctic Ocean and information from these is essential to evaluate the Arctic's influence on past global climates. Drilling the Arctic seafloor beneath the ice pack has for long been a major scientific goal but was not achievable with the *JOIDES Resolution*, which is not ice-strengthened. It was only with the Arctic Coring Expedition (ACEX - IODP expedition 302, *Table 1*), the first of the MSP expeditions implemented by ECORD, that the central Arctic became accessible. ACEX took place in the summer of 2004, using two icebreakers to break the drifting ice-pack to allow the ice-strengthened drilling vessel *Vidar Viking* (*photos 1 and 2*) to keep station and drill.

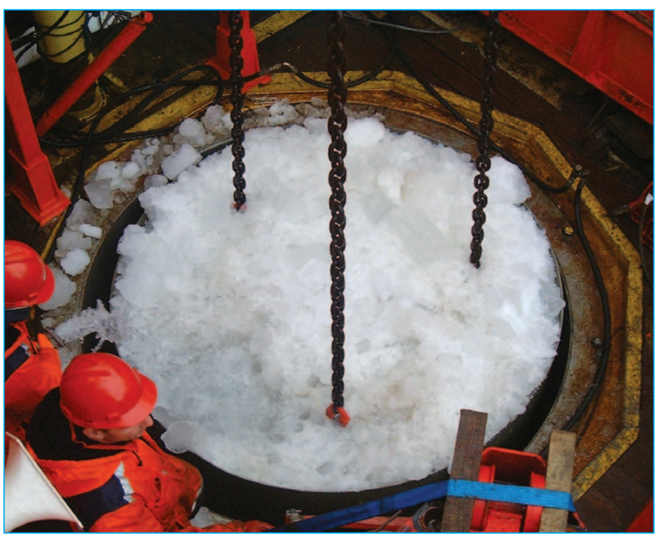


Photo 2: Drillship Vidar Viking with the moonpool ful of sea ice (A. Skinner ©ECORD/IODP).

ACEX had both climatic and tectonic objectives. It set out to decipher the history of Arctic sea ice since ice started to cover the ocean basin. It was also aimed at understanding the complex plate-tectonic evolution of the ocean basin. These include the environmental effects of the opening of the Fram Straight, and the nature and origin of the Lomonosov Ridge that runs through the centre of the basin.

Expedition	Location	ECORD scientists	Drilling platform	ECORD Co-chief scientists
302	Arctic ocean	11 (including a Russian scientist)	*Vidar Viking* (MSP)	1 (J. Backman (Sweden)

Table 1. Participation of ECORD scientists in the Arctic Coring Expedition.

The terrigenous sediments cored during ACEX provide the first long Cenozoic record of the history of Arctic sea-ice. One of the major surprising results was the discovery of ice-rafted debris (IRD) and diatoms associated with sea-ice in sediments from the middle Eocene. This suggests that seasonal sea-ice began to form about 46 Ma ago. Previous evidence from the Norwegian Sea suggested that Northern Hemisphere cooling started at ~12 Ma, while the timing of the intensification of Northern Hemisphere glaciation was dated at 2.7 Ma from the first occurrence of IRD in DSDP cores from the North Atlantic

The microfossil record reveals a shallow-water, near-shore marine setting during the early rifting stages of the Lomonosov Ridge. As rifting progressed, the marine environment changed to one that was dominated by a thick layer of fresh surface water, with highly stratified subsurface waters. At *ca*. 49 Ma, and still in shallow water, the freshwater fern, *Azolla*, dominated the environment of the Lomonosov Ridge. The consequent lack of oxygen available for decomposition resulted in the sequestration of organic carbon on the floor of the Arctic basin, producing a sedimentary record rich in organic carbon.

The discovery of the 49 Ma freshwater episode in the history of the Arctic basin and of the *Azolla* event was totally unexpected. It is possible that the *Azolla* event played a significant part in the evolution of carbon dioxide in the atmosphere, while the *Azolla* sediments may be a source rock for hydrocarbons in the deltas surrounding the Arctic Ocean. The data is also of significant relevance to the work of the United Nations Convention on the Law of the Sea (UNCLOS) - the UN Commission working on national claims to the ocean floor.

Before ACEX it was argued that since Arctic Ocean paleoenvironments were so poorly known, the recovery of any sedimentary record would be true exploration that would increase our knowledge and understanding of this critical region. On the other hand it was argued that drilling in the Arctic is extremely costly and the risk involved related to drilling in such environment would be too high. The results of the drilling show that ACEX was well worthwhile. By October 2010, just six years after the completion of ACEX, 76 peer-reviewed papers that make use of the ACEX cores and results had been published, including eight articles/letters in *Nature* and *Nature Geosciences*. This is an astonishing output from a single expedition. Not only have the drilling results been important scientifically, they have also been of considerable societal benefit.

Clearly drilling of a single site in an ocean four times the size of the Mediterranean has not solved all of the problems of the Arctic Ocean. Because of the critical role of the Arctic in controlling climate in the northern hemisphere and beyond, and because of the unexpected results of the ACEX drilling, further scientific drilling is necessary, despite its logistical problems. This drilling must target both the missing Cenozoic paleoclimate record and the climate record from other critical parts of the Arctic Basin. For this drilling to be successful, an icebreaking drilling ship will be needed.

2.2 - Climate Variability

The ocean plays a crucial role in regional and global climate change. Climate variability occurs at different timescales. At shorter time scales, orbitally driven insolation changes are prominent overlain by millennial Heinrich- and Daansgard-Oeschger events and sub-decadal modes (El Niño Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO)). At time scales of millions of years, ocean/continent configuration and opening and closing of oceanic gateways become relevant. These deeply impact ocean circulation and influence the heat exchange between low and high latitudes, which may affect the moisture flux between ocean and continents.

Four low and mid-to-high latitude key regions were studied with the following overarching questions:

- How do the oceans respond to the build-up of large ice-shields at high latitudes of the North Atlantic and North Pacific during the mid through late Cenozoic and early Quaternary (expeditions 303, 306, 323)?
- What was the extent and precise timing of the build-up of perennial ice-sheets in both hemispheres (expeditions 303/306 and 318)?
- What changes took place in the carbonate balance in the Equatorial Pacific as a response to changes in global climate (expeditions. 320, 321)?

Expedition	Location	ECORD scientists	Drilling Platform	ECORD Co-chief scientists
303 and 306	N Atlantic	8 9	*JOIDES Resolution*	- 1 (R. Stein, Germany)
323	Bering Sea	10	*JOIDES Resolution*	-
320 and 321	E Equatorial Pacific	9 8	*JOIDES Resolution*	1 (H. Pälike, UK) 1 (I. Raffi, Italy)
318	Wilkes Land	8	*JOIDES Resolution*	2 (C. Escutia, Spain and H. Brinkhuis, The Netherlands)

Table 2. Participation of ECORD scientists in IODP expeditions that addressed the Climate Variability theme.

Expeditions 303 and 306 *(Table 2)* established a precise chronology for the late Cenozoic–Quaternary climate proxies in the North Atlantic using geomagnetic, stable isotope, and detrital layer stratigraphy data as well as geomagnetic paleointensity. With this new chronology, suborbital climate variability from the Late Miocene through the Quaternary was proposed for the North Atlantic. The evaluation includes ice sheet-ocean interactions, deep ocean circulation and changes in sea-surface conditions.

Expeditions 320 & 321 *(Table 2)* targeted an age transect across the equator in the Pacific. The result was a detailed inter-calibration of all major fossil groups with an excellently resolved magneto-stratigraphic record (870 dated reversals for the past *ca*. 50 Ma. Ages of critical boundaries (among others Eocene/Oligocene and Oligocene/Miocene) could be well constrained with biogenic carbonate fossils. These expeditions completed a task that was not achieved during earlier DSDP and ODP cruises.

Expedition 323 *(Table 2)* drilled holes in the Bering Sea in the North Pacific. Changes in the nature of the surface water masses of the North Pacific could be identified for the past 5 Ma. The distribution of ice-rafted detritus (IRD) in the cores showed that sporadic cooling started after 3.8 Ma, occurred more regularly only after 2.7 Ma, and reached a maximum at 1Ma at both Bowers Ridge and along the Bering Slope.

Expedition 318 *(Table 2, photo 3)* drilled the Wilkes Land margin off Antarctica from January-March 2010. The first long sedimentary sections from this margin document climate variability between the Early Eocene and the Holocene, including some of the Earth's critical transitions (*e.g.*, Eocene/Oligocene, Oligocene/Miocene) and extreme warm intervals (such as at MIS31 and MIS11). At this margin, Eocene ecosystems with subtropical vegetation were replaced in the early Oligocene (33Ma) by glaciated land. The evolution of the Tasman Sea gateway was successfully constrained. Between 50 Ma to 33 Ma cold currents barely flowed across the Tasman Strait. Only at 15 Ma did the Circum-Antarctic Current become fully established. The well-dated Antarctic glaciation history is important for understanding global sea-level and paleoclimatic and paleoceanographic changes.

Photo 3: Scientists - Tina Van de Flierdt, Carlota Escutia (Co-Chief Scientist), Christina Riesselman and Lisa Tauxe with the first core of Expedition 318 (John Beck, IODP/TAMU).

These expeditions contributed significantly to the marine database relevant for understanding dynamics of the high-latitude ice sheets when climate was warmer. Understanding the mechanisms that drove the climate in the past is necessary for prediction of future climate change. The history of Antarctic glaciation is fundamental to understanding changes in global sea-level and past climates and ocean circulation. Most importantly the IODP expeditions constructed new chronological reference scales for the reliable dating of environmental changes in mid-to-high latitudes and close to the Equator. The results of drilling under this theme link closely with the results of the four expeditions implemented under the Sea-Level Change theme to determine the reaction of the oceans to growth and decay of polar ice sheets. The ECORD community contributed significantly to the outstanding success of the Climate Variability theme.

2.3 - Sea-Level Change

The Sea-Level Change theme focuses on a better understanding of the timing, amplitudes, rates, mechanisms/controls, and effects of sea-level change. The overall objectives of the relevant IODP expeditions were to document the rate and the amplitude of sea-level variations from the Oligocene to modern time, and identify and rank the forcing parameters controlling them. The need to drill in shallow waters is especially important to this topic - the mission-specific platform facilities provided by ECORD have contributed to the development of this scientific theme.

Over the last 5 years, two expeditions have targeted siliciclastic margins, Expedition 313 New Jersey Shallow Shelf and Expedition 317 Canterbury Basin, and two others documented reef carbonate complexes, Expedition 310 Tahiti Sea Level and Expedition 325 Great Barrier Reef Environmental Changes *(Table 3)*. Due to drilling targets in shallow waters, three expeditions were implemented by ECORD using mission-specific platforms.

Expedition	Location	Drilling platform	ECORD scientists	ECORD Co-chief scientists
310	Tahiti	*R/V DP Hunter* (MSP)	9	1 (G. Camoin, France)
313	New Jersey	*L/B Kayd* (MSP)	13	1 (J.N. Proust, France)
317	Canterbury basin	*JOIDES Resolution*	7	-
325	Great Barrier Reef	*R/V Greatship Maya* (MSP)	8	-

Table 3. Participation of ECORD scientists in IODP expeditions that addressed the Sea-Level Change theme.

The objective of **New Jersey Shallow Shelf Expedition 313** was to reconstruct sea-level variations from the

Oligocene to the Present from a transect using 3 boreholes drilled in the offshore shelf *(Figure 2)* correlated with an onshore well drilled under the frame of ICDP. A sequence-stratigraphic interpretation was developed, based on a seismic-stratigraphic interpretation calibrated to well data and on the dating of fluvio-deltaic sediments by biostratigraphy and Sr isotopes. The corresponding eustatic curve was inferred from the sedimentary succession using backstripping methods. The expedition report has been published, and further results are included in a number of papers in preparation. The results have been presented at major conferences.

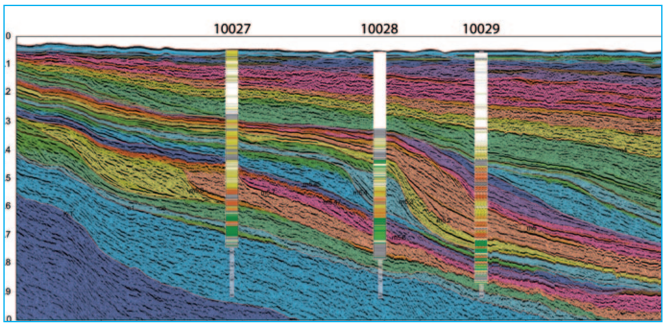


Figure 2: Vertical seismic profiles and drillsite locations

Canterbury Basin Expedition 317, offshore New Zealand, drilled a very thick stratigraphic Cenozoic succession in a margin where subsidence and sediment supply rates were exceptionally high during the Neogene. Sea-level cycles of different frequency and amplitudes were identified by combining seismic stratigraphy, detailed core descriptions, geochemical analyses and precise stratigraphic dating. The origin of the cycles is apparently complex, with Milankovitch cycles probably superimposed on major glacio-eustatic cycles. The expedition results are not yet published.

Tahiti Sea-Level Expedition 310 *(photo 4)* set out to document precisely the last deglacial sea-level rise by studying the sedimentological, geochemical and ecological evolution of the Tahiti reef complex during the last 16 ka. A precise sea-level curve was obtained through the synthesis of multiple proxies, and U-series and ^{14}C dating of the corals. Between 14.6 and 14.3 ka BP, an acceleration of the sea-level rise was correlated with the Bölling warming event. According to fingerprinting experiments, the melting of the Antarctica ice sheet significantly contributed to the sea-level rise. As a result, the reef was drowned and backstepped as carbonate production was not able to keep pace with the sea-level rise. 18 refereed papers (including one in *Science*) have already been published. Two other papers are currently

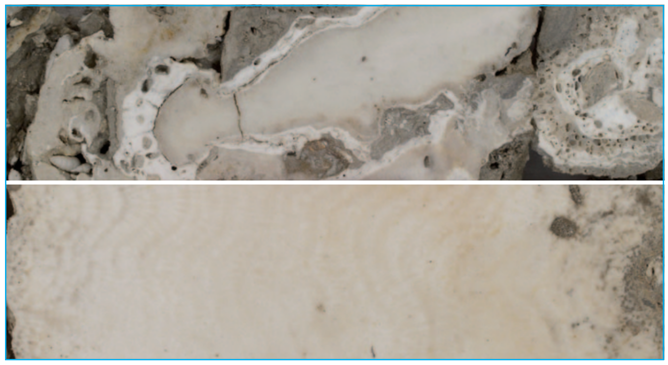


Photo 4: Close-up photographs of coral cores: (1) branching corals and (2) massive coral core (Porites) showing centimetric grooved pairs of light and dark bands.

being reviewed (one in *Nature* and the other in *Geology*) and five proceedings and data reports have been published.

Great Barrier Reef Environmental Changes Expedition 325 drilled 17 boreholes in the reefal barrier to give four regional transects that document the lateral variations of the barrier architecture. The expedition report has been published and data interpretation is still in progress. The resulting sea-level curve will be compared to the curve produced from the Tahiti Sea-Level Expedition especially and will complete the dataset for the 25-16 ka time window.

The Sea-Level Change theme, together with the Climate Variability theme, have a major societal dimension. Understanding the parameters that controlled sea-level variations during recent Earth history will help to predict the effects of ongoing global warming on the present-day shoreline transgression. Such data are also absolutely critical for the calibration of climate numerical models, particularly to ensure correlation between global climate warming and the evolution of CO_2 atmospheric pressure.

The results of the expeditions studying reef evolution in Tahiti and the Australian Great Barrier Reef are outstanding, and major publications already have and will continue to emerge from these expeditions. The high-resolution sea-level curve for the last 16 Ka compiled after the Tahiti Sea-Level Expedition will be complemented by the results arising from the Great Barrier Reef Environmental Changes Expedition. A hypothesis linking ocean circulation associated with the melting of the Antarctica glaciers was inferred by modeling. Similarly, a precise reconstruction of the ocean temperature has provided information on the evolution of oceanic circulation in relation to El Niño climate events. Ranking the parameters that control reef growth during climate changes will be another major outcome of these projects.

The data documenting siliciclastic shelves collected during the New Jersey Shallow Shelf and Canterbury Basin expeditions have challenged the classical models of sequence stratigraphy by considering the cumulative effects of high frequency sea-level cycles. In that sense, the Canterbury Basin looks particularly promising as the very high sedimentation rate in the basin should have recorded high frequency sea-level cycles in the sedimentation.

2.4 - Fluid Flow

Flow of fluids below the ocean floor is linked to a number of key processes:

- Hydrogeological and hydrothermal activity in the oceanic lithosphere and in other active areas,
- Circulation and escape of hydrocarbons and other fluids rising from deep sub-seafloor reservoirs, which may be linked to seafloor biological communities of many kinds and to the microbiological cycling of carbon and other bio-geochemically-active compounds,
- Destabilisation of the sediment cover along continental margins and slopes as a result of the combination of pressure, stress, and geological control on fluid migration,
- Formation of natural gas hydrates in marine sediments, with the associated migration of fluids from depth.

Six IODP Expeditions, 301, 307, 308, 311, 327 and 328, were linked to the Fluid Flow theme *(Table 4)*. These expeditions took place at four different locations and their main focuses were: 301 and 327 (Juan de Fuca Ridge, NE Pacific) oceanic crust hydrogeology, hydrothermal activity and associated microbiology with *in-situ* monitoring; 307 (Porcupine Basin, NE Atlantic) deep-water carbonate/coral mounds, stratigraphy and hydrocarbon sources; 308 (Gulf of Mexico) overpressure and fluid flow in a sedimented continental slope and their consequences; 311 and 328 (Cascadia Margin, NE Pacific) gas hydrate occurrences and their evolution along a transect in an accretionary margin, including *in-situ* pressure monitoring. The topics addressed differ substantially from one location to the other.

Expedition	Location	Drilling platform	ECORD scientists	ECORD Co-chief scientists
301*	Juan de Fuca Ridge	*JOIDES Resolution*	5	-
307	Porcupine Basin	*JOIDES Resolution*	9	1 (T. Ferdelman, Germany)
308	Gulf of Mexico	*JOIDES Resolution*	9	1 (J. Behrmann, Germany)
311	Cascadia Margin	*JOIDES Resolution*	8	1 (M. Riedel, Canada)
327*	Juan de Fuca Ridge	*JOIDES Resolution*	6	-
328*	Cascadia Margin	*JOIDES Resolution*	2	1 (Earl Davis, Canada)

Table 4. Participation of ECORD scientists in IODP expeditions that addressed the Fluid Flow theme.
** expeditions that did not have a full science party.*

Expeditions 301 and 327 to the Juan de Fuca Ridge demonstrated a hydrogeological connection between drill sites, showing fluid communication within the oceanic crust on a metre to kilometre scale. Expedition 301 also contributed to the Deep Biosphere topic. During expedition 327 a series of downhole CORK observatories were installed within the drill holes for long-term monitoring of fluid behaviour, which was a major technical achievement *(photo 5)*. The data from these observatories are not yet available.

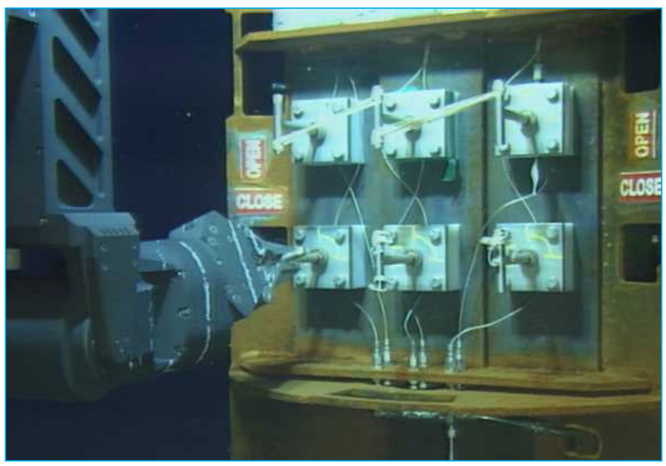


Photo 5: CORK observatory at the eastern flank of the Juan de Fuca Ridge. A remotely operated vehicle opens valves to retrieve fluid samples from a basaltic aquifer (photo G. Wheat, IODP/TAMU).

Expedition 307 in the Porcupine Basin, west of Ireland, suggested that, contrary to expectations, hydrocarbon flow from below did not play a major role in the genesis and growth of the enigmatic carbonate mounds. The lithostratigraphy, geochemistry and microbiology results indicated that gas seeps did not act as a trigger for mound genesis. Another pre-cruise hypothesis that the Porcupine Mounds are present-day analogs for Phanerozoic reef mounds and mud mounds was also discarded. The expedition has shown that the Challenger Mound rests on a sharp erosional surface, which reflects global oceanographic events.

Expedition 308 in the Gulf of Mexico included the first-ever *in-situ* measurements of the variation in physical properties, pressure, temperature and pore fluid compositions within low permeability mudstones overlying a permeable, overpressured aquifer. The measurements also documented severe overpressure in the mudstones overlying the aquifer. Post-expedition studies investigated the links between the generation and timing of overpressure control on slope stability, seafloor seeps, and large-scale crustal fluid flow. New downhole technologies were used for the first time, and have since been successfully applied in other expeditions, both scientific and commercial.

Expeditions 311 and 328 in the Cascadia Margin showed that **(1)** tectonic compression of accreted sediments leads to fluid flow at non-uniform rates resulting in variable pore water regimes, **(2)** there is a grain-size control on gas-hydrate occurrence (*i.e.*, gas hydrate preferentially forms in coarser-

Photo 6 : A chunk of gas hydrate recovered from shallow depth (about 6 m below seafloor) at cold vent Site U1328 - Expedition 311(IODP/TAMU).

grained turbidites) and **(3)** *in-situ* methane produced by microbial CO_2 reduction within the gas-hydrate stability zone is the principal gas source for hydrate formation *(photo 6)*. The results obtained led to the development of a new model for formation of gas hydrates in accretionary prisms.

The Fluid Flow theme is closely linked to several other themes, especially the Deep Biosphere, Oceanic Lithosphere and Seismogenic Zone topics.

ECORD scientists have been active in most aspects of the science arising from these expeditions. Their participation in the Fluid Flow theme has resulted in the publication of 73 scientific papers in peer-reviewed journals.

Fluids play an active role in a range of geological processes that are of utmost relevance to understand the functioning of our planet. Many of those processes are of direct relevance to society as they relate to geohazards (earthquake generation and submarine landslides, leading to tsunami triggering), formation of mineral resources, sustainment of life and biodiversity in extreme environments, and preservation of the past climatic and environmental conditions of our planet in the fossil record.

Fluid flow studies are an important testing ground for new sub-seafloor instrumentation. Already a range of new tools has been developed, and these need further development and testing to be fully reliable in such demanding (and critical) environments.

2.5 - Deep Biosphere

The deep marine biosphere is the most surprising discovery so far made by scientific drilling. Microbial life has been found in nearly all sub-seafloor drill holes sampled to date. It is possible that as much as 10-30% of the Earth's biomass exists in this deep biosphere and can only be studied by scientific ocean drilling. This is one of the great research challenges of modern geosciences and has attracted new generations of microbiologists and biogeoscientists to IODP.

The important scientific problems are:

- To determine the biogeochemical nature of the sub-seafloor biosphere and its impact on geological and geochemical records,
- To discover the means by which microbial life is possible so close to its lower energy limit,

- To define the linkage between rock type, organic carbon content, porewater chemistry and depth of burial with the nature of subseafloor microbial communities,
- To map the extent of the deep biosphere and refine current estimates of its global biomass and
- To constrain whether the deep biosphere is fueled by hydrogen or organic compounds produced abiotically (chemolithoautotrophy) or by geothermal heating of sedimentary organic matter.

To date, deep biosphere studies have been included in most IODP expeditions *(Figure 3)* and good progress has been made. However, these fundamental questions are still far from being successfully answered. Three expeditions towards the end of the current phase of IODP will certainly make further progress in this area of research. These expeditions are 329 (South Pacific Gyre, investigating the most organic-poor sediments of the world's oceans), 336 (Mid-Atlantic Ridge microbiology, the crustal biosphere) and 337 (Shimokita Coalbed offshore Japan).

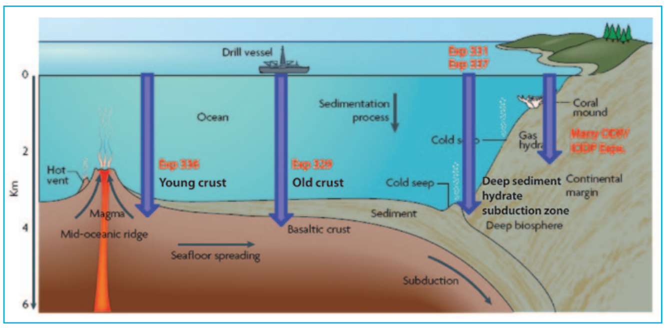


Figure 3: IODP sub-seafloor biosphere targets.

The results of drilling to date show that many archaeal and bacterial lineages with no cultured representative are widely found in sub-seafloor habitats. The archaea include the Miscellaneous Crenarchaeotal Group (MCG), Marine Benthic Group B (MBGB or DSAG), and the South African Goldmine Euryarchaeotal Group (SAGMEG); the Bacteria include affiliates of the Chloroflexii, green non-sulphur bacteria and certain candidate subdivisions (*e.g.*, OP9 and JS1). All of these are abundant in organic-rich or in hydrate-bearing sediments. The factors that control their relative distribution remain elusive. Extrapolation of intact lipid concentrations yields an estimated total microbial biomass of 90 Pg below the seafloor.

To date, the deepest-living microbial communities were found during ODP Leg 210 *(photo 7)* in geothermally heated,

Photo 7: Night sampling of sediments offshore Peru (ODP Leg 201): Poisonous H_2S gas, produced by microbial degradation of organic matter without oxygen (ODP/TAMU).

111 Ma old sediments at 1626 metres below the seafloor. On ODP Legs 201 and 207 and on IODP Expedition 301 live bacterial cells were detected and quantified in sub-seafloor sediments. These were up to 16 Ma old in sites off Peru. In the sediments of the Peruvian continental margin, cellular concentrations combined with distinct changes in microbial community composition increased at sulphate-methane transition zones. High cellular concentrations were also found at interfaces between hydrothermally heated sediments and the underlying basaltic aquifer during Expedition 301 to the Juan de Fuca Ridge. This indicates that microbial activity at the sediment/basalt interface in open ocean sites is stimulated by the supply of electron acceptors provided by the basaltic aquifer. Likewise, microbial activity in deeply buried Cretaceous organic-rich black shales appears to impact the diagenetic regime in the entire overlying sediment column.

Geothermal heating in deep organic-rich sub-seafloor sediments stimulates microbial activity. Related processes may be important in understanding geosphere-biosphere interactions in sedimentary layers close to the upper temperature limit of life. These concepts will be explored in future work such as that on the cores from the recent Expedition 331 (Deep Hot Biosphere, Okinawa Trough) and are highly relevant to the petroleum industry.

ODP Leg 201 provided evidence for the widespread microbial formation of the hydrocarbon gases ethane and propane in low-temperature subsurface sediments off the Peru Margin and in the Equatorial Pacific. Even in sub-seafloor environments with extremely low microbial activity, methane and higher hydrocarbons are found sorbed to the sediment mineral matrix. The first high-resolution data set on the carbon isotopic distribution of acetate came from methane-hydrate bearing sediments drilled at the Cascadia Margin (IODP Expedition 311). Acetate is an intermediate in anaerobic metabolism, suggesting that homoacetogenesis is an important source of acetate in the upper methanogenic zone and showing that the isotopic composition of acetate is sensitive to the modes of *in-situ* carbon cycling.

To help research into the sub-seafloor biosphere, ECORD scientists have developed a device for anaerobic enrichment and isolation of piezophilic microbes. This can be coupled to a pressure coring system without loss of pressure. New molecular-isotopic techniques, such as stable carbon isotopic compositions of volatile fatty acids and intact polar membrane lipids have been developed for the study of carbon flow and biomass in sub-seafloor ecosystems.

Deep biosphere research within IODP is a relatively young science with tremendous potential. Several European research groups are at the forefront of this research. These deep biosphere studies have, until now, relied on strong collaboration between microbiologists, biogeochemists and geophysicists. It would be useful to develop links with the more traditional geological research community. As there are three dedicated deep biosphere expeditions being implemented during the final phase of IODP, these links may grow. On a large scale, the deep biosphere research in IODP will explore the contribution of this large component of the Earth's biosphere to Earth-system processes and global element cycles. As European researchers are among the leaders in this field, the opportunities provided through ECORD are essential for supporting this important area of European research.

2.6 - Ocean Lithosphere

The formation of new ocean crust at the mid-ocean ridges is one of the most dynamic geological processes on Earth, re-paving two-thirds of the surface of our planet in the last 200 million years. Mid-ocean ridge activity depends strongly on the rate at which the plates are splitting apart at the ridges. At fast spreading rates (60 - 200 mm/yr), the mid-ocean ridges are volcanic, a chain of submarine volcanoes fed by magma rising through the Earth's mantle. At slower spreading rates (10 - 40 mm/yr) volcanoes are still an important factor but a large part of the crust is formed by exposure of deep layers in the Earth through slip on giant faults. The Ocean Lithosphere theme investigates how these complex processes operate. Much of the scientific research on this topic is conducted without drilling, on rocks exposed at the ocean floor, but oceanic drilling gives an essential and complementary window into the operation of these processes at depth.

Since ECORD was established, there have been three *JOIDES Resolution* expeditions to study the deep structure of volcanic crust formed by super-fast spreading at more than 200 mm/yr (Expeditions 309, 312 and 335, drilling the deep hole 1256D). There have also been two expeditions to the slow-spreading Mid-Atlantic Ridge (25mm/yr) to drill the internal structure of the Atlantis massif exhumed from depth by a giant fault (expeditions 304 and 305, drilling the deep hole 1309D).

There was strong ECORD representation in the expedition planning, leadership, and shipboard activity of all of the expeditions *(Table 5)*, while the science that underpins the drilling on 304 and 305 arose from research cruises in which scientists from ECORD countries played a major role.

Expedition	Location	Drilling platform	ECORD scientists	ECORD Co-chief scientists
309	Super-fast crust	*JOIDES Resolution*	10	-
312	Super-fast crust	*JOIDES Resolution*	11	1 (D. Teagle, UK)
335	Super-fast crust	*JOIDES Resolution*	9	2 (B. Ildefonse, France and D. Teagle)
304	Atlantis Massif	*JOIDES Resolution*	8	-
305	Atlantis Massif	*JOIDES Resolution*	8	1 (B. Ildefonse, France)

Table 5. Participation of ECORD scientists in IODP expeditions that addressed the Ocean Lithosphere theme.

Hole 1256D, drilled on the super-fast spreading expeditions, penetrated for the first time through the upper oceanic crust (lavas and sheeted dykes) into the lower oceanic crust (gabbros) *(photo 8)*. It showed, as predicted, that the upper crust is unusually thin at such fast spreading rates, and also showed for the first time how the sheeted dykes of the upper crust had been intruded by and reheated by the underlying gabbroic magma. The section also recovered rocks from the roots of black smoker hydrothermal systems, shedding new light on how these systems operate. These observations provide critical constraints on models of the genesis of new ocean crust at mid-ocean ridges. The hole is open all of the way to its base within the gabbros and ready to be deepened farther down into the gabbros as the opportunity arises. This hole has the potential for extension well into the lower crust, producing an unprecedented record of the structure of the crust with associated fundamental new insights into crustal genesis.

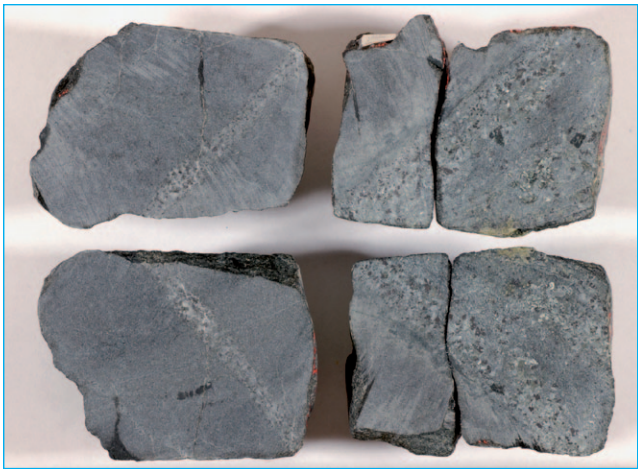


Photo 8: Hole 1256D: Dykes and gabbro boundary (IODP/TAMU).

Hole 1309D, drilled on the slow-spreading Mid-Atlantic Ridge, targeted one of the massifs exposing deep-seated rocks exhumed by large-scale faulting. The drilling was expected to penetrate deep into mantle peridotites, but instead recovered more than a kilometre of varied gabbros, prompting a radical reconsideration of the genesis of these massifs. It was possible to reorient the magnetic measurements made on the core with images made of the wall of the hole during logging to show that the massif had been rotated by more than 45° in the course of its evolution, a very significant contribution to understanding its origin and that of the other related massifs formed at slow rates of spreading. Laboratory work on the core showed that while the fault slipped, new magma was being intruded into the fault zone and at the same time hot hydrothermal fluid was rising fast along the slipping fault, a crucial insight into the dynamics of large-scale faulting.

ECORD scientists have been active in all aspects of the science arising from these expeditions and comprise a large number of the authors of the numerous papers already published on the results of shipboard and laboratory work. Without the involvement of ECORD researchers, several of the most significant publications from this drilling would not have emerged, or would have been far less effective.

The strongest link with other themes, and one that is most important to both themes, is with the Juan de Fuca Hydrogeology topic of the Fluid Flow theme. The drilling associated with the Ocean Lithosphere theme has contributed significantly to improving our knowledge of the hydrothermal systems at both slow-spreading and fast-spreading ridges. The Juan de Fuca drilling has provided very significant insights into the dynamics of fluid flow within the ocean crust and the chemical alteration associated with this flow. Hydrothermal circulation at both high and low temperatures, close to the spreading axis and far away from it, is critical in determining the global cycling of elements between crust and ocean. A link with the Deep Biosphere theme is the discovery during drilling at the Juan de Fuca Ridge that microbial activity continues down into the lavas beneath the overlying sediments.

2.7 - Seismogenic Zone

IODP research on the seismogenic zone focuses on mega-splay faults within accretionary prisms which are typically responsible for the mega-size shallow earthquakes in subduction systems. There have been two active projects in IODP on this topic, the NanTroSEIZE and CRISP projects.

During the evaluation period, there have been eight expeditions in NanTroSEIZE with *Chikyu (photos 1 and 9)* and one in CRISP with *JOIDES Resolution (Table 6)*. NanTroSEIZE comprises several expeditions and will eventually produce a transect of holes where the deepest is planned to intersect the seismogenic zone off the Kii Peninsula, Japan. The intersection depth of this mega-splay fault is about 6 km below the seafloor, and it is expected to be achieved on Expedition 338 (staffing in progress). CRISP is a similar multi-expedition project as NanTroSEIZE, and the first expedition (334) has been carried out in the Costa Rica subduction zone.

ECORD scientists have acted as Co-chief Scientists on four of the eight NanTroSEIZE cruises (315, 319, 332 and 333) that have taken place so far. Numbers of scientific staff involved in the expeditions has been at a very good level with 2-9 berths per expedition (note: expedition 326 had no science

Expedition	Location	Drilling platform	ECORD scientists	ECORD Co-chief scientists
314	Nankai*	*Chikyu*	5	-
315	Nankai	*Chikyu*	9	1 (S. Lallemant, France)
316	Nankai	*Chikyu*	8	-
319	Nankai	*Chikyu*	8	1 (L. McNeill, UK)
322	Nankai	*Chikyu*	8	-
326	Nankai**	*Chikyu*	-	-
332	Nankai*	*Chikyu*	2	1 (A. Kopf, Germany)
333	Nankai	*Chikyu*	7	1 (P. Henry, France)
334	CRISP	*JOIDES Resolution*	7	1 (P. Vannucchi, Italy)

Table 6. Participation of ECORD scientists in IODP expeditions that addressed the Seismogenic Zone theme.
** expeditions that did not have a full science party;** no science party*

party). ECORD also provided one of the Co-chief Scientists on the CRISP Expedition and were allocated 7 berths.

The overall scientific achievements of the expeditions include significant new understanding of the evolution of splay faults, particularly on subduction inputs, frontal thrusting, mid-slope mass wasting, splay faults, and the locked zone. One observation is that the activity of the Nankai Trough splay fault varies though time with higher

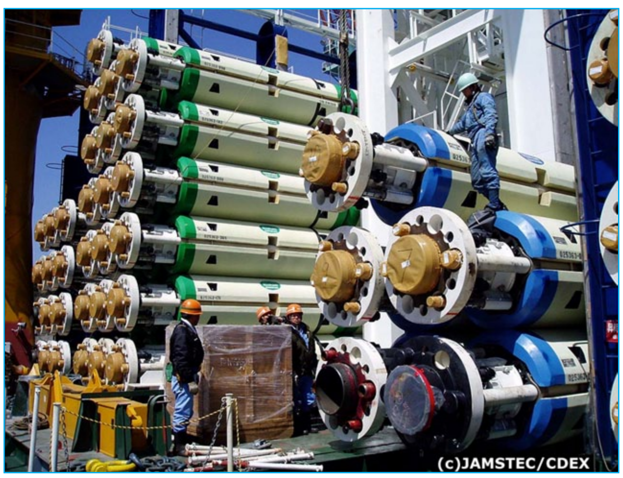


Photo 9: Riser tubes aboard the drillship Chikyu.

and lower activity periods (with a periodicity of ~0.5 Ma) and is reflected in the accommodation of plate convergence and frontal prism deformation. The drilled frontal-thrust faults turned out to show very soft friction properties, which may indicate continuous relaxation of stress and lower tsunami risk from these structures. In addition to the drilling results, NanTroSEIZE has successfully installed a borehole observatory (CORK, *photo 10*) in the Nankai Trough, which will be later connected to a network of existing seafloor observatories for real-time data transport. The level of scientific impact by ECORD scientists is considered to be a good achievement and of good quality. This is reflected for instance by the *Strasser et al. (2010)* paper in *Nature Geoscience*. Judging from the publication record of Stage 1, the NanTroSEIZE science outputs have significantly benefited from ECORD contributions.

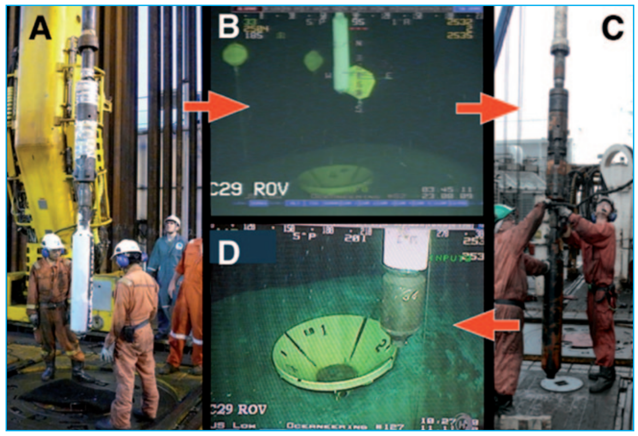


Photo 10: Cycle of operations at IODP hole C0010A: SmartPlug (white) and bridge plug with rubber seals (still wrapped) on the rigfloor (left), during deployment (top), and after recovery (right). The rusty unit got refurbished, extended by 30 cm to host the osmo-sampler and FLOCS chamber, and got deployed as GeniusPlug (bottom) (© JAMSTEC/IODP).

The NanTroSEIZE and CRISP expeditions are strongly focused on seismogenic zone studies. The fluid regime and its lateral and horizontal variation in the forearc wedge and decollement has a crucial role in controlling the location and behaviour of the seismic and aseismic zones. Fluid flow and chemistry studies are well covered in NanTroSEIZE in close combination with tectonic studies. On the other hand, opportunities for deep biosphere studies do not seem to be systematically exploited in the seismogenic zone expeditions. However the Deep Biosphere topic was included in expedition 316 with excellent results on sulphur cycling in the uppermost 150 m of sediments *(Riedinger et al. 2010)*.

The publication record of the NanTroSEIZE Stage 1 expeditions consists of ~180 items ranging from preliminary reports to abstracts, journal articles and proceedings volumes. Expedition reports on NanTroSEIZE have been published in Scientific Drilling for expeditions 314-316, 319 and 322. Eighteen papers have been published in peer-reviewed journals. It is not straightforward assessing exactly what the ECORD contribution is to this considerable volume of work, but there are at least three papers (one on the deep biosphere) with an ECORD scientist as the first author. These are all in high-level journals, including one in *Nature Geoscience (Strasser et al. 2010)*.

Seismogenic zone research within IODP is well covered in the *Scientific Drilling* journal (IODP's own journal published jointly with the International Continental Scientific Drilling Program (ICDP)) which includes both expedition and science reports. The theme is understandably of great interest to the general public, reflecting the high societal value of seismogenic zone research, and is well represented in brochures and hand-outs.

We recognise the major significance field of research within IODP, and the important new observations that have been obtained on subduction system splay faults. ECORD scientists have been very active in this theme and their contributions are of high quality. We see, however, that even more can be extracted from this topic, especially by strengthening European participation. An important opportunity in this field would be to further develop seafloor drill-hole observatories for early warning systems of earthquakes. In addition, the application and development of sea-bed drilling platforms that are already technically available could become a cost-effective means in the foreseeable future to improve drilling capability on the seafloor, and would be ideally adapted to the ECORD concept of mission-specific platforms. The exceptional depth of the planned drill holes, and thus expected high borehole temperatures, will provide unique opportunities to test the upper temperature limit of the deep biosphere. Experiments taking advantage of these opportunities should be added to the ECORD strategy together with deep biosphere teams.

2.8 - Overall evaluation of the scientific achievements of IODP

IODP drilling has already made an enormous contribution to our understanding of the Earth. This recognition is based on the published scientific achievements from the earlier expeditions (301-316). Preliminary results from the more recent expeditions (317-337) suggest that this contribution will increase substantially.

The ***ACEX Expedition*** gave the first significant evidence for the history of the Arctic Ocean, which plays a critical role in global climate. The drilling not only gave a new timing for the development of sea-ice in the Arctic, it also revealed a freshwater phase in the history of the ocean that resulted in organic-rich sediments, which may be a source for the Arctic oil deposits. The enormous scientific and societal benefits from the ACEX Expedition show that Arctic drilling must continue as a high priority activity within ECORD. The missing Cenozoic paleoclimate record must be a high priority for future research.

The six IODP expeditions under the theme of ***Climate Variability*** theme have added a wealth of critical information about this topic over the past 50 Ma. There were three different types of target. Expeditions 303 and 306 established a new precise climate chronology for the last 10 Ma in the North Atlantic. Expeditions 320 and 321H produced a complete stratigraphy of the Equatorial Pacific for the last 50 Ma. Expeditions 318 (Wilkes Land) and 323 (Bering Sea) studied climate change and icecap history in two near-polar regions. All six expeditions are critical to setting the framework of global climate change in the past and to making predictions for the future.

The four expeditions related to ***Sea-Level Change*** are closely linked to those studying climate change. All four have a major societal dimension, since they constrain much more closely than has previously been possible the relationship between changing global temperature and the corresponding change in sea level. Two of the expeditions (the New Jersey Shallow Shelf Expedition 313, an MSP, and the Canterbury Basin Expedition 317) targeted siliciclastic continental margins, whereas the other two, both MSPs (Tahiti Sea-Level Expedition 310 and Great Barrier Reef Environmental Changes Expedition 325) targeted coral reefs. The Tahiti Sea-Level Expedition has already shown that the rise in sea level at the end of the last ice age may have been as fast as 50mm/yr. The results of these expeditions will be fundamental in testing numerical models of climate change.

We recommend better coordination between IODP and the International Continental Scientific Drilling Program (ICDP) in studies of ***climate and sea-level change***, since joint interpretation of both sets of results is necessary for constraining numerical models of future climate change. Coordinated evidence would also ensure that more attention is paid to observations of the geological record by the entire climate change community

In planning future expeditions relating to ***climate change and sea level***, a modeling strategy should be integrated with the final proposal. The number of parameters to take into account are so high, and their interactions so complex that the numerical modeling should be used to discriminate and rank the forcing parameters. Feedback between data interpretation and modeling results is critical.

Fluid Flow was the target of six expeditions, all of which were extremely successful, that examined four very different environments. Expedition 308 in the Gulf of Mexico shed an entirely new light on fluid overpressures in sedimentary formations, critical for understanding a wide range of geohazards. Expeditions 301 and 327 studied fluid flow in the oceanic crust very successfully, using a wide range of techniques. Expeditions 311 and 328 applied a similar approach to obtain important new information on fluid expulsion from an oceanic collision zone. The sixth expedition, 307, demonstrated very clearly that existing models for the formation of carbonate mounds are incorrect. All of these expeditions have substantially increased our knowledge of how fluid processes work and how they relate to the other scientific themes of IODP. Work on fluids should be given priority in the years to come.

Most of the ***Fluids*** expeditions used downhole instrument packages to measure the conditions in the holes. Some of these are intended to be deployed for up to several years to establish the long-term trends in fluid behaviour. Linking the long term monitoring of the borehole instrumentation to cabled observatory, such as NEPTUNE-Canada or other seafloor observatories, is a most promising route to follow.

The ***Deep Biosphere*** research in IODP has shown that this topic is evolving very fast and has generated a wealth of new information about this mysterious part of the Earth's biosphere. Considerable steps have been taken to characterise the components of the deep biosphere and determine how its ecosystems function. This has shown how this large component of the Earth's biosphere may contribute to Earth System processes and element cycles. European researchers are among the leaders in this field: the opportunities provided through ECORD are essential for supporting an important area of European research. Deep biosphere sampling should be included whenever possible in future drilling projects. Efforts should be made to bring together the deep biosphere research community and the more traditional geology research community to exploit potential synergies.

IODP drilling of the ***Ocean Lithosphere*** has produced two major breakthroughs. For the first time the contact between the upper and lower ocean crust at a fast-spreading ridge been cored, showing that it is an intrusive contact, and thus contributing a critical advance in our models of mid-ocean ridges. As important was the discovery of a large and complex gabbroic body at the heart of one of the detachment domes in the Atlantic, where peridotite had been expected. Once again this has led to a major reassessment of previous concepts. There are strong links between this topic and the Fluid Flow and the Deep Biosphere themes, and these need to be developed and extended.

The ***Seismogenic Zone*** research is of fundamental importance to a large number of countries, including Japan and the USA. There have been eight expeditions that address this topic, seven of them in the Nankai Trough offshore Japan, where the riser drillship *Chikyu* has been active. Though the eventual targets are deeper than has been reached so far, the emerging science is very impressive, especially from the drilling through the splay fault in the Nankai Trough and the determination of its long-term behaviour. Downhole instrument packages have also been important in this drilling, with the capability of further development in future. An important opportunity is the further development of seafloor drill hole observatories for early warning systems of earthquakes.

Seismogenic zone research has considerable societal value, as shown by the recent earthquakes and tsunamis. However special care is needed when discussing the societal benefits of this research, as the drilling results already achieved, and those expected to be achieved in future, may be challenging to apply in practice in early warning and possible prediction of mega-splay earthquakes.

Overall the scientific achievements of this first phase of IODP are truly impressive, and give every reason for continuing IODP into a second phase.

3 - Evaluation of mission-specific platform operations

The evaluation of the mission-specific platforms is based on summary reports from ESO, excellent presentations in Bremen of activities in Leicester, Edinburgh and Bremen and tour of the core-storage facility including laboratories.

3.1 - The ECORD Science Operator

Mission-specific platform operations are coordinated on behalf of IODP by the ECORD Science Operator (ESO) *(Figure 4)*. The overall planning and management of each expedition are the responsibility of the ESO consortium led by the British Geological Survey (BGS) in Edinburgh. BGS provides the Science Manager, Operations Manager, Data Manager and Outreach Manager for ESO as well as the Staff Scientists for each MSP expedition. The Bremen Core Repository (BCR) provides the ESO Curation and Laboratory Manager and the Public Relations Manager. The European Petrophysics Consortium (EPC) provides logging and petrophysics support both onshore and offshore.

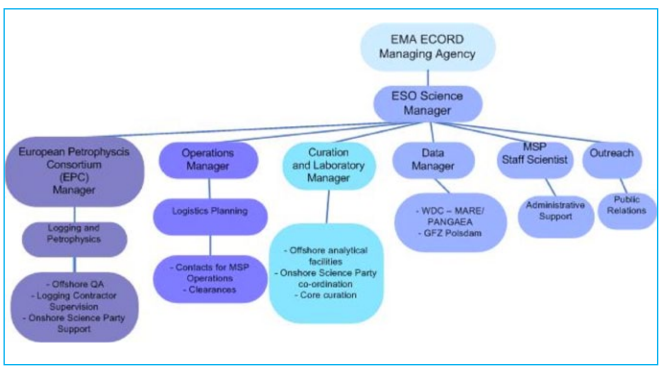


Figure 4: The management structure of the ECORD Science Operator.

To date, ESO has implemented four MSP expeditions *(photo 11)* that were programmed during the first phase of IODP, 302 (Arctic Coring Expedition (ACEX)), 310 (Tahiti Sea-Level Expedition), 313 (New Jersey Shallow Shelf Expedition) and 325 (Great Barrier Reef Environmental Changes Expedition). Four MSP operations are currently being scoped with a view to implement at least one expedition by the end of IODP in 2013.

3.2 - Offshore Operations

The procedure before each expedition takes places is lengthy and intricate. Four main steps are required for each expedition: **Scoping** identifies the project requirements, its design and coring platform specifications. ***Tendering and contracting*** sets out to **(1)** evaluate requests, **(2)** produce a tender list of suitable providers and dispatch a tender, **(3)** evaluate the responses and select the best supplier, **(4)** conduct contract negotiations, **(5)** place contracts and **(6)** place the award notice in the Official Journal of the European Union. This is a lengthy process in which there is a limited choice of platforms and drilling operators, most of whom are not used to achieving science objectives. Operations involve **(1)** logistics and co-ordination of ESO partners, contractors and scientists, **(2)** contract management and **(3)** ESO team management. ***Health and safety and environment*** involve both mobilisation and operations themselves.

Photo 11: The drillships of the MSP expeditions operated by ECORD, clockwise Vidar Viking (ACEX 302), DP Hunter (Tahiti Sea-Level Exp. 310), Kayd (New Jersey Shallow Shelf Exp. 313) and Greatship Maya (GBREC Exp.325) (All photos © ECORD/IODP).

The great diversity of MSP expeditions means that each of these steps varies greatly from one expedition to the next, setting new challenges for ESO every time. For example, as the number of potential platform operators is very limited, this may weaken the position of ECORD during tendering and negotiations for operations at sea. Experience has shown that there are a number of critical factors that can be important. For example, mobilisation/demobilisation costs may be as much as one-third of the total cost of the expedition and can be minimised by looking for working windows that reduce the contractor costs, including back to back operations where possible. One of the main issues for ESO is managing different levels of staff experience and scientists. Pre-operation workshops including operators, ESO partners, contractors and scientists can help to ease the operation overall. It may also be useful to consider using unconventional technologies such as seabed drills that can operate in a wide range of environments and may give better results at lower overall cost. It is possible that there is scope for ESO expertise to be used for non-IODP projects such as EU-funded projects and science/industry collaborative work.

MSP operations are a valuable contribution to IODP that complements the capability of the *JOIDES Resolution* and *Chikyu*. By providing platforms that can operate in ice-covered waters and shallow-marine environments such as coral reefs, the MSPs fills a gap in scientific requirements that otherwise could not have been satisfied. The contribution of ECORD to operations at sea is well appreciated within IODP.

The whole procedure before an operation at sea takes places is rather lengthy and intricate. The fact that the number of potential platform operators is very limited is a particularly critical bottleneck that may weaken the position of ECORD during tendering and negotiations for operations at sea. The effort made by the ECORD Science Operator (ESO) to apply efficient, timely and less costly procedures must be acknowledged, given the boundary conditions, both in terms of scientific requirements and the unique character of each MSP operation.

3.3 - Core curation, laboratories and MSP expedition Onshore Science Party

The Bremen Core Repository (BCR) is hosted by the Center for Marine Environmental Sciences (MARUM) at the University of Bremen. The BCR is one of the three IODP core repositories around the world with responsibility for storing, archiving, handling and distributing cores from the Arctic and Atlantic oceans and the Mediterranean Sea *(photo 12)*. The BCR presently stores a total of about 141 km of core in about 220,000 storage tubes (each 1.5 m long). In addition, BCR keeps the lake sediment cores of ICDP, and acts as the national core archive of Germany. Since 1969 more than 1.2 million samples of core have been taken at the BCR for more than 2400 scientists, with a total of 4381 sample requests. Each core in the repository, dating back to cores collected during the very earliest days of DSDP, has been entered into the Drilling Information System (DIS) to allow comprehensive searches to be made of the contents of the repository.

Photo 12: The Bremen Core Repository is the largest of the IODP core repositories. Several kilometres of DSDP, ODP and IODP deep-sea cores are stored in a refrigerated hall (A. Gerdes ©ECORD/IODP).

In its role as part of ESO, the BCR is responsible for handling the core for all MSP expeditions. The BCR is also responsible for hosting the post-expedition Onshore Science Parties and the related core description *(photo 13)*. Because each MSP is different, ESO are not able to provide ships equipped with laboratories capable of all the standard measurements routinely conducted on the expeditions of the *JOIDES Resolution* and the *Chikyu*. Nor is it possible for the platforms used in most MSP expeditions to accommodate the same size of science party as other IODP expeditions. However, the science of the MSP expeditions still requires a large group of scientists to be involved. As a result, the core handling process for MSP expeditions includes both offshore and onshore phases. The offshore phase comprises core recovery, core measurements and analysis of the core for ephemeral properties in small, transportable offshore laboratories. The onshore phase includes the core splitting, preservation, geological and petrophysical logging, and other determinations. The BCR has a suite of laboratories that are fully equipped to carry out all of these functions. After each MSP expedition, when the cores have been returned to Bremen, the full science party for the expedition assembles at the BCR to work on the core as though they were at sea on one of the other IODP ships. The BCR staff are trained to use the laboratories and to supervise the scientists at work there. They also work with petrophysics

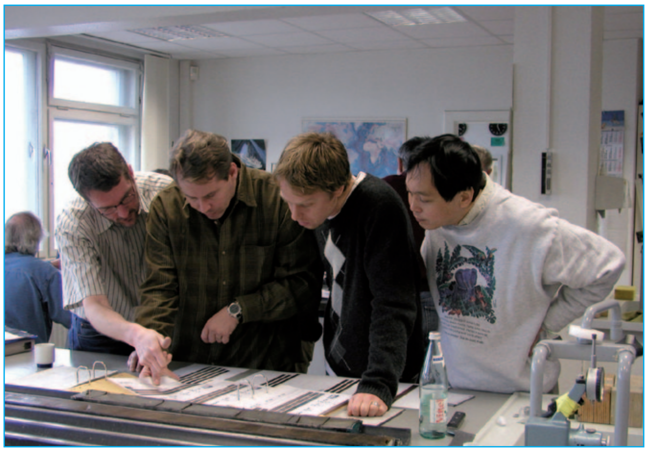


Photo 13: Scientists describe the core samples of the Arctic Coring Expedition during the Onshore Science Party in Bremen (© ECORD/IODP).

staff from the European Petrophysics Consortium. The resulting data are input to the Drilling Information System (DIS). This arrangement has proved to be very effective, and is an important part of the work at the repository.

Since 2007, the BCR has also been responsible for organising one of the annual ECORD summer schools *(photo 17, page 26)*. This is an important educational function that prepares scientists taking part in IODP expeditions, by providing a virtual ship experience, as well as educating a new generation of scientists and providing the skills required for ocean drilling research.

Our impressions and observations during our visit to BCR were very positive. The laboratories are well-organised and effective. The available instrumentation was up-to-date, and there was a sufficient number of scientific and technical staff to provide the required services. Use of students in technical assistants in sampling and core measurements further improves the educational values of the BCR. We were not clear initially how the capacity of the laboratory is divided between IODP and other customers; this relationship is shown in *Figure 1*.

3.4 - Petrophysics

Downhole logging of the drill holes and petrophysical measurements on newly-recovered cores are a crucial part of the scientific effort on an IODP expedition. Within ESO this work is carried out by the European Petrophysics Consortium (EPC), a joint venture of the Universities of Leicester (UK), Montpellier (France) and Aachen (Germany), led by the group at Leicester. There are three EPC activities that contribute to ECORD and hence to IODP:

- On each MSP there is an EPC Petrophysical Staff Scientist in charge of the logging process, and an EPC petrophysicist working on the logs and the shipboard petrophysical measurements *(photo 14)*.

Photo 14: Inside the petrophysics container, J. Inwood, Petrophysics Staff Scientist at work during the New Jersey Shallow Shelf Expedition (© ECORD/IODP).

- On some MSP expeditions the EPC is also the logging contractor, providing a suite of special slimline logging tools developed at Montpellier for logging narrow-bore drill holes.
- EPC petrophysicists work take part in the post-expedition Onshore Science Parties *(see 3.3)* to conduct further petrophysical measurements in the Bremen laboratories.

All of these operations require a more specialised range of skills than are usually provided by Earth scientists or engineers. The suite of slimline tools (less than 50mm in diameter) is especially important for ECORD, since this allows drilling of holes with a smaller drill rig and lighter drill pipe, a necessity when drilling sites in shallow water.

4 - Evaluation of outreach activities

Whereas the MSP operations and subsequent Onshore Science Parties are managed entirely by ESO, the ECORD Outreach Team consists of representatives from EMA, ESO and ESSAC, therefore we have evaluated their activities separately. The ECORD Outreach Team also works closely with colleagues in the US and Japanese Implementing Organisations and the Outreach and Communications Manager at IODP-MI to ensure that the messages that are put out to the science community and the public are well co-ordinated.

The team liaises on all aspects of general outreach activities such as the ECORD websites - *http://www.ecord.org* - the ECORD Newsletter, which is published twice a year, and displays at booths at international conferences such as the annual European Geosciences Union (EGU) meeting *(photo 15)*. The team has recently produced a 15-minute film of ECORD's achievements, which will be made available on the programme websites and distributed to a wide range of organisations including funding agencies. A shorter 6-minute version was also produced for social networking sites such as YouTube.

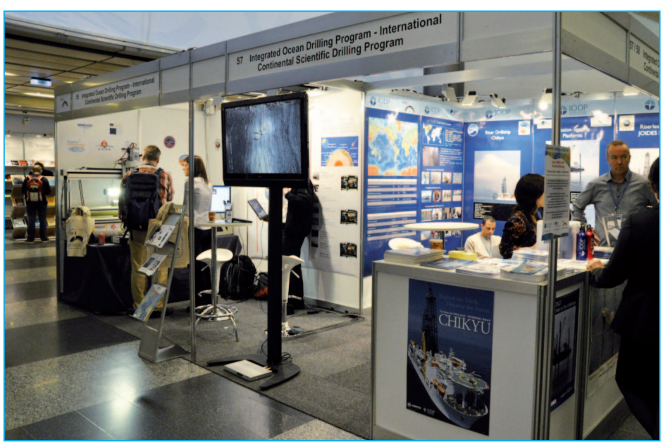


Photo 15: The joint ECORD/IODP-ICDP exhibition booth organised at the European Geosciences Union Conference in 2011 (photo T. Wiersberg, ICDP).

Photo 16: Greg Mountain, Co-chief Scientist of the New Jersey Shallow Shelf Expedition is interviewed by a US television reporter (A. Stevenson © ECORD/IODP).

As well as promoting the overall objectives of ECORD within IODP, the team has specific responsibility for promoting the science and technological achievements of the MSP expeditions that ESO manages on behalf of IODP. These activities include the production of expedition brochures or flyers; the maintenance of website information, which in recent years has included social networking sites such as Facebook and Twitter; and local and international media activities during both the offshore phase of the operations and the Onshore Science Parties held at the Bremen Core Repository.

The media activities associated with each MSP expedition involve working with the public relations departments of the science party members' organisations, especially the co-chief scientists, in the build-up to the offshore operations. A press conference is held prior to each expedition and where possible journalists are invited onboard the platform to interview the science party and ESO team. These events attract considerable media interest, for example the New Jersey Shallow Shelf Expedition in 2009 was covered by local and national TV channels in the USA *(photo 16)* as well as major newspapers such as the Philadelphia Inquirer. The Great Barrier Reef Environmental Changes (GBREC) Expedition was featured by the BBC (on-line and radio) and the national Australian TV/radio networks. While it is difficult

Photo 17: Students learn how to sample pore water from a sediment core at the ECORD Bremen Summer School 2010 (photo J. Riethdorf).

to measure precisely the results of these media activities, the review of the impact of the GBREC pre-cruise media conference in the days following the event indicated that there were at least 40 separate items featured on TV, radio, websites and newspapers. Many of these were international news networks in countries such as Australia, New Zealand, India, Japan, China, Thailand, Germany, the USA and UK and so reach a far wider audience than we are able to measure.

While the team's objectives are principally aimed at public outreach, educational activities are also supported through the ECORD Summer School programme *(photo 17)* and the Distinguished Lecturer Programme, in which scientists work with and deliver lectures to university students from ECORD member countries and the broader science community.

We consider ECORD outreach to be impressive, covering wide range of activities. Outreach is largely based on telling stories, and in ECORD there are many fascinating stories to tell. The discoveries made by the drilling programme open up new doors and ECORD tells the stories with great skill. The coverage of ocean drilling stories by the BBC, Australian TV and major newspapers in the USA is very good.

TV is and will be for many years the most important medium for distributing information and stories to the public. We therefore recommend that ECORD aims to have closer cooperation with broadcasters such as the *National Geographic* and *Discovery* channels. There are also several smaller film producers specialising in natural history documentaries who often offer their film productions to the main TV channels.

The production of leaflets, brochures, newsletters and posters is impressive both in quality and quantity. ECORD has been successful in making products that are similar in style, which can be recognized from one product to the next. The focus on drilling ships on the front pages of all outreach materials is something that connects the IODP family. This approach may, however, be a barrier to scientists and society who are not familiar with IODP, and may deflect from the scientific stories behind the drilling. The websites also show a strong focus on the drilling, and it is necessary to look beyond the front pages to see the stories. We recommend that to communicate with a wider audience ECORD should consider being more problem/story oriented and not so method/drilling oriented.

Communication with the scientific community is important and ECORD/IODP is represented at most large meetings of Earth scientists. IODP and the International Continental Drilling Program (ICDP) now closely co-operate in having joint booths and townhall meetings at events such as the European Geosciences Union (EGU) attended by more than 10,000 scientists, and this co-operation should be developed even further.
The use of booth and townhall meetings has developed rapidly in many organisations and there is often no good method of assessing their impact. To improve their outreach activities, ECORD should, together with other IODP outreach teams and ICDP make a survey of their impact both within the earth science community in general and the public.

The geographical separation between the EMA (France), ESO (UK and Germany) and ESSAC (currently based in Germany, but moving to Spain in late 2011) outreach staff makes the coordination of the outreach activities important and the outreach team showed convincingly how they manage to work together. The size and importance of each expedition brings people together even if it is probably a little more expensive than having an organisation in a single location.

5 - Proposal Handling and Scientific Outputs

5.1 - Proposal assignment to main themes

As of April 2009 the 107 active proposals belong to the following main topics of the current IODP Initial Science Plan "Earth, Ocean and Life": Deep Biosphere and Subseafloor Ocean (26), Environment (43) and Solid Earth (38). Proposal design is a bottom-up process either initiated by specific workshops or individual ideas addressing specific long-term goals and objectives outlined in the IODP Initial Science Plan.

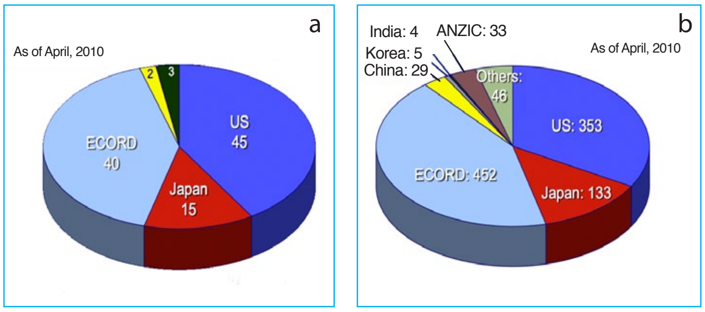


Figure 5: Proposal numbers by IODP Members (a) and region of activity of proponents of the active proposals (b), after R. Stein AWI, Bremerhaven.

As of April 2010 105 active proposals by IODP members are under evaluation or ready to be implemented as for missions and expeditions *(Figures 5a, 5b)*. Four proposals requiring MSP expeditions are currently being scoped by ESO, two of which are highly ranked by the IODP Science Advisory Structure (SAS), Chicxulub K-T Impact Crater (No. 548) and Hawaiian Drowned Reefs (No. 716). Of the 105 proposals, 40 have ECORD lead proponents (38%) *(Figure 5a)*.

5.2 - Proposal evaluation procedure

The IODP proposal preparation and handling procedures are the same for MSP operations and regular IODP actions. The first step is for pre- and full-proposals to be evaluated by the Science Support and Evaluation Panel (SSEP), which if positively evaluated recommends that a full-proposal is submitted. Particular to IODP is the so-called nurturing process, which helps to promote the best scientific ideas independent of proposal writing skills or, for example, progress in acquiring site-survey information. If the proposal is considered mature, which may take a few months to a few years to achieve, it will be sent for external scientific review and a check by the IODP panels. If the proposal is evaluated positively it is then ranked against the full list of approved proposals by the Science Planning Committee (SPC). During IODP the time taken from proposal submission to expedition implementation was between 59 months to 168 months (average 87.5 months). This long evaluation procedure is due to the complexity of ocean drilling, which results in many iterations before a proposal can be ranked and scheduled into a logistically sound 1 or 2-year expedition programme. Budgetary factors, for example if a new piece of equipment or engineering support has to be provided by IODP, are another obstacle that may hinder progress of the expeditions.

5.3 - Scientific outputs

Post-cruise activities start with intensive sampling *(Figure 6)* and the preparation of IODP Reports and Proceedings based on primary data *(Figure 7)*. These preliminary compilations, combined with intensive electronic data exchange and/or

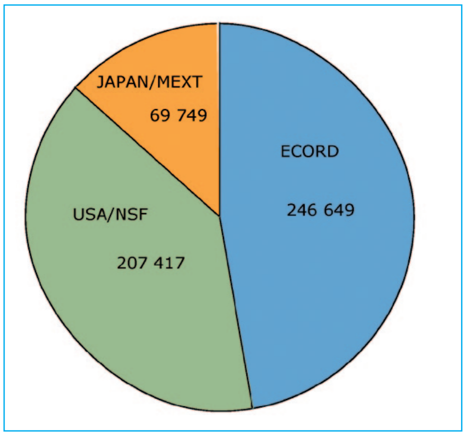


Figure 6: Sampling activity of different consortia for Expeditions 301-339.

post cruise meetings between different working groups, establish the basis for the success of any expedition. The number and quality of the published papers *(Figures 8 and 9)* indicate that, during the past 10 years, the expedition teams have effectively exploited data intellectually to a very high degree. The publication statistics impressively document that ECORD scientists contributed very significantly to the scientific achievements and the overall outstanding progress of IODP.

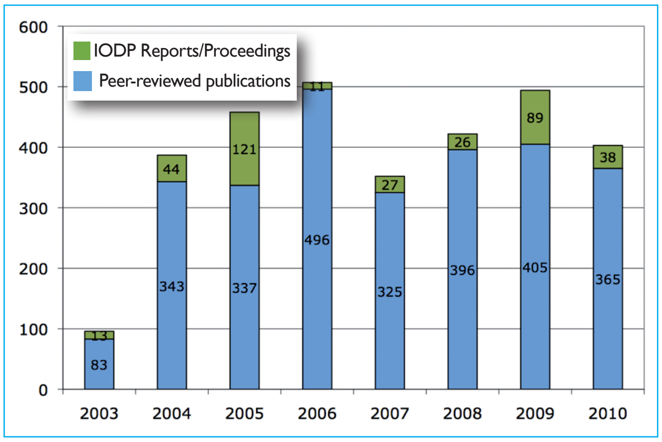


Figure 7: Statistics of internal reports (important post-cruise working tools during the moratorium phase) and peer-reviewed publications from shore-based ocean drilling research during the past 7 years.

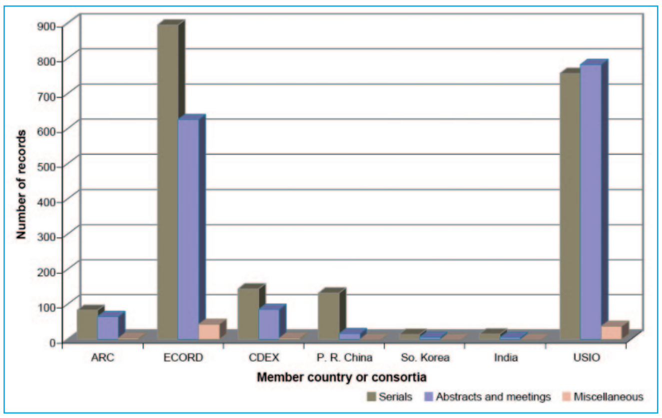


Figure 8: Publication activity 2003-2009 of ECORD scientists compared with other consortia (Serials = journals (Nature, Science, EPSL, Paleoceanography etc.).

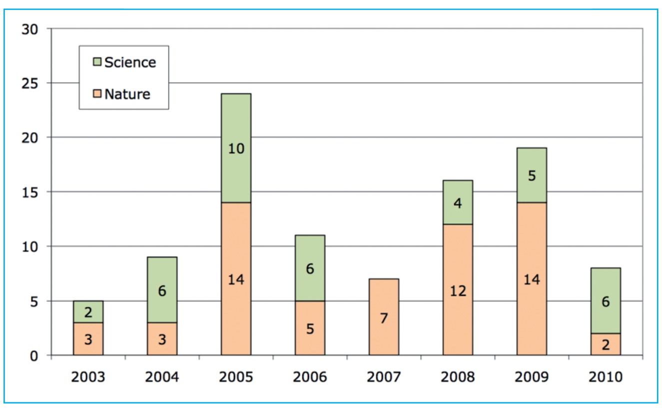


Figure 9: Nature and Science output of the ECORD consortium.

We recognise that although the IODP evaluation procedure is complicated and tedious, the scientific evaluation procedure screens very high-quality research proposals as shown by the number of high-class achievements in all scientific domains. We rate the MSP concept as an especially successful part of IODP and worthy of further support.

The selection of and development of new projects is extremely important. Most expeditions have a multitask purpose, and the framework that IODP has developed to allow an evolutionary process for new projects in which scientists can propose additional activities in an open competition is extremely good. The value of the scientific network for young scientist participating in ECORD cannot be underestimated. We also recommend that scientists from ECORD member countries should, together with other IODP and ICDP members, initiate more joint IODP/ICDP proposals for co-ordinated MSP actions.

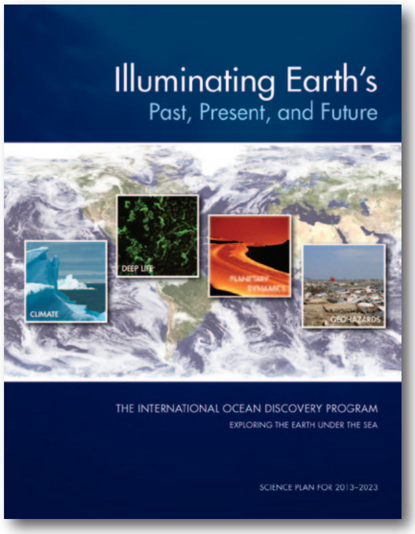
Looking through the different ranking lists of the past five years, we have speculated on the reasons why the same proposal may be ranked highly (in the top ten proposals), but in the next round can fall into the bottom third. We recommend that the SPC works towards a more transparent evaluation policy resulting in more consistent ranking of proposals. Logistics per se should not be the reason for such changes in proposal prioritization. However, if logistics must have relevance to ranking, the expedition plans should be extended and cover 3 to 4-year periods.

ECORD scientists have been active in many aspects of the science arising from the expeditions and, though not quantified, make up a significant number of the authors of the numerous papers already published on the results of shipboard and laboratory work. Several papers have been published in high-ranking journals such as *Nature*.

6 - The new Science Plan and future ECORD organisation

6.1 - The new Science Plan - the challenges for 2013 onwards

The new Science Plan *(below)* is an ambitious document that addresses the 10-year period from 2013 to 2023. The plan builds on 40 years of success in previous scientific ocean-drilling programmes, but introduces new scientific methods and models that clearly identify cutting-edge research opportunities in the future.



The scientific and societal challenges presented in the science plan are enormous, emphasising the need for more Earth-system science as societies become increasingly vulnerable to changes in our natural environment. For example, the effects of rapid climate and environmental changes on biodiversity, and the impact of natural events such as earthquakes and tsunamis that have led to massive loss of life and property destruction as witnessed in recent years. There is a clear need for scientists to better understand these changes and events to help contribute to policy decisions that may forecast and protect society from their consequences.

IODP has been a very successful international collaboration between 24 countries, demonstrating the benefit of joining funding, facilities and expertise to address problems that could not be dealt with by individual countries. However, IODP is only one such international collaboration and it is very promising to see that efforts will be made to develop relationships with other organisations, although we would have liked to see a more detailed description of these relationships. New collaborations with, for example, the International Continental Scientific Drilling Program (ICDP), NEPTUNE Canada (NorthEast Pacific Time-Series Undersea Networked Experiments) and a number of Antarctic initiatives such as the European Science Foundation's EPICA project (European Project for Ice Coring in Antarctica), SHALDRIL and SCAR-ACE *(see Annex)* will improve networking towards a more integral understanding of the complex processes that shape the Earth.

The future research goals may also open up new collaboration with industry as innovative drilling, sensor and sampling technology will be needed to successfully fulfil some of the objectives described in the science plan. Exploring interactions with industry not only provides technological benefits, it can all provide access to additional financial resources for ocean drilling.

We applaud that future drilling activities directed towards environmental themes will actively adopt a data-model-integration approach. This will provide a more sound knowledge of natural fluctuations and improve both the data/model calibration and consequently the actual models. This approach is necessary to identify forcing mechanisms and to allow scientists to track the 'tipping points' in environmental change and will lead to significantly improved predictions of these changes.

The science plan is divided into 4 scientific themes and 14 scientific challenges. The plan provides descriptions of these themes, followed by sections on *Education and Outreach and Implementation*. The division of the plan into these scientific themes perhaps loses the emphasis on multidisciplinary research that has characterised the ocean-drilling expedition to date, and which has led to significant major discoveries.

Theme 1 is related to *Climate and Ocean Change*, in which a major scientific challenge is to develop a better understanding of the Earth's response to elevated levels of atmospheric CO_2. Existing models need the input of more data to understand these responses and, in particular, there is a need for more and better data on regional precipitation patterns. This is a theme in which close cooperation between IODP and ICDP is important.

One of the main challenges under Theme 2, *Biosphere Frontiers*, is to better understand the relationship between biodiversity and rapid environmental changes, including climatic changes. Large volcanic eruptions and impacts by meteorites have changed the biodiversity abundance and distribution patterns throughout Earth's history. Detailed studies of these events and the consequent changes in biodiversity are one of the highest scientific priorities over the next 10 years. The science plan also discusses the relationship between climate, human evolution and human societies, which will be an important field of research. New DNA data are already an important tool and, to use them to their full potential, there is a need for close cooperation with other scientific programmes.

The *Earth Connections* theme focuses on fundamental scientific problems, one of which is the major challenge of drilling into the mantle. The science plan puts forward a convincing argument for the importance of studying these problems and the value of investing in the expensive drilling operations that are required. Another area of great interest is magnetism and the geodynamo and the understanding of changes in the Earth's magnetic field with time. Mineral resources are also briefly mentioned under this scientific theme; however with the increasing worldwide demand for raw materials we would have expected there to be a stronger emphasis on resources in the science plan. Furthermore, energy resources such as oil and gas, gas hydrates and geothermal energy are not addressed in the science plan in any great detail.

The fourth theme is *Earth in Motion*. The societal importance of this subject is clearly argued. Destructive earthquakes with accompanying tsunamis and landslides are a major challenge for many countries. The development of sub-seafloor geohazard observatory networks requires a major investment in obtaining the knowledge necessary to develop an early warning system for earthquakes. Development of such laboratories should be a joint project between IODP and the ICDP.

Training the new generation of scientists is an important task for IODP and the programme of *Education and Outreach* is well presented, although we feel it is not presented in the detail that this activity deserves. Today's technologies provide many channels for communication, and drilling operations have a potentially large public audience. For example, there is the possibility to stream drilling operations on the programme website.

The last chapter in the science plan, *Implementation*, is a mixture of technical information and a description of the procedures for project selection. This section is the weakest part of science plan, which could have been improved by presenting some of the new projects. The chapter could have identified the expeditions that will have the highest priority in the next 5 years, with a description of the challenges related to each project.

6.2 - The role of ECORD in the next phase

Based on the experience gained during the current IODP and the expertise gathered in the consortium within EMA, ESO and ESSAC, ECORD can continue to contribute to the new 2013-23 across a wide range of activities. We anticipate that ECORD could not only contribute to the scientific programme, but also broaden the technological concepts of MSP'S to include new drilling approaches. Though we recognise that the process of implementing an IODP MSP expedition was often lengthy and intricate in the past due to a number of factors, we strongly support the concept of the ECORD Science Operator (ESO). It must be carried on and we should applaud here their efficiency in the past. Given the boundary conditions, they have successfully strived to implement less costly procedures for MSP operations each with specific scientific and technological requirements.

Between 2013 and 2023 mission-specific platform expeditions will be crucial, as it is expected that the MSP approach will include sea-bed rock drilling and long piston coring. Moreover, only MSPs will be able to access shallow shelf/marginal and high northern latitude seas and in particular the central Arctic, which are key areas for studies of climate and sea-level change. The rocks and sediments of these regions hold archives of the rate and amplitude of abrupt environmental and climate changes at high temporal and spatial resolution. These key areas further reflect reliable and direct links between continental and open-ocean records (for example solute and particle run-off providing insights into the crustal and subcrustal dynamics causing sea level changes etc.). ECORD scientists will actively cooperate on real-time monitoring array-designs and sensor-chains in the frame of marine geohazard surveys (*e.g.*, earthquakes, tsunamis and other mass wasting processes). Here we present some of our more general conclusions of the evaluation and re-iterate some of the key recommendations.

7 - ECORD Evalution Committee key recommendations

We recommend that ECORD should be continued at an activity level somewhat higher than present. There are still large area of our continental shelves and deep oceans that are unexplored and there are many models that have to be tested.

The enormous scientific and societal benefits from the Arctic drilling show that scientific research in the Arctic must continue as a high priority activity within ECORD. The missing Cenozoic paleoclimate record must be a high priority for future research. The Arctic Coring Expedition clearly demonstrated the importance of MSP operations within IODP. The Arctic Ocean is four times the size of the Mediterranean, but is only accessible with the help of icebreakers for three month a year. The future of Arctic research is therefore to a high degree dependent on improving or building new ice-breaking research platforms.

Given the fact that climate is a global affair, better coordination between IODP and the ICDP is recommended because only joint actions between the two programmes can provide a solid information base that is mandatory for establishing reliable modeling scenarios for future climate change. Together, the two programmes will make climate modelling more credible and useful for developing environmental, economic and technological strategies for future challenges.

ECORD members, jointly with other IODP and ICDP members, should initiate more integrated IODP/ICDP proposals for coordinated MSP actions.

For future expeditions, we recommend that a modeling strategy should be closely associated to the work plan. There are a significant number of parameters that have to be taken into account, and their interactions are so complex, that numerical modeling would help to discriminate and rank the forcing parameters. Feedback between data interpretation and modeling results are critical.

Linking the long-term monitoring of IODP borehole instrumentation off the western coast of Canada and the USA to the NEPTUNE-Canada cabled observatory seems a promising route to follow. For its scientific and technological achievements, and also for the promise they contain, Expeditions 311 and 328 to the Cascadia Margin should be considered as highly significant.

Efforts should be made to bring together the deep biosphere research community and the more traditional geology research community to exploit potential synergies. Deep biosphere sampling should be included whenever possible in future drilling projects.

We recognise that there is an important opportunity within IODP for further development of seafloor drill-hole observatories for earthquake early warning systems. However, special care should be taken in discussing the societal benefits of the seismogenic zone research, as the drilling results already achieved, and those expected to be achieved in future, may be challenging to apply in practice in early warning systems and possible predictions of mega-splay earthquakes.

Although IODP scientists have become used to long-term technical planning and preparation of complex projects, a key recommendation is that IODP/ECORD should consider implementing a simpler process of project selection and development. For example, a process more similar to that of the International Continental Scientific Drilling Program (ICDP) could be considered.

ECORD should apply best practices to cost estimations of MSP operations, and use economy as the principal criterion for operations whenever required. Mobilisation/demobilisation costs should be minimised as much as possible by looking for opportunities that may result in substantial cost reduction in contracting platforms (*e.g.* back to back operations). The Bremen Core Repository was found to be a very functional facility, which is providing an excellent service to the IODP science community.

ECORD outreach activities should aim to highlight the IODP science stories and reduce the emphasis on drilling activities. The outreach team should explore opportunities to work with small TV companies to deliver the science stories. A survey of the impact of using different forms of information would allow future activities to be prioritised.

For the new phase of ocean drilling, we encourage collaboration with other initiatives such as ICDP, Neptune Canada etc., and the development of concrete plans. We recommend that new technologies are investigated to improve communication to larger audiences.

8 - Concluding Statement

Seventy percent of the Earth's surface is covered by water and the oceans cover important geological and biological landscapes. Large areas of both our continental shelf and deep oceans are largely unexplored. IODP has been the most important vehicle for exploring these areas and ECORD has made it possible for small nations to participate.

ECORD has been a great success within the IODP, and has provided the ECORD member countries with the opportunity to access data that would have been impossible otherwise.

The mission-specific platform concept has, through for example the work in the Arctic and the Great Barrier Reef, shown the importance of flexible platforms to solve specific technical problems.

ECORD scientists have been active in designing the IODP, with many successful proposals contributed to the science programme during the last decade. The scientific output from ECORD activities has been very high both in quality and quantity.

ECORD scientists have had a very high level of participation in IODP expeditions and the ECORD countries have benefited from this important scientific network.

However, even in a successful organisation like ECORD there is room for improvement of the organisation, scientific selection processes and outreach.

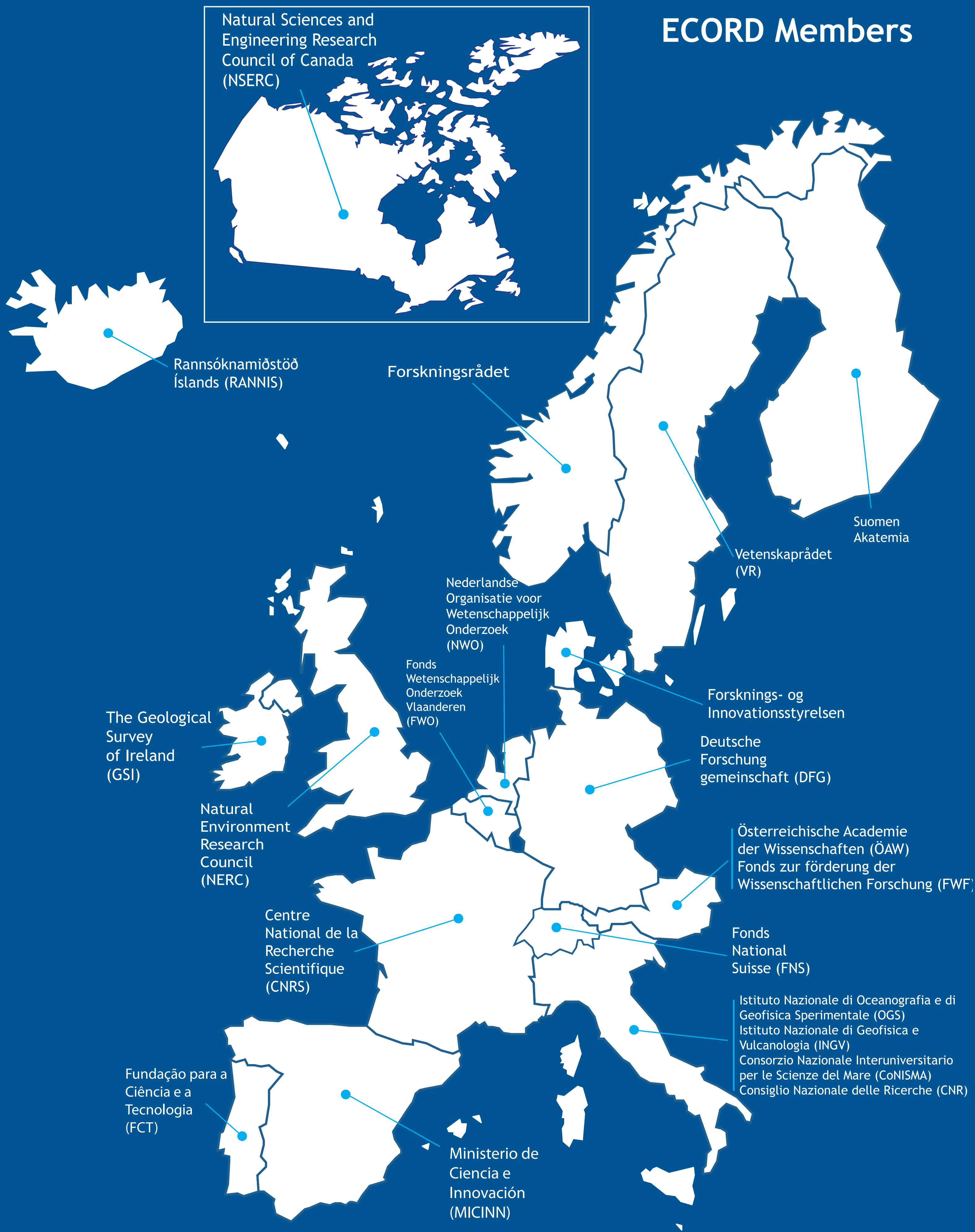
The new Science Plan, elaborated by the international community for the next phase of ocean drilling, introduces new scientific methods and models that clearly identify cutting-edge research opportunities in the future. The scientific and societal challenges are enormous, emphasising the need for more Earth-system science as societies become increasingly vulnerable to changes in our natural environment. The contribution of MSPs is essential in providing access to shallow shelves and most of the Arctic, which are key areas for studies of climate and sea-level changes.

The ECORD activity must be continued with funding higher than today.

Annex - List of Acronyms

ACEX: Arctic Coring Expedition
ANZIC: Australia-New Zealand IODP Consortium
AWI: Alfred Wegener Insitute
BBC: British Broadcasting Corporation
BCR: Bremen Core Repository
BGS: British Geological Survey
CDEX: Center for Deep Earth Exploration
CNRS: Centre National de la Recherche Scientifique
CORK: Circulation Obviation Retrofit Kit
CRISP: Costa Rica Seismogenic Project
DIS: Data Information System
DSAG: Deep-Sea Archaeal Group
DSDP: Deep Sea Drilling Project
DS^{3}F: Deep Sea and Sub-Seafloor Frontier
EC: European Commission
ECORD: European Consortium for Ocean Research Drillling
EGU: European Geosciences Union
EMA: ECORD Managing Agency
ENSO: El Niño Southern Oscillation
EPC: European Petrophysics Consortium
EPICA: European Project for Ice Coring in Antarctica
EPSL: Earth and Planetery Science Letters
ERA-Net: European Research Area Network
ESO: ECORD Science Operator
ESSAC: ECORD Science Support and Advisory Committee
EU: European Union
FLOCS: Flow-Through Osmo Colonization System
GCR: Gulf Coast Repository
GFZ: Deutsches GeoForschungsZentrum
ICDP: International Continental Scientific Drilling Program
IODP: Integrated Ocean Drilling Program
IODP-MI: Integrated Ocean Drilling Program Management International, Inc.
IFP: Institut Français du Pétrole
IRD: Ice-rafted debris
JAMSTEC: Japan Agency for Marine Earth Science and Technology
J-DESC: Japan Drilling Earth Science Consortium
JOIDES: Joint Oceanographic Institutions for Deep Earth Sampling
KCC: Kochi Core Center
K-T: Cretaceous-Tertiary
MARUM: Center for Marine Environmental Sciences
MCG: Miscellaneous Crenarchaeotal Group
MBGB: Marine Benthic Group B
MEXT: Ministry of Education, Culture, Sports, Science and Technology
MoU: Memorandum of Understanding
MSP: Mission-specific platform
NanTroSEIZE: Nankai Trough Seismogenic Zone
NAO: North Atlantic Oscillation
NEPTUNE: NorthEast Pacific Time-Series Undersea Networked Experiments project
NSF: National Science Foundation
ODP: Ocean Drilling Program**SAGMEG**: South African Goldmine Euryarchaeotal Group
SCAR-ACE: Scientific Committee on Antarctic Research - Antarctic Climate Evolution
SHALDRIL: Shallow Drilling on the Antarctic Continental Margin
SPC: Science Program Committee
SSEP: Science Support and Evaluation Panel
TAMU: Texas A & M University
UNCLOS: United Nations Law of the Sea
USAC: US Advisory Committee
USIO: US Implementation Organization

ECORD Members



http://www.ecord.org

ECORD European Consortium for Ocean Research Drilling

IODP Integrated Ocean Drilling Program