JOIDES Journal

Joint Oceanographic Institutions for Deep Earth Sampling
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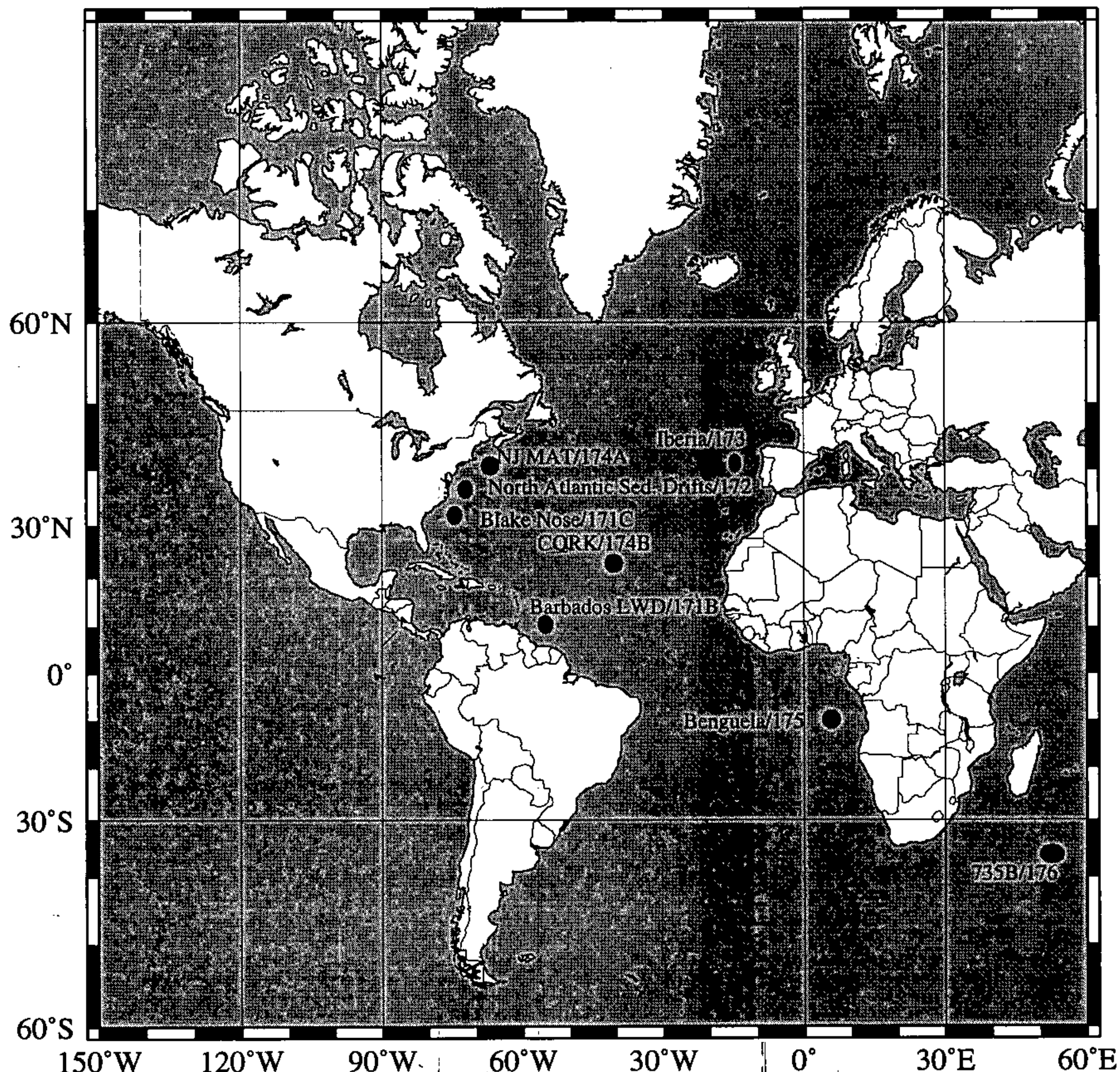

Leg 162, 163 & 164 Reports

International News and Meetings, Proposal News

JOIDES Panel Memberships

COVER:
Schematic map showing the locations of the drilling legs for FY97.

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Table of Contents

JOIDES Journal

Joint Oceanographic Institutions for Deep Earth Sampling

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Introduction

It is with great sadness that I write this introduction to the *JOIDES Journal*. I am sure that all readers are aware by now that Rob Kidd died on Sunday June 9 this year. Below there is an obituary and a tribute from the Site Survey Panel, with whom Rob was closely associated for many years. Many of you who knew Rob personally will be only too aware of how he always looked to the future, and with your help we can make at least a part of what he had planned for come to fruition.

By this I am of course referring to a proposed new JOIDES advisory structure, one that will both benefit the scientific "users" of the drill ship, and that should also help to streamline the management process, allowing the Program to become much more efficient and remain the world's premier geoscience research program. The basis of the new advisory structure is that it will be a three-tiered arrangement, with proponents sending proposals to Science Steering and Evaluation Panels who will, when appropriate, arrange for each proposal to be mail reviewed externally. Then the top science committee will evaluate each proposal in terms of how it fits with the goals of the ODP Long Range Plan and it will produce global rankings for the very best of the drilling proposals. Once all the details of the proposed new advisory structure have been finely tuned, which PCOM aims to do at the forthcoming meeting in Townsville in August, the details will be published both in the *JOIDES Journal* and on the WWW.

Another change that will shortly be evident is in the format of the *JOIDES Journal*. You will recall that about a year ago we asked readers to respond to a questionnaire regarding a new *Journal* format. The response (at under 10% of circulation) was disappointing, but nevertheless gave us a pointer in which direction the *Journal* should evolve. Many of the detailed reports from the Science Operator and Wireline Services Operator will be greatly reduced, probably to simple abstracts, and the *Journal* will become much more of a news magazine. Readers who wish to obtain details of the Science Operator and Wireline Services Operator reports can still do so either via the WWW, or by writing to either of these service providers and requesting the reports. The current JOIDES Directory, which incidentally most of those who responded to our survey said they found to be one of the most useful sections, has for some time been available on the WWW via the JOIDES Office home page. We will be keeping this as part of the *Journal* at least for the time being. The new format will begin with the next (October 1996) issue of the Journal.

Finally I must apologise for the lateness of this combined February/June 1996 issue. With the many tasks that the JOIDES Office has had to undertake this year (the Long Range Plan, International mid-term Review, and new JOIDES Advisory structure to name but a few), culminating with the death of Rob Kidd, there were simply too many tasks and not enough time.

Julian Pearce
PCOM Chair

Obituary: Robert Benjamin Kidd

Robert Kidd, Professor of Marine Geology in the University of Wales, Cardiff, was both an eminent scientist and a distinguished servant of marine geoscience. Rob obtained his first degree at Kingston Polytechnic, then moved to the University of Southampton, studying the sediments of the Tyrrhenian Sea for his PhD. Rob joined the UK's Institute of Oceanographic Sciences in the summer of 1973, and almost immediately was seconded to the Deep Sea Drilling Project at Scripps Institute of Oceanography near San Diego as a staff scientist. On his return to IOS, Rob and his colleagues there pioneered work on combining the data from sediment cores with the imagery being obtained from the GLORIA side-scan sonar technology then being developed in the Institute.

In 1979 Rob was appointed Head of Science Operations for the Ocean Drilling Program at Texas A&M University. Rob's success in this post opened the way for him to return to the University College of Wales at Swansea in 1986 as Professor of Geology. Having been raised in west Wales it was a source of pride and joy to him to return there as a professor. He oversaw the merger of Geology and Oceanography Departments in Swansea before moving to Cardiff where he built a thriving marine geology research group. Rob was one of the strongest proponents of marine geological research in the UK and he worked tirelessly to promote the activities of the Ocean Drilling Program. Rob sailed on five drilling cruises, three as chief scientist.

When, in 1985, the opportunity arose for the Natural Environment Research Council (the UK member of ODP) to bid to lead the scientific planning of the Program (for the first time outside of the US), Rob was by general acclaim the person to turn to for the crucial role of scientific leader. He had the respect of the community, a clear vision of where the Program should go, and an understanding of what was practical and politically possible. Through his leadership, the geoscience community around the world developed a new vision of the role of ocean drilling in future scientific advance, which has brought ODP to the threshold of renewal into the next century. Rob had strong views on many aspects of marine geology and it is a tremendous tribute to his character that he was able to promote these views without making enemies. One always knew that Rob was promoting science and not himself. He considered the role of PCOM chair to be the pinnacle of his scientific career.

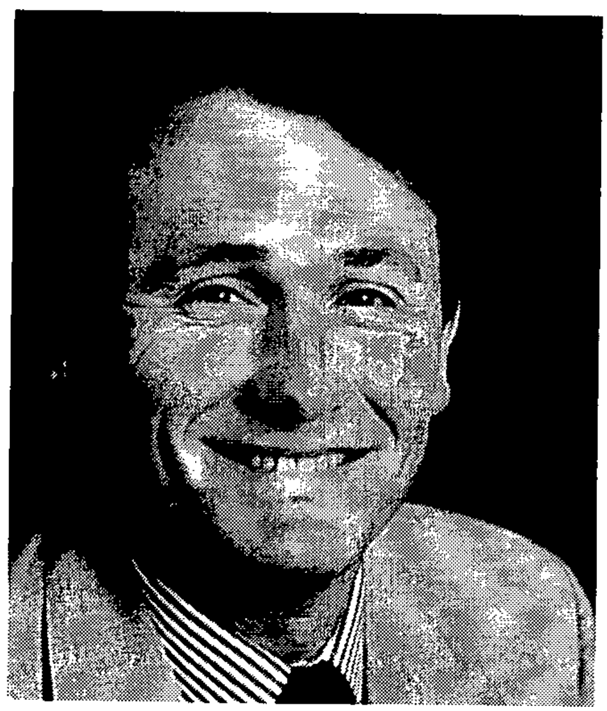
Rob had borne stoically for many years the pains and uncertainties associated with heart problems. He was struck down at the very moment of receiving the accolade of his peers in British earth sciences by the award of the Major Edward Coke Medal of the Geological Society, at Burlington House on 4 June. The citation for this award records the wide acclamation that his research in palaeo-oceanography, sediment drift and high resolution stratigraphy have received. Equally or even more enduring will be the affection and respect of all who worked or relaxed with him, and those who argued with him as well.

Rob loved his work and was immensely proud to be PCOM Chair. But, above all, he loved his family. Those of you who have had the privilege of knowing Rosalie and their sons will realise and understand that his family was his greatest achievement.

A tribute to Rob Kidd from present and past associates of Site Survey Panel

It would be difficult to find any JOIDES panels in ODP that Rob did not influence, one way or another. However, one panel where he had an everlasting influence was the Site Survey Panel. Rob's association with this panel goes back to the early days of ODP (1983) when he was the Science Operations manager at TAMU and attended this panel as a TAMU liaison. After moving back to the UK (1986), it was not long before he found his way back to this panel as the UK representative. He remained with SSP until his resignation in 1993.

Although the role of this panel in guiding PCOM on site survey readiness of various proposals was well recognised in the ODP, it was not until Rob took over the helm in 1988 that some firm guidelines about data submission to the Data Bank were established. His guidelines, although they have undergone some revisions since, are still followed by this panel. They were designed not only to help the proponents of various proposals on the type of data needed as prerequisite for site selection for drilling in different environments, but also to assist panel members in judging uniformly the readiness of proposals for drilling. Rob also introduced the concept of "proposal watchdogs" to SSP. He was most instrumental in conveying to PCOM and to other thematic panels the importance of site survey assessment of a proposal. He believed strongly that the success of a Leg depended largely on proper site selection and this he advocated strongly to the panel members. He understood the importance of this panel, and he pushed hard for SSP to become an effective, proactive panel instead of just a rubber stamp for site proponents. It was in large part his energy that fuelled the reshaping of this panel into its current form. Because he loved looking at different kinds of data, he used to watchdog one or two proposals besides chairing the meetings, a task subsequent chairs have not been able to do. Even though Rob resigned from the panel when he became UK representative to PCOM in 1993, he maintained a keen interest in SSP and was able to attend a few of its meetings either as a UK alternate member or, most recently, as a substitute PCOM liaison member.



Another of Rob's characteristics was to be able to make time to get to know most of the people connected with SSP. This included people from the Data Bank, the JOIDES Office and many of the liaisons who attended the meetings. He made a point of spending enough time with the Data Bank staff to know how they handled large quantities of data efficiently and effectively. Because Rob was so approachable, others felt comfortable working with him. The oceanographic community has lost an energetic, articulate scientist, advocate and friend. He will be long remembered and greatly missed.

JOIDES Committee Reports

Planning Committee (PCOM)

La Jolla, California, 4–9 December 1995

The Planning Committee held its annual meeting in La Jolla adjacent to Scripps Institution of Oceanography. The main business of the meeting was discussion of the FY97 science plan, discussion and implementation of the new ODP Long Range Plan (LRP) and budgetary considerations.

FY97 Science Plan – Ship Schedule

PCOM heard presentations of the drilling proposals in the 1996 Drilling Prospectus from the Thematic Panel Chairmen, and, based upon these and the thematic panel rankings, requested the science operator to produce a ship schedule which is as follows:

- 171A Transit
- 171B Barbados LWD
- 171C Blake Nose
- 172 NW Atlantic Sediment Drifts
- 173 Iberia II
- 174A New Jersey Shelf
- 174B CORK Site 395A/Engineering
- 175 Benguela
- 176 Hole 735B

The FY97 ship schedule ends with the *JOIDES Resolution* in Cape Town, South Africa in December 1997, allowing for a favourable weather window for a Southern Ocean leg in early 1998 and the ship to move into the Indian Ocean, continuing along the path outlined by PCOM in April 1995.

Long Range Plan – Implementation

By the time this article goes to press, the new ODP Long Range Plan should be available to the community. In December PCOM reviewed the processes that it had gone through to produce the document and unanimously endorsed its publication. This plan builds on the first ODP Long Range Plan, published in 1990, and envisages at least two further Phases of the ODP. The current, Phase II, comes to an end in 1998, when the member nations and consortia will be asked to recommit to ODP for a further 5 years onto Phase III.

The start of Phase III (1999–2003) will represent the first fully operational period where the Planning Committee will be asking the Science Operator to schedule proposals that address specific scientific problems identified in the LRP. However, the Program will retain its proposal-driven remit, and therefore will still have flexibility to schedule the drilling of exciting scientific proposals that were not envisioned when the LRP was formulated. Phase III will be characterized by ODP collaborating with other major geoscience initiatives to achieve joint goals. This will include the use of other platforms and also the investigation of problems that require multiple-leg drilling, in line with the formal call for proposals for multi-leg and multi-platform drilling which will be issued shortly by the JOI office in Washington DC.

In Phase IV, JOIDES anticipates the additional availability of deep drilling with a riser system. The call for proposals mentioned above will also invite proposals now to begin planning for these operations, as they will be very complex and require long-term planning and site survey.

The JOIDES Executive Committee addressed the question of the implementation of the LRP with some fundamental challenges for the whole of the ODP advisory structure (see EXCOM Report, below).

Budgetary matters

The flat budget proscribed by ODP funding through to the end of Phase II is beginning to have some very serious implications for the Program. In December PCOM received a presentation from the JOI Program Director, Dave Falvey, on how the implementation of Project Management would help with budget forecasts, and also on engineering and the JANUS Projects at ODP-TAMU. At the request of the TEDCOM representative at the annual meeting, PCOM agreed to postpone a decision of the continuance of the DCS project until their April meeting. As regards other engineering activity at ODP-TAMU, this has been drastically reduced so that, apart from operational items required for scheduled legs, there are only two true 'development' projects underway at present. These are the Motor Driven Core Barrel upgrade, and the development of a new Hammer Drill-in Casing system (these should make high-angle bare-rock spud-ins almost a routine operation). PCOM was very impressed with the potential of the Hammer Drill-in Casing system, and a sea-test for this piece of equipment will form part of Leg 174B.

Publications

PCOM spent considerable time discussing the issue of ODP publications and leaned heavily on the expertise of the Information Handling Panel (IHP) and the survey carried out by the publications sub-committee.

PCOM also requested that the price of the *Results* and *Proceedings* Volumes be increased to $60, and that the distribution of volumes be widened rather than to cut the size of the production run.

Other PCOM business

PCOM supported a recommendation from the PANCH (JOIDES Panel Chairs) meeting which asked that each of the thematic panels designate one of their US panel members, with appropriate expertise, as ad-hoc liaisons to SSP. The rationale behind this is that they can then be called on by the SSP Chair to substitute for occasional US absentee SSP members, as there is no formal alternate system for US advisory panel members.

PCOM agreed to try to lighten the workload of SSP by giving the following instructions to the thematic panels and SSP.

1. SSP will only consider the top 5 ranked proposals from each thematic panel during their meetings.
2. Thematic panels will identify proposals ranked in the top 5 that lack adequate data and are thus unlikely to make it into the prospectus within two years. SSP may exclude these proposals from consideration and may instead include, after consultation with the PCOM Chair, proposals ranked lower than 5th place.

Also PCOM agreed to support the SSP recommendations that require, from now on, proponents to submit both primary and alternate site locations in proposals where the area of operations is to be in ice-infested waters. The alternate sites should be located so that they can be realistically occupied in the event of ice preventing drilling of the primary site(s).

Planning Committee (PCOM)

Aix-en-Provence, France, 22–25 April 1996

The Planning Committee held its spring meeting at CEREGE in Provence. The main items of business were the evolution of the JOIDES advisory structure, deciding upon a four-year ship track for the *JOIDES Resolution*, Publications, DCS and a number of budgetary matters. The meeting concluded with a joint session with representatives from JAMSTEC.

Evolution of the JOIDES Advisory Structure

Following the international mid-term review report (see JOIDES Office WWW home page), and publication of the new ODP Long Range Plan (LRP; available from JOI Inc.), EXCOM tasked PCOM with developing an implementation strategy for the LRP, which included, if deemed necessary, changes to the JOIDES advisory structure.

PCOM, in considering this charge and the EXCOM directive that "Drilling proposals submitted to ODP should henceforth be evaluated in the context of the LRP", determined that a complete revision of the way that ODP science is planned and implemented would produce significant benefits, in both the management of the Program and for the scientific 'user' community.

During its deliberations, PCOM developed an initial 3-tier science advisory structure model (proponents and working groups, internal nurturing/proposal review and external mail review, and finally, ranking /scheduling) that was presented to EXCOM in June 1996 for its consideration. EXCOM (see report below) commented on that initial model and is expected to give its formal approval to begin the transition to the new advisory structure in either late 1996 or early 1997.

PCOM will refine the advisory model at its August 1996 meeting prior to final presentation to EXCOM. Once the model has been approved for implementation, details will be published in the *JOIDES Journal* and on the WWW.

Publications

This has been a controversial issue for some time. The PCOM publications sub-committee made a series of recommendations at this meeting, most of which were endorsed by the full Planning Committee, but, since then, a focused group with representatives from the PCOM publications sub-committee, ODP-TAMU and JOI held a meeting in College Station to try to determine a long-term (5 years or more) publication strategy that would achieve two aims: (a) to reduce costs; and (b) to make ODP publications more widely available and open to the general scientific community. This revised publications strategy will again be discussed at the August PCOM and once the details are finalised, it will be published.

Diamond Coring System

PCOM received encouraging reports on the development of the heave controller for the Diamond Coring System, and recommended to JOI that funding be made available to produce a working system. Currently the schedule aims for a sea test in FY99.

Other Business

In terms of the *JOIDES Resolution* track, PCOM confirmed its general direction would be from the Indian Ocean into the western Pacific for FY99. Also PCOM recommended some priority changes in budget allocations which will allow Leg 170 (Costa Rica Margin) to use LWD technology.

PCOM also constituted an Antarctic Detailed Planning Group (DPG). This was because there are a significant number of highly ranked proposals in that geographic region, and, with a very restricted weather window, it may be possible to fulfil the goals of different proposals by combining some of them into logistically feasible drilling packages. The DPG was tasked to look at all proposals in the Southern Oceans and to produce a prioritised drilling plan that would be discussed by PCOM at its August meeting when it chooses which highly ranked proposals will be placed into the drilling prospectus (from which the final selection of proposals for scheduling will be selected).

Executive Committee (EXCOM)
Chantilly, Virginia, 29–31 January 1996

The prime item of business at this EXCOM was to develop an initial response to the findings of the report of the International Mid-Term Program review committee, chaired by Dr. Gordon Greve. This mid-term review was viewed as crucial by all members of the Program, as its findings will be used by individual member nations as they decide whether or not to commit to Phase III of the Program, from 1998–2003. The issues explored by EXCOM included Program management, advisory structure evolution and budgetary matters.

EXCOM endorsed the new ODP Long Range Plan and expressed its enthusiasm, shared by PCOM and the Mid-term Review Committee, for the new focus of ODP and the exciting science it will make possible. EXCOM said that it is committed to the implementation of the plan, although it recognised that this will require significant changes in current management and planning practices. EXCOM also noted that the technical and financial challenges that the Long Range Plan places before the entire JOIDES community are considerable and indicated, from past experience, that the JOIDES advisory structure as a whole will need to work together to establish clear scientific, technical and administrative priorities in order to ensure that the Program meets the challenges it has set itself.

EXCOM intend that the ODP scientific and management implementation plans will be completely linked to the goals of the Long Range Plan, and thus enable a clear demonstration of the accountability of the entire Program – from panels through to ODP Council – in terms of the Long Range Plan. EXCOM stated that it thought these changes will be essential to both maintain the viability of the Program, and provide the most compelling rationale for the continuation and evolution of ocean drilling into the 21st century.

EXCOM stated that, as an initial part of the implementation strategy of the LRP, drilling proposals submitted to ODP should henceforth be evaluated in the context of this Long Range Plan and each year's Program Plan should clearly identify how each leg contributes to the goals of the Long Range Plan. EXCOM also requested the Planning Committee to develop a detailed implementation strategy for the LRP, including necessary changes to the scientific planning structure. EXCOM will review this implementation strategy at its June 1996 meeting.

The LRP explicitly states that the Program will work in partnership with other global geoscience Programs to investigate joint objectives. EXCOM strongly endorses these closer ties with international groups and, so long as the science goals of those Programs complement those of ODP, encourages them to submit proposals to ODP to utilise the unique capabilities of the *JOIDES Resolution*.

As part of the continuing efforts to look for cost savings and encourage innovation, EXCOM requested both JOI and PCOM to provide, by June 1996, recommendations on specific services, and their related costs, that are currently provided, for Wireline Logging Services and Site Survey Data Bank Services to ODP. This information will be used by EXCOM to advise JOI on the scope of RFP's that will be issued for provision of these services from 1998 to 2003.

EXCOM also recognised a need for immediate and concerted actions to secure the necessary funds for evolution and growth of ODP through Phase III to the time when ODP becomes a two-ship operation in Phase IV (2003). The International Review committee also embraced the ODP Long Range Plan, and recommended that to achieve its short-term goals (pre-2003) would require real growth in the budget of about 2.5% per year.

In the light of this recommendation, EXCOM requested that the following actions be taken:

- JOI, in consultation with the Planning and Budget Committees, examines the important new innovations in the Program (Borehole Utilisation, Legacy Holes, *inter alia*) and detail their costs. EXCOM have also asked these committees to advise JOI on what existing components (publications, logging, indeed all components) might be dropped or reduced to accommodate these new initiatives and clearly label the costs, benefits and losses. The Executive Committee believes that this step is fundamental to addressing concerns from the national funding agencies that all cost-cutting measures have been examined prior to requesting additional funds. EXCOM have asked for action on this by June 1996.
- JOI, with appropriate consultation, should develop full financial projections for the Long Range Plan with the goals of presenting EXCOM, before June 1996, with the information to allow all EXCOM members to advocate increases in contributions with their respective funding agencies, possibly at the real growth level of 2.5% per year (98-03).
- EXCOM at the 1994 Kyoto meeting recognised the necessity for a leadership role by one or more nations if the Program is to engage in riser drilling as advocated by the LRP. EXCOM requested all partners on ODP Council to begin immediately to consider possible new mechanisms and partnerships to build the required financial structure to support the two-ship Program.

EXCOM then turned its attention to the longer term (Phase IV). The committee voiced its appreciation of all the efforts made by the Japanese authorities (in particular, the Science and Technology Agency and the Japanese Marine Science and Technology Center) for their studies in application of riser capability in scientific ocean drilling, and recommended that Japanese authorities continue work towards construction of a new drilling vessel with riser capability beyond that of the current JOIDES Resolution. In order to facilitate planning for this vessel and its use, EXCOM recommended that the PCOM and OD21 science planners organise a series of discussions on scientific research as soon as possible (and asked that the discussions identify the relationships between the goals of the ODP and the OD21 Science Programs and report back to EXCOM at its June 1996 meeting).

In looking at the technological requirements for the Program, EXCOM recommended that the TEDCOM and OD21 discuss the engineering development needs of OD21 as soon as possible. They asked that engineering development workshops identify the technical and engineering development needs of OD21 and a timeline to meet these needs (they requested a full report back to EXCOM by January 1997, with a progress report in June 1996).

EXCOM explicitly identified STA/JAMSTEC, MONBUSHO and JOI as key organisations in the current and expected future ocean drilling operation and requested that these organisations discuss options for international operation and management of Phase IV of the ODP LRP and their funding implications. (EXCOM requested a report in January 1997, again with a progress report in June 1996).

EXCOM also wished to express its gratitude to the shipboard personnel of Leg 163. This they did with the following Consensus statement:

Facing extreme hurricane conditions, 60 to 70 foot seas, and damage to critical navigation and manoeuvring systems while in iceberg-laden waters off Greenland, the crew of the JOIDES Resolution extracted the vessel from danger and brought her safely to Halifax. The Executive Committee recognises the courage, skill and fortitude displayed by the participants of Leg 163 and expresses its most sincere thanks to the crew, staff and scientists, who even in the most trying of circumstances epitomised the character and spirit of research, exploration and the pursuit of excellence.

Executive Committee (EXCOM) Report

Oslo, Norway, 24–25 June 1996

The main business of this meeting was consideration of PCOM's draft Long Range Plan Implementation strategy and the proposed new JOIDES science advisory structure. The outcome of EXCOM's deliberations are well summarised in the following EXCOM Motion:

EXCOM Motion 96-2-3

(1) The EXCOM endorses the concept of a 3-tier planning structure for ODP that includes:
   (a) long and short-term science, technology and operations planning;
   (b) detailed development of themes and thematic review of proposals; and
   (c) programmatic proposal planning (working groups).

(2) The EXCOM endorses the concept of separating long-term strategic planning from shorter-term operations strategy by:
   (a) the formation of a Science Advice Committee (SCICOM) that will be responsible for long-term strategic science, technology and budget planning and for accountability of the ODP to the Long Range Plan. This committee should have proportional representation, but EXCOM urges PCOM to develop a consultative mechanism with the ODP members to maintain a thematic balance;
   (b) the formation of an Operational Advice Committee (OPCOM) that will interact with SCICOM and be responsible for the shorter-term scientific, technical and operational planning necessary to develop each year's scientific drilling.

(3) The EXCOM endorses the concept of establishing two thematic review panels (Earth's Environment, Earth's Interior) responsible for:
   (a) advising and interacting with SCICOM on thematic development within ODP;
   (b) obtaining reviews of drilling proposals, and evaluating and synthesizing those reviews for SCICOM;
   (c) communicating and interacting with programmatic planning groups (a.k.a. working groups).

(4) The EXCOM endorses the concept of having SCICOM establish programmatic planning groups of finite lifetime. These planning groups will use unsolicited, solicited, and self-developed proposals to develop or contribute to mature drilling proposals.

Programmatic Planning Groups will be established based on: SCICOM perception of need and/or recommendations of other JOIDES committees and/or requests from global programs and/or recommendations of other individuals in JOIDES.

EXCOM had a number of concerns over the details of the PCOM model and an EXCOM/PCOM subcommittee met in Washington in early July to clarify these points. The resulting science advisory model will again be discussed by PCOM in August, and will be returned to EXCOM for ratification either later in 1996 or early in 1997.

At this meeting, EXCOM also tasked PCOM with producing a 5-year science plan that, after preliminary budgeting, will be used as part of the case for renewal of the Program into Phase III (1998–2003).

North Atlantic Arctic Gateways II

Science Operator Report Leg 162

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A complete Scientific Preliminary Report for this leg (and others) is available from Ocean Drilling Program, 1000 Discovery Drive, College Station, Texas 77845-9547, USA, or via the Internet World Wide Web at http://www-odp.tamu.edu/publications/

ABSTRACT

Leg 162 is the second of two legs designed to investigate what role three major northern geographical areas (the Northern Gateway region, the Greenland–Norway sea, and the Southern Gateway region) have played in regulating the global climate system. To accomplish this goal the biogenic fluxes ($CaCO_3$, opal, and organic carbon), lithologic fluxes, and geochemical records contained in the cores were, and will continue to be, analyzed in order to reconstruct the temporal and spatial variability of the oceanic heat budget, the history of intermediate and deep water formation, and the history of glaciation on the surrounding land masses on millennial, Milankovitch, and tectonic time scales. In addition, because of the very high sedimentation rates (10–20 cm/ky) at some of the drilled sites, we will be able to analyze the sediments on century (Dansgaard–Oeschger events) time scales. Perhaps more importantly, these paleoceanographic reconstructions will span millions of years instead of the 100,000-year time-spans typical of piston cores. Before generating time scales for these sedimentary sequences, composite records were constructed at each site based on continuous data obtained by the multisensor track (including magnetic susceptibility, natural gamma radiation, and gamma-ray attenuation, or GRAPE, which measures bulk density), as well as on color spectral reflectance measurements. The sites are arrayed, in combination with the Leg 151 sites, as broad north–south and east–west transects to examine the evolution of vertical and horizontal gradients in water-mass properties over time and to date the inception of high northern latitude glaciation.

The drilling schedule included 56 days at sea with coring operations at nine sites (Sites 907, 980, 981, 982, 983, 984, 985, 986, 987). We began on the sediment drifts south of Iceland, eventually moving northward to the Svalbard Margin, Fram Strait, and the East Greenland Margin as sea ice retreated through the month of August. Overall, we recovered 6730.74 m of core, setting a new record for recovery during a single leg, and made over 1 million shipboard measurements.

INTRODUCTION

Understanding the causes and consequences of global climatic and environmental change is an important challenge for society. The northern polar oceans are of great relevance to this task, because they directly influence the global environment through the formation of permanent and seasonal ice-cover, transfer of sensible and latent heat to the atmosphere, and by deep-water formation and deep-ocean ventilation which control or influence both oceanic and atmospheric carbon content. Thus, any serious attempt to model and understand the Cenozoic variability of global climate must take into account the climatic processes occurring in this region.

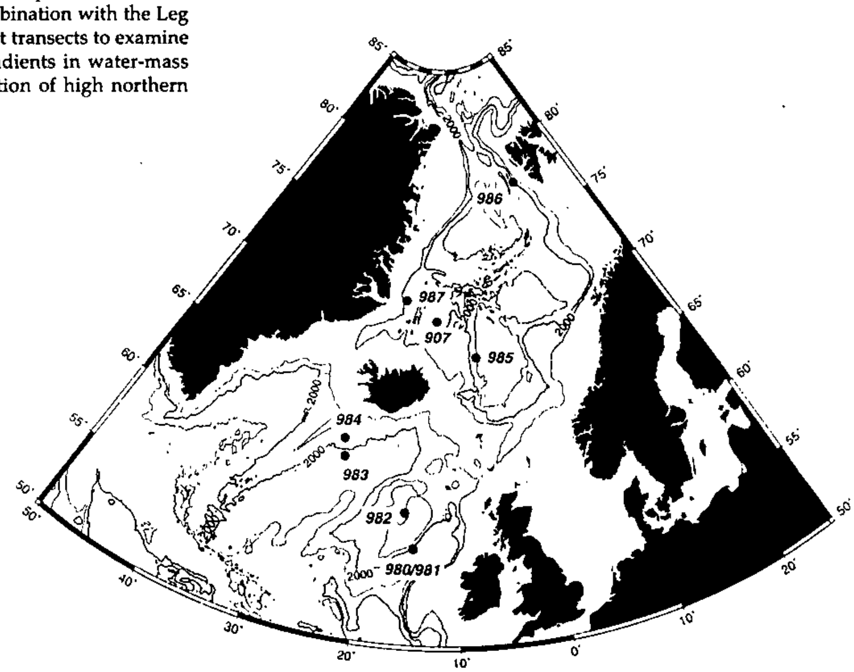

Figure 1. Bathymetric map (in meters) of sites cored during Leg 162, which departed Edinburgh, Scotland, on 8 July and returned to Reykjavik, Iceland, on 3 September, 1995. Sites 980–984 form a depth transect and a surface-water transect from warm to cool areas of the North Atlantic. Sites 907, 985, and 987, together with previous ODP sites, form a transect from temperate areas off Norway to the polar waters off Greenland. Site 986 is positioned off the location of the Svalbard/Barents Sea Ice Sheet in the European Arctic, and Site 987 off the Greenland Ice Sheet.

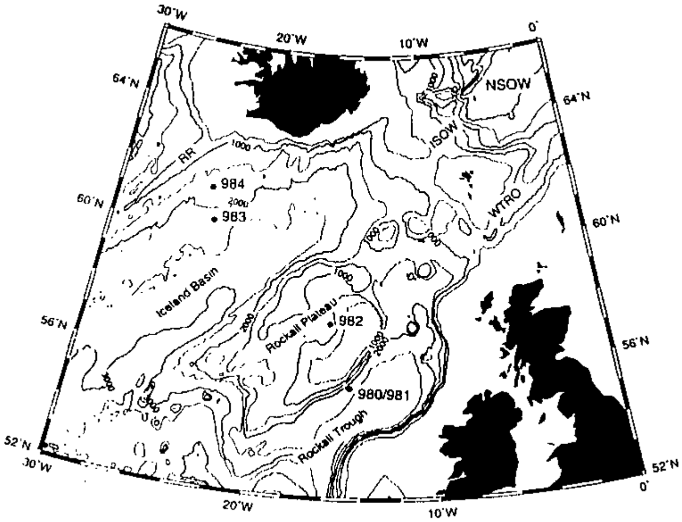

Figure 2. Bathymetry (in meters) of the Southern Gateway region of the northeast Atlantic showing major physiographic features. Norwegian Sea Overflow Water (NSOW) originates in the Nordic seas, and in this region spills across the Greenland–Scotland Ridge as Wyville–Thompson Ridge Overflow Water (WTRO) or Iceland Sea Overflow Water (ISOW). RR = Reykjanes Ridge.

Leg 162 represents the second in a two-leg program designed to investigate three geographic locations in the high northern latitudes (the Northern Gateway region, the Greenland-Norway transect, and the Southern Gateway region; Fig. 1). Our goal is to reconstruct the temporal and spatial variability of the oceanic heat budget, the history of intermediate- and deep-water formation, and the history of glaciation on the surrounding land masses. Ultimately, we want to understand the role played by the high northern latitude seas in the global climate system on time scales ranging from decades (Heinrich/Dansgaard–Oeschger events) to millions of years.

Overall, the choice of sites for Leg 162 was guided by two primary scientific objectives. First, we wanted to recover sequences with sedimentation rates high enough to delineate millennial-scale variability in lithologic, biologic, and geochemical characteristics. This goal was attained by recovering sedimentary sequences at five sites located on sediment drifts in the North Atlantic (Fig. 2) and on rapidly accumulating continental slope regions in the Nordic seas. Both of these areas have average accumulation rates greater than 10 cm/ky. Continuous sediment recovery was documented over millions of years at almost all the sites, and clear evidence was found for variability of sediment physical properties on millennial time scales over many different time periods (Fig. 3). In addition, the drift sites (980, 981, 983 and 984) open a new window of exploration in the pelagic realm of the deep sea, and will allow us, for the first time, to study the evolution of millennial-scale climate variability in the North Atlantic over millions of years. In particular, we will be able to evaluate the amplitude and frequency of millennial-scale variability during the mid-Pliocene, a period warmer than today.

The second objective of Leg 162 was to recover sequences in a spatial array suitable for examining the evolution of vertical and horizontal gradients in water-mass properties. The North Atlantic sites form a depth transect in the northeastern basins spanning the depth interval of glacial intermediate water-mass formation (specific depths of sites: Site 982 – 1150 m, Site 984 – 1660 m, Site 983 – 1995 m, Site 980 – 2180 m, and Site 981 – 2184 m). Likewise, two of the sites (983 and 984) are located just south of waters spilling over the Iceland–Faeroe Ridge while the other sites (981 and 982) are just south of the Wyville–Thompson Ridge Overflow. These sites will allow us to examine the history of North Atlantic thermohaline circulation both on millennial and Milankovitch time scales. In addition, the sediment records of two sites, 981 at 2157 m and 982 at 1150 m, extend back to the upper Miocene and lower middle Miocene, respectively. These long sediment sequences will allow us to examine how North Atlantic thermohaline circulation responded to tectonic changes in the sill depth of the Greenland–Scotland Ridge, as well as other tectonic (e.g. the Isthmus of Panama) and climatic events (e.g. the middle Miocene glaciation of Antarctica) that may have influenced the physical oceanography in the source areas of bottom-water formation.

The sites in the North Atlantic also form a NW–SE surface-water transect (Fig. 2), which crosses the major area of polar front movement on glacial–interglacial (G–I) cycles. Thus, we should be able to compare E–W gradients in surface-water temperature and iceberg trajectories on suborbital time scales, and further improve our understanding of the dynamics of Heinrich events and the even shorter duration Dansgaard–Oeschger events. Likewise, in the Nordic sea, Sites 987, 907 and 985 complete an E–W transect originally begun with Leg 104 Sites 642, 643 and 644. With these sites we will be able to reconstruct the history of the strong climatic gradients in the Nordic seas caused by warm-water inflow (the "Nordic heat pump") in the east. This warm inflow is compensated by outflow of cold, polar waters in the west and cold deep-water outflow across the bottom of the Southern Gateway ridge.

Lastly, with the addition of Site 986 on the Svalbard Margin and Site 987 on the Greenland Margin, the Nordic sea sites are situated to determine the long-term initiation and growth history of the three major regional ice sheets: the Barents Sea Ice Sheet, the Scandinavian Ice Sheet, and the Greenland Ice Sheet.

CORING STRATEGY

Our strategy at most sites was to core three holes to refusal using the Advanced Hydraulic Piston Corer (APC) followed by the Extended Core Barrel (XCB). On the deepest holes the Rotary Core Barrel (RCB) was used. This approach allowed the retrieval of continuous sedimentary records without gaps due to core breaks or drilling disturbance. At every site, interhole comparison of magnetic susceptibility, GRAPE bulk density, natural gamma radiation, and spectral reflectance data permitted the development of continuous composite sequences. Furthermore, as these data were collected and compared in real time, we were able to adjust the coring strategy at each hole to provide maximum recovery of intervals that fell at core breaks in the first or second holes.

Triple APC coring was also necessary to exceed normal ODP sampling density guidelines, and thus to permit ultra-high resolution paleoceanographic studies. At some sites, a 5-cm sample interval will give a temporal resolution of about 300 years. Likewise, triple APC coring provides enough material to generate continuous U-channel sequences with which to study century- to millennial-scale variability in the intensity of the Earth's geomagnetic field, as well as other magnetic properties of the sediments.

Coring began on the Feni Drift located on the southeast flank of the Rockall Plateau, at Sites 980 and 981. We gained time at this site despite APC recovery that was significantly deeper than projected. Using this extra time in addition to time gained by an early departure from Leith, we chose to deepen the next site by about 100 m more than was originally planned. As a result, Site 982 on the Rockall Plateau was drilled by APC and XCB to refusal at a depth of ~610

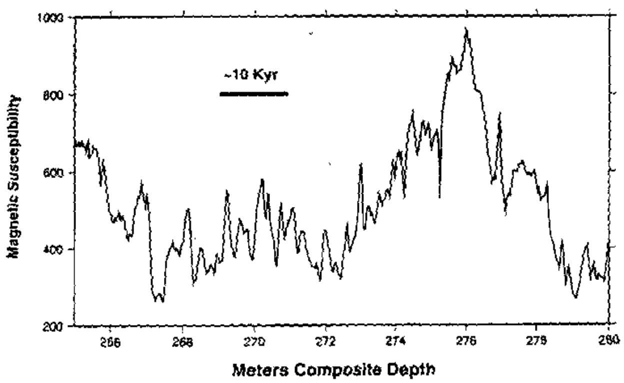

Figure 3. Example of millennial- and suborbital-scale variability on top of longer orbital periods of 40 ky in the magnetic susceptibility of sediments from Site 983. The susceptibility signal reflects changes in mineral input to the site which varies with the state of climate. This interval is from about 1.9 Ma. Depth is based on a composite scale obtained from correlating results from the Site 983 holes.

mbsf. Departing Site 982, with significant time savings, we steamed to a second priority, alternate site that was on our cruise track: Site 983 on the Gardar Drift. We spent about two days recovering three APC holes to approximately 250 mbsf. After coring Site 983, we moved to the nearby Bjorn Drift (Site 984) where we completed our proposed drilling objectives.

After moving north of Iceland, we cored two additional APC holes at Site 907 (907B and 907C) visited previously on Leg 151 (Hole 907A). Following Site 907, we would have proceeded to EGM-4, but for heavy ice cover in that region. As we needed to remain near Iceland to wait for resupplies (i.e. core liners), we elected to drill our second alternate Iceland Plateau site (Site 985). As soon as possible, we proceeded north to Site 986 on the Svalbard Margin. As we were finishing operations at this site, it was apparent that the proposed sites on the Yermak Plateau (including contingency sites) were well within the area of sea ice and hence could not be cored. We thus proceeded to our last target on the East Greenland Margin, Site 987 (EGM-4).

Four holes cored deeper than 400 m were logged on Leg 162: Sites 982, 984, 986 and 987. We typically chose to run the Formation MicroScanner (FMS), the Geological High-Sensitivity Magnetic Tool (GHMT-A), and the Geochemical Logging Tool (GLT) after the Quad Combo. These tools were run in order to measure *in situ* properties characteristic of the lithology such as bedding structures, downhole magnetic susceptibility, and major element abundances, as well as magnetic polarity sequence. The downhole logs are particularly useful in intervals where shipboard measurements were not possible due to a lack of recovery or coring disturbance, and proved to be extremely interesting when combined with discrete physical properties, pore-water chemistry measurements (e.g. see "Site 982" section of "Results"), and seismic stratigraphy. With these data we have also been able to develop synthetic seismograms in order to link the cored sequences to the seismic sequences of the region more directly, an objective that was particularly important on the Svalbard and East Greenland Margins. Likewise, the logging data will allow us to scale the recovered and typically expanded sedimentary sections back to their true subsurface depths.

RESULTS

Overview

One of the most exciting results of this leg is that so many continuous sequences with high sedimentation rates were recovered from areas where major components of the climate system can be monitored. In addition, a complete magnetostratigraphic record from the interval of the Northern Hemisphere Ice Ages was obtained at nearly every site. Sedimentation rates for four of the five North Atlantic drift sites are shown in Fig. 4. Almost all of these sites have upper Pleistocene sedimentation rates greater than 10 cm/ky, and Site 984 has upper Pliocene sedimentation rates in excess of 15 cm/ky. It is clear from many of the records collected that detailed sampling will allow us to investigate changes in surface- and deep-water chemistry and sediment lithology on the time scale of hundreds to thousands of years.

The drift sites are interesting for two reasons. First, these sequences will provide information about the chemistry of water masses in these regions through time by isotopic and trace element analyses. Second, we will also be able to infer paleocurrent velocities through sedimentological analyses. Such investigations will allow us to test the response of thermohaline circulation to climate changes on many time scales and in many different climate regimes.

At all the sites, high-resolution continuous measurements of key lithologic parameters were made, such as magnetic susceptibility and spectral reflectance. Such data allowed development of composite sequences and continuous time series of all parameters with no significant gaps in the triple APC sections. Ground-truthing the cause of variation in these non-intrusively measured parameters will be a high priority for initial shore-based studies. For instance, it appears that spectral reflectance may be a good indicator of carbonate content in the sedimentary sections.

In order to understand the transformation of the Earth's climate system into an ice age world during the Neogene, it is important to identify where and why ice sheets started to form. Data on the inception, variability, and dynamics of these ice masses needs to be assessed for each ice sheet individually in order to understand which areas are the most sensitive to early ice sheet growth. For example, when did glaciation shift from mountain and fjord style glaciation to fully fledged ice sheets, and when did marine-based ice sheets begin to extend to the outer continental shelf? To obtain this information, we cored Sites 986 and 987 close to the Svalbard and East Greenland margins, respectively. These last two sites of Leg 162 were planned in order to core continental margin sediments proximal to major Northern Hemisphere ice sheets: namely, the Barents/Svalbard Ice Sheet in the European Arctic and the Greenland Ice Sheet. With these sequences we will be able to document and date the main phases of glaciation of the respective ice sheets, as well as ground-truth the seismic network used to map the main glacial sequences on the margins. The successful coring of deep holes at both locations was a major achievement of the leg. Shipboard analyses document very different evolutionary histories of the two ice sheets, and provide new insight into similarities in the dynamics of glacial deposition between the two sites. At Site 987, glacial deposits exist throughout the sediment section, suggesting continuous glaciation on Greenland since the late Miocene, with major ice sheet expansion and deposition in the early and late Pliocene. The Barents/Svalbard Ice Sheet appears to be much younger, probably starting in the late Pliocene with major expansion to the shelf break occurring in the Pleistocene.

Finally, at almost every site an interesting discovery was made from the pore-water profiles. A downhole decrease in interstitial sulfate was observed at all sites. This decrease appears to be related to sedimentation rate; that is, greater and more rapid depletions of dissolved sulfate are observed during faster rates of deposition. This decrease may occur because fluxes of organic matter are greater at higher sedimentation rates, or because rapidly deposited sediments may restrict diffusive communication with overlying seawater to relatively shallow depths within the sediment. Besides the reduction of organic matter, the other important process which controls pore-water geochemistry is the alteration of basement rock as well as volcanic material within the sediment column. The degree of depletion in the Mg^{2+} profiles at these sites reflects the age and nature of the basement and the proximity of the site to a volcanic source. Sites 980, 981 and 982 exhibit the smallest Mg^{2+} depletions, reflecting

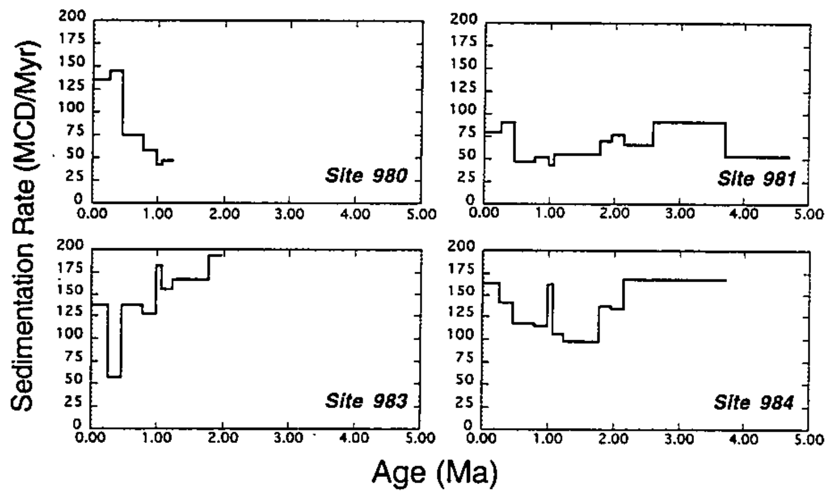

Figure 4. Age vs. sedimentation rates for North Atlantic Drift Sites 980, 981, 983, and 984.

the influence of a rifted continental block (i.e. the Rockall Plateau) and the great distance from a volcanic source. The remaining sites are all located on oceanic basement and many receive significant inputs of volcanogenic sediment from Iceland. High heat-flow at Sites 907 (121°C/km) and 986 (152°C/km) may also contribute to the extent of Mg^{2+} depletion by accelerating reaction rates between interstitial waters and basement (and/or sedimentary volcanic material).

Several of the most unexpected geochemical results are reflected in the dissolved chloride profiles. Dissolved chloride usually behaves conservatively in sediment pore waters, but three of the Leg 162 sites display downhole depletions in chloride concentrations (985, 986 and 987), four show little to no change (907B, 980, 981 and 983), and two sites record downhole increases in chloride (982, 984). Several processes were considered to explain such anomalous chloride behavior: (a) decomposition of methane hydrates (e.g. < 400 mbsf at Sites 982 and 985); (b) hydration (Site 982) or dehydration (e.g. > 400 mbsf in Site 982) of clay minerals; and (c) variable paleosalinity of the ocean (Sites 982 and 985). Additional shore-based work is necessary to test these hypotheses.

Sites 980/981

Sites 980 and 981 are located on the Feni Drift, east of the Rockall Bank, in the northeast Atlantic. The drift was deposited along the northwestern flank of Rockall Trough under the influence of geostrophic currents formed by Norwegian Sea overflow waters flowing across the Iceland-Scotland Ridge and deeper waters originating from the south (including Antarctic bottom water). The excess deposition of fine-grained sediment on the Feni Drift produced expanded sediment sections (> 10 cm/ky) that are ideally suited for high-resolution paleoceanographic studies.

The extremely high sedimentation rates and strong magnetic signal at Site 980 will permit high-resolution studies of paleomagnetic transitions, as well as secular variation in the intensity of the magnetic field. Likewise, these two sites, ~4 km apart, provide a natural laboratory for investigating the effects of sedimentation rate on pore-water chemistry and organic matter preservation. In particular, sulfate reduction appears to be more prevalent in the upper sections of Site 980 vs. 981, with Site 980 displaying approximately 25% higher accumulation rates. Major ion and stable isotopic studies on pore-water samples collected on the ship will be completed on shore.

Site 982

Site 982 (NAMD-1), the site with the shallowest water depth (1145 m), will allow documentation of the evolution of intermediate waters of the North Atlantic during the Neogene. This record will help reconstruct water-mass behavior in the North Atlantic on glacial–interglacial time scales of the Pliocene/Pleistocene, as well as during the middle to late Miocene interval when the Iceland-Scotland Ridge subsided to depths that allowed deep water exchange between the Nordic seas and the North Atlantic. This site should also enable reconstruction of the intermediate water-mass structure of the North Atlantic during the latest Miocene Messinian events. In addition, the recovery of a lower middle Miocene section should document North Atlantic water-mass circulation at times when no North Atlantic Deep Water (NADW) was thought to exist.

Age control for the sequence is primarily based on magnetostratigraphy, and on calcareous nannofossil and foraminiferal biozonation. The magnetic signal is too weak to provide reliable polarity sequences below the Matuyama/Gauss boundary (2.6 Ma) and calcareous fossils provide the primary age control below this boundary. The bottom of the drilled sequence is about 19 Ma, and no major breaks in sedimentation are indicated by shipboard analyses. Sedimentation rates average about 25 m/my for the mid-Pliocene to Pleistocene. Below this level sedimentation rates increase to about 32 m/my.

A sharp horizon was identified at 268 mbsf consisting of a poorly recovered, silicified foraminiferal sand cobble. This horizon, in sediments 7–8 Ma, marks the upper regional seismic reflector of the Rockall Basin (reflector R1). Downhole logs indicate that the silicified material is a 4 m-thick sequence which we tentatively interpret as a turbidite. This silicified layer apparently formed a barrier that dampened or disabled pore-water diffusion, as indicated by distinct differences in pore-water profiles above and below the layer. This apparent lack of diffusion may open possibilities for studying differences in ocean chemistry (especially salinity) before and after the Messinian salinity crisis.

Site 983

Site 983 (GARDAR-1) is located on the Gardar Drift at a water depth of approximately 1995 m on the eastern flank of the Reykjanes Ridge. This is the approximate mid-depth of Glacial North Atlantic Intermediate Water (GNAIW) during the last glaciation. Obtaining a long-term history of this water mass is one of the primary scientific objectives of this site. In conjunction with Sites 980, 981 and 982 to the east, this site will also be used to assess E–W gradients in surface-water conditions as well as to monitor Norwegian–Greenland Sea overflows across the Greenland–Scotland Ridge. In particular, Site 983 lies on the northwest margin of the Iceland Basin directly downstream of overflows from the Iceland–Faroe Ridge. The high sedimentation rates expected (and found) here will provide an unprecedented record of both glacial–interglacial and millennial-scale variations in thermohaline circulation, surface-water temperatures, and ice-rafting history during the late Pliocene and Pleistocene.

Site 984

Site 984 (BJORN-1) is located on the Bjorn Drift at a water depth of approximately 1660 m on the eastern flank of the Reykjanes Ridge. This is within the core of GNAIW during the last glaciation. The major objectives of this site were the same as for Site 983 to the south (see above).

Site 907

The primary objective of drilling operations at Site 907 was to recover an undisturbed pelagic sedimentary sequence with carbonate and IRD records. Shore-based studies of the one hole cored by Leg 151 at Site 907 in 1993 provided a reliable stable isotope record of the last 1 Ma, and a record of IRD back to more than 7 Ma. Given that a detailed paleoclimatic record can be extracted from these sediments, we wanted to return to this site and finish the planned triple coring to provide a complete and undisturbed high-latitude section for much of the Neogene. Thus, the site was reoccupied by Leg 162 and two additional holes were cored (Holes 907B and 907C).

High-resolution shipboard multisensor track (MST) data allowed us to combine the MST records from Legs 151 and 162 to generate a spliced composite section. We were thus able to fill in recovery gaps over core breaks in Hole 907A and will now be able to complete the high-resolution paleoclimate studies begun on Leg 151.

Site 985

Site 985 (ICEP-3) is located on a gentle slope of the Iceland Plateau, at a water depth of 2799 m, and is part of the paleoenvironmental transect with Sites 907 and 987. The site was a second-priority site for Leg 162, and was cored due to operational constraints which required our staying in the vicinity of Iceland. With the recovered sequences we intend to (a) monitor the history of oceanic and climatic fronts moving east and west across the Norwegian Sea, (b) derive an open-ocean record of IRD and carbonate accumulation, and (c) document the history of formation of northern-source deep waters.

Site 986

Site 986 (SVAL-1B) was drilled on the Svalbard Margin to examine the onset of glaciation in the European Arctic and establish the history of the Svalbard–Barents Ice Sheet, including a probable transition from a terrestrial to marine-based ice sheet in the Barents Sea. Four holes were cored with a maximum penetration of 964.6 mbsf. The sequence penetrated all the main regional seismic reflectors (R1–R7) of the Svalbard–Barents Sea margin, with good ties to the reflectors and main seismic sequences from core physical property measurements and wireline logging. These data will allow us to document the main phases of glacial erosion and deposition on the margin. The sediments recovered are predominantly fine- to coarse-grained siliciclastics with varying amounts of gravel. Dropstones (> 1.0 cm in size) are abundant in most cores of the upper sedimentary sequence (0–561.8 mbsf). Sedimentary rocks are common throughout this sequence, whereas igneous and / or metamorphic rock fragments are more common in the interval from 380–550 mbsf. Over 500 dropstones greater than 1.0 cm in size are present from 2.58 mbsf to 845.3 mbsf.

High methane content in the rapidly deposited sediments and a high dropstone content led to variable recovery. However, all main seismic units are documented by recovery, and important additional information from wireline logging of the upper 500 m of the sequence enables a comprehensive description of the formations.

Although age constraints are relatively uncertain throughout the sedimentary sequence, sedimentation rates at Site 986 appear to have remained between 160 to 360 m / my from the Pliocene to Holocene. Foraminifer and calcareous nannofossil evidence indicate an age between 3.6 and 2.4 Ma for the sequence below 700 mbsf, whereas a dominant reversed magnetization in the lower sequence may indicate an even younger age. The shipboard results suggest that the fan buildup on the Svalbard Margin happened in the Pliocene–Pleistocene due to glacial erosion / deposition. A major shift in glacial style and ice sheet size took place in the Quaternary, and is characterized by the onset of excessive debris-flow sedimentation, which probably originated from ice sheets grounded at the shelf break. Debris flows are more conspicuous and thicker during the initial phase of this development than those flows during the later stages.

Methanogenesis occurs as shallow as 20 mbsf at Site 986 due to the high sedimentation rates. High methane content prevails throughout the section with higher-mass hydrocarbons becoming more abundant with burial depth. A low salinity level at about 50 mbsf indicates that methane clathrates may be decomposing, whereas a strong reduction in chlorine content and salinity below 400 mbsf may be attributed to dewatering of clays due to high heat flow. Downhole temperature measurements and shipboard thermal conductivity measurements documented a higher heat flux at the site than previously anticipated.

Site 987

Five holes were cored at Site 987. Maximum penetration was 859.4 mbsf, which is estimated to be within a few meters of the oceanic basement. All major seismic sequence boundaries were penetrated, and there was overall good recovery. Despite gas expansion problems in the upper few hundred meters of the section, offsets between holes could be determined for approximately the upper 180 mbsf, and a continuous spliced section was produced for the upper 100 mbsf (approximately the last 1 Ma). Paleomagnetic data provided time control, which enabled detailed documentation of the glacial history of the Greenland Ice Sheet back to the late Miocene. Biostratigraphic age information is scarce due to the predominance of intervals lacking microfossils. The recovered sediments are mostly fine- to coarse-grained siliciclastics. Evidence of glacial depositional environments prevails throughout the recovered section.

Turbiditic downslope sediment transport seems to have been an important sedimentary process during the Pleistocene and late Pliocene at this location. Units II (upper Pliocene) and IV (lower Pliocene) are very similar, and appear to have originated from gravity-driven debris flows. Units III (lower to upper Pliocene) and V (lower Pliocene to upper Miocene) appear to have a higher component of hemipelagic deposition with less downslope sediment transport than in Units I, II and IV.

The high deposition rates at this site are reflected by the change from sulfate reduction to methanogenesis at shallow burial depth (30 mbsf). Methane content as high as 68,000 ppm was observed at 74 mbsf, and it decreased somewhat downsection. No evidence for gas hydrates was found, and natural gas profiles reflect normal biogenic processes. The organic matter content is variable, primarily reflecting marine organic matter with low C/N ratios.

The seismic stratigraphy, lithostratigraphy, sediment physical properties, and wireline logging results at Site 987 reflect variations in the frequency and amount of gravity-driven sediment transport from the East Greenland Shelf, which is in accordance with the site being located on the northeastern flank of the Scoresby Sund glacial fan. Intervals of more frequent debris flows form the most distinct seismic reflectors. Results of the shipboard paleomagnetic studies indicate a late Miocene age for the lowermost cored sediments immediately above basement. A main result of coring at Site 987, based on the paleomagnetic data, is that new and younger ages than previously proposed can be assigned to the main buildup of the Scoresby Sund Fan. The main phase of fan construction took place in the late Pliocene to Pleistocene. Although glacial marine deposition and downslope transport is characteristic of most of the drilled sequence, two phases, one in the early Pliocene and another in the late Pliocene, are the most noticeable intervals of thick debris-flow deposition, presumably from an ice margin at the paleo shelf break.

Science Operator Report Leg 163

SE Greenland Margin

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ABSTRACT

ODP Leg 163 was the second of two drilling legs to the Southeast Greenland margin to core a sequence of subaerially erupted basalts associated with continental breakup that occurred in the early Tertiary. Together with Leg 152 this program addressed the nature of rifting and breakup at this rifted continental margin and, in particular, assessed the impact of the Iceland mantle plume on breakup and early spreading. These investigations build on earlier DSDP and ODP drilling of seaward-dipping reflector sequences (SDRS) on the Rockall and Vøring Plateaus (Legs 81 and 104), with these SDRS occurrences and associated extensive subaerial exposures of Tertiary basalts on Greenland, the Faeroe Islands, and the western British Isles collectively forming the North Atlantic Volcanic Province. Principal results are as follows:

(1) completion of the record of volcanic evolution of the East Greenland margin at latitude 63°N, from continental breakup to oceanic crustal production;
(2) fundamental constraints on the age of SDRS volcanism, from preliminary identification of the first two magnetic polarity reversals yet discovered in the East Greenland SDRS; and
(3) the identification that the Iceland plume mantle component is more strongly expressed in the composition of the basalts at latitude 66°N compared with 63°N.

The third result, together with previous evidence from DSDP Leg 81 and ODP Leg 104, provides sufficient information to map the basic compositional structure of the mantle melting regime that existed during the initiation of the Iceland plume and breakup of the North Atlantic.

INTRODUCTION

Strategy

The Southeast Greenland margin is a type example of a volcanic rifted margin. The margin is characterized by a broad seaward-dipping reflector sequence (SDRS) composed of basalt that onlaps continental (mainly Precambrian) crust to the west and terminates eastward in oceanic crust of early Tertiary age (Figs. 1, 2). In the Northeast Atlantic, seafloor-spreading anomalies 24n–24r are the oldest identified pair of anomalies. Anomaly 24n is developed off Southeast Greenland as a double-peaked anomaly, reflecting the three short positive events C24n.1 through C24n.3 and relatively high spreading rates during this interval (approximately 3 cm/yr.half-rate).

The minimum age of the Southeast Greenland SDRS is constrained by the seaward occurrence of well-developed seafloor-spreading anomalies (Fig. 1). In the north, close to the Iceland–Greenland Ridge, the SDRS extends seaward to chrons C22n–C21n (49–47 Ma). However, most of the Southeast Greenland SDRS is found landward of and is older than C24n.1 (53 Ma; Cande and Kent, 1992). Weak and semilinear magnetic anomalies are present over the main SDRS and may represent either low-amplitude anomalies older than C24n (e.g. C25n–C27n, 56–61 Ma) or short magnetic events within C24r.

Evidence for significant magmatism and tectonism during continental breakup is not restricted to the offshore areas. A coast-parallel dike swarm and associated seaward flexuring of the crust one present from 63°N along the east Greenland coast and northward. Within this zone, gabbroic and syenitic intrusions are present (Fig. 1) and locally associated with basaltic lavas overlying thin sediments. Farther north, a much more extensive and thick flood-basalt province is preserved (Fig. 1). Comprehensive studies of the onshore region are being conducted in parallel with ODP drilling and will be augmented in 1996 with a program of deep crustal seismic imaging that includes the region. In particular, ODP drilling and field geological studies will aim at correlating the on- and offshore parts of the crustal flexure zone and the volcanic stratigraphy within the two areas.

Drilling was positioned along two margin transects, located distal (Legs 152 and 163) and proximal (Leg 163) to the Iceland plume center. The two transects were named EG63 and EG66, respectively, in reference to their approximate latitudes. At each transect, drilling was targeted at the pre-rift crust, the breakup unconformity and earliest volcanism, the transition from initial continental volcanism to ocean crust volcanism, and, most seaward, a reference hole in steady-state spreading crust. This drilling strategy was designed with two primary objectives:

(1) investigation of the development with time along each transect would tell us about the progressive weakening of the continental crust and the associated magmatic development;
(2) the study of magmatic development and the magma source at different offsets from the Iceland plume would enable us to evaluate possible radial zonation in the original plume structure.

Additional reference points for the second objective are provided by the earlier DSDP Leg 81 drilling at the Hatton Bank margin (most distal southern offset) and ODP Leg 104 drilling at the Vøring margin (intermediate northern offset).

Geophysical Database

Legs 152 and 163 were based on a large set of seismic data over the Southeast Greenland margin (Fig. 3). The database comprises three different sets of seismic data: (1) regional to detailed grids of shallow, high-resolution multichannel seismic (MCS) data; (2) a regional grid of deep 7-s (two way traveltime, TWT) MCS data; and (3) deep 14-s (TWT) MCS data. In addition, aeromagnetic and regional marine gravity data exist.

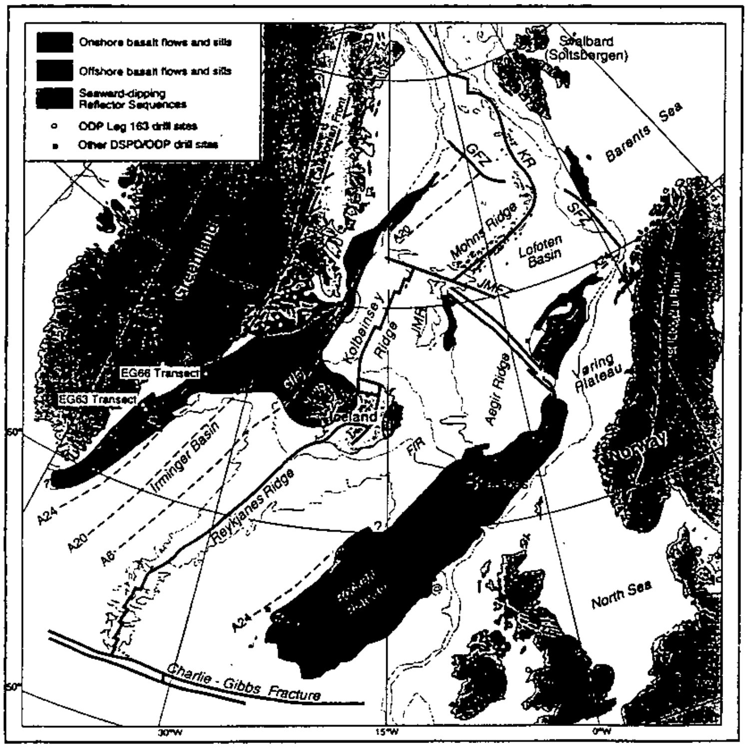

Figure 1. Geological map showing the distribution of seaward-dipping reflector sequences and continental flood basalts of the North Atlantic Volcanic Province. ODP and DSDP drill sites along the volcanic rifted margins of the North Atlantic are shown. Subaerially erupted basalts show flood basalt structure landward of the inferred continent/ocean boundary and have a SDRS structure seaward of the boundary. The part of northwestern Iceland that shows an SDRS-like structure is included. Note that the spreading history of the Iceland Plateau north of the GIR (Greenland–Iceland Ridge) is different from that south of the GIR. In the young crust north of the GIR, the typical SDRS structure is not continuously present and extends to a depth of only about 2 km. However, below the GIR itself, the SDRS may attain a thickness of 10 km.

Leg 152 Results and Implications for Leg 163

A number of important observations made during Leg 152 drilling into the Southeast Greenland SDRS significantly affected the detailed planning of Leg 163. These include the following: (1) highly tilted to subvertical pre-rift sediments occur below the inner part of the SDRS; (2) an early, continentally hosted and contaminated basaltic to andesitic volcanism of 61–62 Ma overlies these sediments; (3) the upper limit of these lower lavas is a sharp transition – possibly a hiatus – into picritic to tholeiitic lavas followed by basalts of a rather uniform composition that resemble depleted tholeiites from Iceland and appear to make up the main part of the SDRS; and (4) all recovered igneous units were erupted subaerially. Thus, Leg 152 confirmed that the SDRS is a wedge of predominantly basaltic material extruded subaerially in accord with the model for crustal accretion in Iceland and with the interpretation of seismic data.

The Leg 152 findings imply the presence of a rapid transition from continental to oceanic crust below the inner part of the SDRS. During formation of this continent to ocean transition, pre-rift sediments were deposited in a basin of unknown width and, later, in a zone close to the final line of breakup, subjected to faulting and crustal extension, uplift and erosion prior to volcanism.

The Leg 152 data are deficient in a number of aspects. These include a lack of suitable material for age determination of the oceanic succession (i.e. the main part of the SDRS), non-continuous sampling of the transition from initial picritic to depleted tholeiitic volcanism within the oceanic succession, and non-recovery of the oldest part of the continental volcanic succession. In addition, the pre-rift sediments were poorly sampled because of their subvertical orientation, and they have been too strongly metamorphosed to yield any age-diagnostic fossils or palynomorphs.

Leg 163 was planned to overcome these deficiencies within the southern EG63 transect, as well as to sample the breakup and early seafloor spreading volcanism in a more proximal position to the proposed Iceland "hot spot" track along the northern EG66 transect. The faint signature of the Iceland plume in the Leg 152 rocks suggests that a stronger plume imprint could be present at this location closer to the former plume axis, which, if true, would indicate a radial zonation within the original plume structure.

Integration of observations from drilling, field geology, and geophysics on crustal structure and deformation, timing of volcanism and the involvement of Iceland plume material in the breakup process eventually will enable a critical review of current models of plume structure and the impact of mantle plumes on the process of continental breakup.

Drilling Plan

In order to meet the main objectives, a total of six first-priority sites was planned for the two transects. Three sites were planned for the innermost part of the EG63 transect. Two sites were targeted to increase the sampling of the pre-rift crust and oldest volcanic cover, and one site was to deepen Site 915 in order to provide stratigraphic overlap with Site 917 (Figs. 2, 3). Three sites were also planned for the northern EG66 transect. The two sites within the innermost part had objectives roughly similar to the inner sites of the EG63 transect, although less ambitious in terms of stratigraphic coverage. The additional seaward site was planned in SDRS-type oceanic crust of Anomaly 22 age (i.e. in steady-state accreting Icelandic-type oceanic crust).

Changes in the Drilling Plan Imposed by Drilling Problems and Weather

Damage to the ship sustained during shallow-water coring and extreme storm conditions reduced the scientific drilling operations at Leg 163 to less than half of the planned program. Recoil from a break in the drill pipe on 10 September 1995 damaged the top-drive assembly after only one day of drilling at the first, shallow-water site. A port call to Reykjavik, Iceland, was made in order to make the necessary repairs. Permission to drill in water depths shallower than 300 m was temporarily withdrawn by ODP/TAMU, pending review of safety procedures and the delivery of supplemental drilling hardware. Operations therefore resumed at the deeper water sites along the southern EG63 transect on 16 September. Drilling progressed, though with interruptions, because of heavy seas and icebergs drifting across the drill sites, until 29 September.

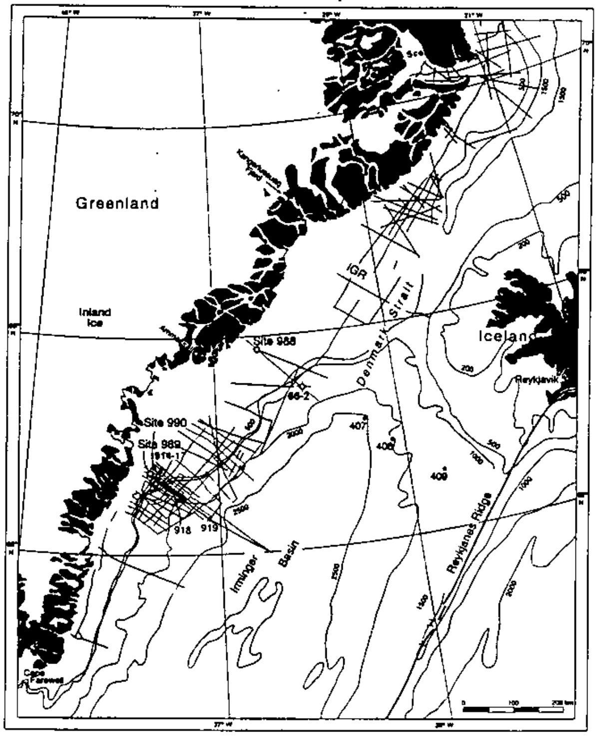

Figure 2. Seismic track map and regional bathymetry. Previously drilled holes and Leg 163 drilled sites and planned sites are shown. Ice-free, subaerial bedrock outcrop is stippled.

Extreme hurricane conditions built rapidly through the night of 29 September. Several times the NNE wind exceeded 100 kt, and it remained at hurricane force for at least 26 hr. By the morning of 30 September, the ship was being battered by short-period, 60–70 ft high waves, and she was unable to maintain position without risking severe damage. The ship's bridge took water through a broken window, which caused both radars to fail and threatened the computers for the dynamic-positioning system. Numerous thrusters were mechanically damaged or became inoperable because of flooding. In spite of reduced manoeuverability, the ship was able to maintain heading in the wind and sea while it was being forced south at a speed of up to 4 kt. While drifting in this manner, there was an increased potential of colliding with icebergs. When the storm abated to gale force on 1 October, the ship was turned to the south and the transit to Halifax, Nova Scotia, for repair was started.

At this point, major repairs and a thorough examination of the ship's structure and systems were needed. This ruled out the possibility of further drilling operations during Leg 163. As a result of these untimely events, only three of the planned six sites were occupied.

RESULTS

Site 988

Site 988 is located 56 km east of the East Greenland coast, within the northern drilling transect EG66 (Figs. 2, 4). The site was selected to penetrate deeply into the feather-edge of the SDRS that overlies the transition zone between continent and ocean crust. The primary drilling objectives at this site were to determine the composition, age, and eruption environment of the SDRS in a position close to the Iceland–Greenland Ridge for comparison with the distal SDRS cored during Leg 152.

Lithologic Unit I is a thin layer (0–10 mbsf, estimated from seismic profiles and the drillers' log; 0.4 m recovered in Core 163-988A-1R) of Quaternary(?) glaciomarine sediments, including rounded cobbles of gabbro, white and pink fine-grained granite, dark gray to black aphyric basalt, and gneiss. The compacted diamicton recovered at Leg 152 Sites 914 through 916 (Figs. 2, 4) to the south is absent at this site. The glaciomarine rocks unconformably overlie basaltic basement (igneous Units 1 and 2) at about 10 mbsf.

Two flow units were recognized in the core recovered from the interval 10–32 mbsf. Igneous Unit 1 is a dark, greenish-gray, plagioclase-pyroxene-olivine-phyric basalt. The upper contact was not recovered, but the lower contact is preserved in Section 163-988A-5R-1, (Piece 10); the thickness of the unit is between 19 and 21 m. The unit has a massive aspect and is sparsely vesicular; the vesicles are filled with smectite/saponite and some contain the zeolite chabazite. The glassy groundmass and the majority of the sparse olivine phenocrysts have been replaced by brown smectitic clay. Other phases are unaltered. Igneous Unit 2, of which only 90 cm was recovered from the interval 29 to 32 mbsf is, by contrast, highly to completely altered, with relict clinopyroxenes in a clay matrix. Texturally, this unit appears to represent the top of a fragmental, perhaps scoriaceous, basalt flow top. Shipboard X-ray fluorescence (XRF) data show that both units have high Nb/Zr (0.12) and Ce/Y (1.2), identical to Tertiary basalts from Iceland (Fig. 5). The low Ni content and low Mg# of Unit 1 (about 74 ppm and 0.50, respectively) are consistent with the evolved three-phase phenocryst assemblage of this basalt. Both units were most likely emplaced as lava flows, but the absence of an upper contact in Unit 1 means that we cannot eliminate the remote possibility that it is a sill. The highly oxidized aspect of Unit 2 is consistent with emplacement as a flow in a subaerial environment.

The basalts at Site 988 are subhorizontal to gently dipping, and show only modest amounts of brittle deformation. Subhorizontal magmatic flow-banding is noted locally. Subhorizontal calcite-filled veins occur at a spacing of 0.5–1.0 m. Joints and veins filled by calcite and clay were also found in a subhorizontal and subvertical bimodal distribution. An alteration halo around one subvertical fracture was noted.

Paleomagnetic data for the Site 988 basalts were obtained from the archive-half sections of Cores 163-988A-1R through 5R using the shipboard cryogenic magnetometer. The initial natural remanent magnetization (NRM) intensity of the core was between 5 and 10 A/m. Demagnetization of each section by up to 30 mT removed a steep downward-dipping remanence, possibly acquired by drilling, and reduced intensities to 5–10% of initial values. The core has a consistent reversed polarity with two exceptions. One interval (section 163-988A-1R-2, 5–55 cm) of apparent normal polarity occurs within what appears to be a single thick flow. As this is an unlikely occurrence, we conclude that two pieces of core were inverted during labelling and splitting. Another interval of normal polarity is located in the highly altered clay-rich flow top material of Unit 2 present near the bottom of the last section (section 163-988A-5R-2, 0–10 cm). The magnetic orientation of this material was probably affected by the high degree of secondary alteration observed or possibly by the drilling process.

Measurements of index properties from minicores yielded an average bulk density of 2.907 g/cm^3, an average grain density of 2.969 g/cm^3, porosities of 10% or less, and P-wave velocities from 4.94 to 5.73 km/s for igneous Unit 1. P-wave velocities measured directly in the working half of the split core increase downcore through Unit 1, from values of 5.5–5.7 km/s at the top of Unit 1 to 6.0 km/s near its base. An intermediate level (26.14–26.18 mbsf) with unusually high velocities appears to correlate with flow banding observed at that level (Section 163-988A-4R-1,Piece 5, 32–38 cm). The highly vesicular, fragmented, altered basalts from Unit 2 were not measured.

Site 989

Site 989 is located 23 nmi east of the East Greenland coast. It is one of the three drill sites planned for the southern drilling transect EG63 (Figs. 2, 4). Drilling at Leg 152 Sites 915 and 917 had penetrated a thick lava sequence that recorded development from an early continental crust-contaminated volcanism, through transitional picritic and tholeiitic volcanism contemporaneous with breakup, into steady-state oceanic volcanism. Site 989 was selected to penetrate and sample the very oldest lavas of the SDRSs that overlie the breakup unconformity and underlying, layered pre-rift crust. The primary drilling objectives at this site were to (1) determine the stratigraphy, composition, age, and eruption environment of the volcanic rocks above the breakup unconformity; (2) determine the nature and age of the breakup unconformity; and (3) determine the nature and deformation of the continental basement and/or pre-rift sediments beneath the volcanic sequence.

Lithologic Unit I is a thin layer (0–4 mbsf) of Quaternary(?) glaciomarine sediments unconformably overlying basaltic basement (igneous Units 1 and 2). The only material recovered consists of discrete rock fragments, including gneiss, aphyric basalts/metabasalts, quartzite and dolerite. The lithologies of these clasts are consistent with an ice-rafted origin, even though no finer-grained matrix was recovered. The relatively weak nature of the sediments recovered at Site 989 suggests that these are glaciomarine deposits, rather than overcompacted glacial tills.

Two igneous flow units were recognized in the core recovered from the interval 4–84 mbsf (Hole 989B). From seismic data, these are interpreted to lie stratigraphically below the lavas drilled at Site 917 and represent the oldest part of the SDRS. Igneous Unit 1 is at least 69 m thick, the thickest lava flow yet reported from an SDRS. It is notable for its constant grain size, constant vesicularity, high mesostasis content, and repeated bands showing quench textures. These features indicate rapid cooling during solidification throughout the lava flow. We interpret Unit 1 as a compound lava flow consisting of numerous individual flow units 0.1–10 m thick. The large number of thin flow units, together with the absence of sharp flow contacts, may indicate both (1) proximity to the eruptive vent and (2) rapid eruption of the entire lava flow. The observed decrease in maximum flow unit thickness upward in the lava may reflect an exponentially diminishing eruption rate with time.

Unit 1 is essentially aphyric. The groundmass consists of plagioclase, augite, magnetite, trace olivine, and mesostasis. Clay alteration is total for both mesostasis and olivines, whereas plagioclases and augites are generally fresh. The textures vary between two extremes: (1) a very fine-grained rock with quench textures of spherulitic, acicular, and skeletal plagioclases (and sporadic augites) within a vesicular and mesostasis-rich matrix; and (2) a "normal" fine-grained intersertal, intergranular to variolitic and sub-ophitic rock with large disseminated vesicles (up to 20% and up to 4 mm across). The transition between quenched and normal textures may be sharp (internal flow boundaries) or gradational.

Igneous Unit 2 is porphyritic with phenocrysts of plagioclase, augite, and trace olivine in a very fine-grained matrix. Olivine phenocrysts occur as individual disseminated grains that are now totally altered to clay. Plagioclase and augite phenocrysts are fresh, commonly strongly zoned and resorbed (plagioclase), and in glomerocrystic clusters. The groundmass has a seriate texture defined by microphenocrysts of very elongate plagioclases (4–5% of groundmass). Stubby olivines (trace to 2%) and anhedral augites (<1%) also form microphenocrysts. The groundmass (up to 0.2 mm grains) consists of plagioclase laths, equant augites, euhedral to skeletal magnetite, and mesostasis in an intersertal/intergranular to variolitic texture.

The two units recovered at Site 989 are both strongly depleted in a number of incompatible elements such as Zr, Nb, Ti and P, and presumably melted from a depleted mantle source (Fig. 5). Both lava flows are composed of evolved basalt, which implies storage in a magma chamber underlying this part of the volcanic succession. Similar crustal magma chambers were invoked for the lavas in the Lower Series at Site 917, which have assimilated a Sr- and Ba-rich

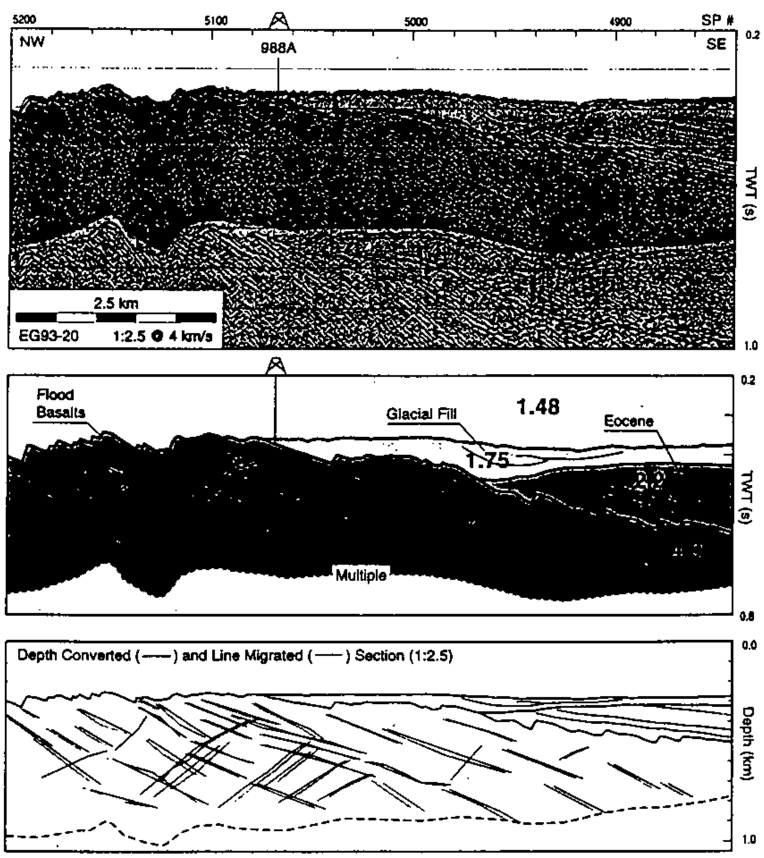

Figure 3. Seismic cross-section through Site 988 (top). Interpretations shown in line drawing (middle) and migrated section (bottom). The Eocene age of the postrift sediments is inferred through correlation with the EG63 transect. Seismic velocities used in the depth conversion and migration are in km/s.

crustal component. The low Sr and Ba contents in the Site 989 lavas preclude a direct correlation with the Lower Series in Site 917. In contrast, the lavas at Site 989 have either escaped crustal contamination or have assimilated a crustal component very different from that which contaminated the lavas in Site 917.

Physical property measurements (P-wave velocity, bulk and grain densities, porosity) of Unit 1 are quite constant with depth and correlate well between the holes. The transition from Unit 1 to Unit 2 is clearly recognized, with average P-wave velocity increasing from 5.2 to 6.0 km/s, density increasing from 2.8 to 3.0 g/cm^3, and porosity decreasing from 12% to 2%. The 3% average reduction between P-wave velocity measurements performed on minicores vs. half-rounds may be due to drilling-induced fracturing of the outer edges of the cores.

Deformation of the cored sequence at Site 989 is principally in the form of brittle fracturing, manifest as veining and jointing. Veining is commonly present as two conjugate sets, one postdating the other, but both infilled with a combination of green clays and zeolites. Measured dips within Unit 1 for flow banding and other forms of textural variation, such as vesicular layers, are scattered but are concentrated between 15° and 45°. These features are interpreted to be chilled surfaces of flow units within a compound flow.

Unit 1 recovered in both holes appears to carry a normal magnetic polarity with a mean inclination of 68.4°. If confirmed, this will be the first flow of normal polarity reported from the East Greenland margin, and current stratigraphic evidence correlates this normal event with Chron C27n. Unit 2 appears to contain both normal (top) and reversed polarity. The top part of the flow was possibly remagnetized during the emplacement of the normally magnetized Unit 1. All discrete samples from Holes 989A and 989B sections, demagnetized to 80 mT and measured on the cryogenic magnetometer, carry normal polarity. Discrete samples from the lower part of Unit 2 contain reversed polarity. Confirmation of the magnetic polarity must await further alternating field and thermal demagnetization studies on shore.

Site 990

Site 990 is located 28 nmi east of the East Greenland coast, within the southern drilling transect EG63. It was one of three drill sites planned to complete the stratigraphic sampling of the earliest volcanism along this margin (Figs. 2, 4). The site was located at the position of previous ODP Site 915 in order to penetrate more deeply the lava succession to test the hypothesis that Iceland-type oceanic crustal accretion and steady-state production of Iceland-type tholeiites were initiated within this stratigraphic interval. Another important objective at the site was to sample material suitable for precise radiometric and magnetostratigraphic age determinations in order to assess the magnitude of a suspected hiatus in volcanic activity, located between the Middle and Upper series lavas at Site 917.

Because the sedimentary section had been cored at Site 915 during Leg 152, Site 990 was washed to a depth of 182.0 mbsf and rotary cored below that level. Sediments were recovered in the interval 182.0–202.3 mbsf and subdivided into two lithologic units. According to ODP convention, these two units are termed lithologic Unit I and lithologic Unit II, even though data from Site 915 indicate that the material above 182 mbsf probably forms two additional lithologic units. As a result, we correlate lithologic Units I and II at Site 990 with lithologic Unit III at Site 915. The ages of both Site 990 units are unknown, but the ages of the overlying sediment and underlying basalt at Site 915 suggest an early Eocene age.

Lithologic Unit I is a calcite-cemented mixed-cobble conglomerate, dominated by clasts of altered basalt, gabbro, and dolerite; quartzite and siliciclastic siltstone form the remainder of the cobbles. The cobbles are generally rounded to well rounded and range in size from 4 to >12 cm in diameter. The matrix is a poorly sorted silty sand, with angular grains, sand-sized mudstone intraclasts, and calcite cement.

Lithologic Unit II directly overlies basalt and is a clayey volcaniclastic

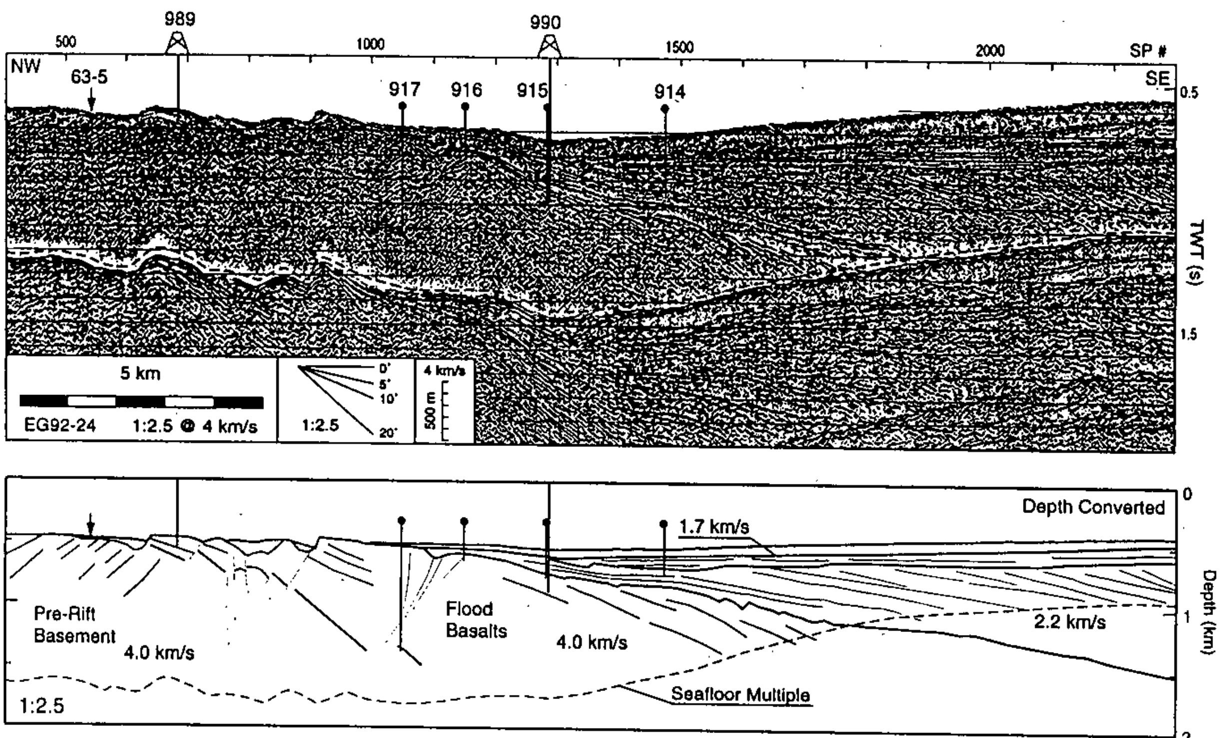

Figure 4. Seismic cross-section through Site 989 (top). Interpretations shown in line drawing (middle) and migrated interpretation (bottom). Steeply dipping to subvertical pre-rift sediments were encountered in the rotated fault block located below the lava sequence at Site 917. Seismic velocities used in the depth conversion and migration are given in km/s.

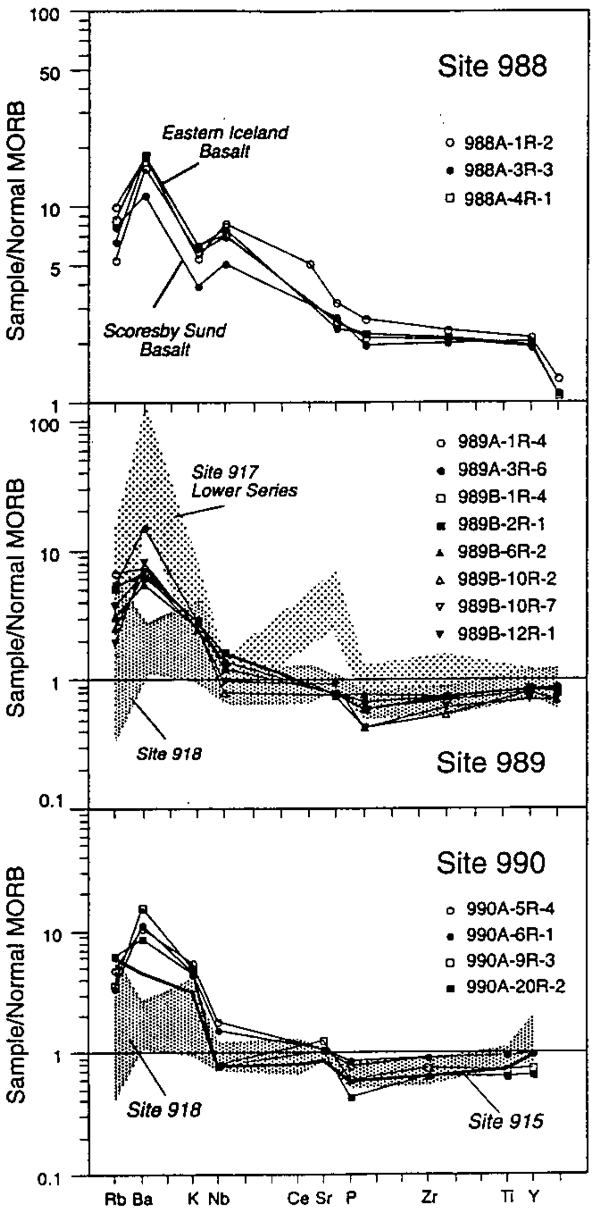

Figure 5. N-MORB normalized minor-element and trace-element spidergrams of cored basalts from the SDRS along the EG66 transects (Site 988) and EG63 (Sites 915, 917, 918, 989, and 990). The Site 917 data include only samples with 6–9% MgO; samples with high Nb/Zr were also excluded. The Site 990 lavas are virtually identical in composition to lavas recovered from Site 918, 72 km farther offshore and in the center of the seaward-dipping reflector sequence. This observation implies that seafloor-spreading-type magmatism was established soon after breakup of the continental margin (represented by the Site 917 Upper Series). The Site 988 lavas are considerably enriched in the incompatible elements compared with those from the EG63 transect. The Site 988 lavas are about 300 km closer to the GIR than lavas from the EG63 transect and are similar to Tertiary basalts from Iceland and Scoresby Sund, East Greenland. The offset from the Iceland plume and its palaeoposition (GIR), at which we observe this marked enrichment are similar to that mapped by DSDP Sites 406–408 (Fig. 2) and along the Reykjanes Ridge. This observation suggests that the generation of enriched, Iceland-type tholeiites has been limited to about the same (~200–300 km) offset from the center of the Iceland hot-spot since the inception of rifting and ocean floor formation.

breccia, dominated by basaltic debris. Clasts in the breccia are altered basaltic material. The matrix of the breccia is dominated by clay and iron oxides, probably derived from the alteration of basaltic material, and minor well-rounded silt to fine sand-sized quartz grains. The presence of poorly developed flow indicators, the repeated vertical changes between clast-supported and matrix-supported fabric, and the absence of macroscopic pedogenic features indicate that Unit II was deposited by a moving fluid, such as a matrix-rich debris flow, after a limited distance/energy of transport. The large size and the rounding of the clasts in lithologic Unit I suggest that this unit was deposited in a high-energy environment, possibly a high-gradient stream, a shallow, wave-influenced marine setting, or a fan delta. Additional sedimentary material, apparently untransported, was recognized as red, brecciated to clayey material on the tops of flow units within the basalt basement. This material has been described as part of the igneous sequence, but reflects *in situ* alteration and soil development.

Thirteen flow units were recognized in the core recovered from the interval 212–325 mbsf, on the basis of changes in the phenocryst assemblage or the presence of weathered and/or vesicular flow tops. Lava flows fall into one of three types: aa, pahoehoe, and transitional. Pahoehoe flows dominate in the lower part of the drilled sequence, whereas aa flows are ubiquitous in the upper portion. The top of the volcanic section at this site (and the previously drilled Site 915) is deeply weathered and oxidized, indicating that eruption occurred subaerially with some time gap between successive flow units.

Flow units cored at Site 990 range from aphyric to highly olivine or plagioclase-olivine-clinopyroxene phyric basalt. The olivine content decreases upward in the section, whereas both grain size and flow thickness increase upward. There is a subtle but systematic compositional variation in trace-element contents from the base to the top of the sequence (i.e., decreasing Cr and Ni and increasing V, Nb, Zr and Y). In general, the lavas are moderately evolved, with low trace-element abundances, and geochemically similar to the one unit recovered from Site 915 and all units at Site 918 (72 km to the east; Fig. 5). No lavas similar to the Upper Series units cored at Site 917 (3 km to the west) were found, indicating that the transition from the breakup-related series to the Iceland-type tholeiitic series that dominates the oceanic SDRS is abrupt and occurs over a stratigraphic interval of <100 m.

The basaltic rocks recovered at Site 990 exhibit numerous planar, primary magmatic features that consist of vesicular layers, elongated patches of filled vesicles, and widely developed diffuse, thin flow bands. Many of these magmatic features occur in an almost horizontal attitude. The only evidence of deformation consists of a relatively dense network of veins and, to a lesser extent, of fractures, some of which show the development of slickensides. The veins, usually 1–2 mm thick, are commonly lined and filled with green clay. Other minerals less commonly seen in veins include zeolite minerals, carbonates, native copper and gypsum.

Paleomagnetic data for the Site 990 basalts reveal a magnetic reversal between the upper two normally magnetized flows and the lower 11 reversely magnetized flows. Integration with Leg 152 results suggests that the normal polarity interval may be correlated with either magnetochron C25n or C26n and the underlying reverse polarity interval with C25r or C26r. The discovery of normal polarity intervals, together with results from future radiometric dating, offers the promise of a precise chronology for East Greenland margin volcanism.

Measurements of index properties from half-round cores and discrete minicores correlate with the flow structure. Specifically, P-wave velocities and bulk densities vary from 2 km/s and 2.3 g/cm^3 in altered, vesicular flow tops to 6 km/s and 3.0 g/cm^3 within the central, more compact portions. From the high rates of recovery and detailed sampling, it is apparent that the often reported differences between velocity and density measurements on discrete core samples and estimates derived from seismic reflection or downhole logging result from preferential recovery of the compact, central flow material. Magnetic susceptibilities range from 100 x 10^{-5} to 5000 x 10^{-5} SI. Thermal conductivity values are similar to those measured at Hole 989B, namely ~2 W/m/K.

CONCLUSIONS

Despite the significant loss of operational time because of environmental conditions, extraordinary recovery of core at three critical sites provided the material to address most of the high-priority objectives of the leg. However, the main tectonic objective of drilling through the breakup unconformity and sampling the pre-rift crust (presumably sediments) was not fulfilled.

The following are the initial, major results of the cruise:

(1) There now exists a virtually complete record of the volcanic evolution of the East Greenland margin at latitude 63°N, from earliest, depleted and continentally contaminated, relatively deeply segregated magmas, through breakup-related picritic and tholeiitic magmas derived by shallower and larger degrees of melting, to a steady-state oceanic magma series.

(2) Preliminary identification of two magnetic polarity reversals, the first ever recorded from the early Tertiary age volcanic materials of East Greenland, and the recovery of fresh, feldspar-phyric flow units suitable for radiometric dating, offer the promise of a detailed and precise time scale for the volcanic activity. This basic chronology will reveal the timing and rates of volcanic and tectonic processes.

(3) The Iceland plume mantle component is more strongly expressed in the compositions of basalts at latitude 66°N compared with 63°N. Together with evidence from DSDP Leg 81 (Hatton Bank, Rockall Plateau) and ODP Leg 104 (Vøring Plateau), we now have sufficient information to map the basic compositional structure of the mantle melting regime that existed during the initiation of the Iceland plume and breakup of the North Atlantic.

Science Operator Report Leg 164

Gas Hydrates

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ABSTRACT

Leg 164 was devoted to refining our understanding of the amounts and in situ characteristics of natural gas hydrate stored in marine sediments. Drilling on the Blake Ridge at Sites 994, 995 and 997 found that finely disseminated gas hydrate occupies a minimum of 1% of the sedimentary section between 200 and 450 m below seafloor (mbsf). Some solid gas hydrate nodules also occur. Free gas is dispersed throughout a zone a few hundred meters thick below the gas hydrate-bearing zone. Coupled with geophysical data indicating that sedimentary gas hydrate occurs throughout a laterally extensive portion of the Blake Ridge, the results of Leg 164 confirm that enormous amounts of methane are contained in these sediments.

Sites 994, 995 and 997 were drilled to 700–750 mbsf on the Blake Ridge and penetrated through the predicted depth of the bottom-simulating reflector (BSR) into the sediments below. The Blake Ridge sediments consist largely of a monotonous sequence of nannofossil-rich clays that were deposited from contour currents at rates varying from 40 m/My in the Pleistocene to 150–350 m/My for the Miocene–Pliocene sequences. Minimal compositional or facies changes occur near the depth of the BSR (~450 m). Cores from all three sites are very gassy and underwent vigorous expansion, which resulted in low recovery. Some nodules of hydrate and one massive gas hydrate zone greater than 30 cm thick were recovered. Decomposition experiments on gas hydrate samples yielded volumetric ratios of gas to water of 130–160, and demonstrated that the gas filling the hydrates was ~99% methane. As anticipated, the ephemeral nature of gas hydrate under surface conditions made sampling difficult. Therefore, emphasis was placed on proxy sampling and downhole tool measurements that allow the in situ conditions of the gas hydrate to be reconstructed.

Closely spaced pore-water samples were taken because interstitial water chloride concentrations can be used to make quantitative estimates of the amount of gas hydrate present in the sediment before coring. During gas hydrate formation, water and methane are taken out of the pore waters, leaving the residual pore waters increasingly saline. Over time, locally elevated chloride concentrations associated with gas hydrate formation diffuse away. When gas hydrate in sediments decomposes during drilling and core recovery, water and gas are released back into the pore space, freshening the pore waters. Pore-water profiles from Sites 994, 995 and 997 are very similar and indicate three distinct chloride concentration zones: (1) a zone of progressive freshening with depth to ~200 mbsf; (2) a zone that extends to the approximate depth of the BSR (~450 mbsf) of highly variable chloride values characterized by local anomalously fresh values; and (3) a zone of nearly constant chloride beneath the BSR. These anomalies are interpreted to indicate that a minimum of 1% of the sedimentary section within the zone from 200 to 450 mbsf is filled with gas hydrate.

An unprecedented level of success was achieved using the pressure core sampler (PCS), a device that returns a short core to the surface at formation pressures so that gases are not lost. Gas volumes captured by the PCS indicate that gas concentrations are grossly in excess of gas saturation, thus demonstrating that free gas exists beneath the BSR. Gases also occur throughout the sedimentary section below.

Vertical seismic profiles were used to locate the precise depth of the BSR and indicated no significant lateral changes in velocity above the BSR. However, velocities as low as 1400 m/s were measured beneath the BSR at Site 997. Well-logs disclosed distinct zones of

higher electrical resistivity and velocity that coincided with chloride anomaly zones indicative of gas hydrates. Preliminary well-log analysis of the resistivity data indicate that gas hydrate occupies 3–5% of sediment volume throughout this zone. A minimum of 13 in situ temperature measurements were made in each hole to establish temperature gradients. Extrapolation of these thermal gradients makes it possible to estimate the maximum depth at which gas hydrate is stable, based on experimentally-determined phase boundaries. The results indicate that the base of gas hydrate stability is ~30 m (Site 997) to ~100 m (Site 994) below the observed BSR depth.

INTRODUCTION

Gas hydrate is a solid phase composed of water and low-molecular-weight gases (predominantly methane) that forms under conditions of low temperature, high pressure, and adequate gas concentrations – conditions that are common in the upper few hundred meters of rapidly accumulated marine sediments. Although gas hydrate may be a common phase in the shallow geobiosphere, it is unstable under normal surface conditions, and thus surprisingly little is known about it in natural settings.

Large quantities of natural gas may be stored in gas hydrate-bearing sediments because as much as 164 times the saturation concentration of gas at STP conditions exists in these solid phases per unit volume. It is estimated that there are about 10^4 Gt (Gt = 10^{15} gm) of carbon stored in gas hydrate in sediments, which is about twice the estimate of carbon in all other fossil fuel deposits. Moreover, there may be considerable volumes of free gas trapped beneath the overlying gas hydrate-cemented zones associated with the bottom-simulating reflector (BSR), as well as dissolved gas in the pore fluids.

Gas hydrate is believed to be common in continental margin sediments because seismic reflection data have indicated its presence in every ocean basin. Gas hydrate is usually detected in seismic reflection data by the presence of a BSR. The BSR often cuts across sediment bedding planes, thus clearly distinguishing itself as an acoustic response to a diagenetic change rather than a depositional horizon. The BSR is believed to represent the base of the gas hydrate stability zone, which occurs at depths between about 200 and 600 m below seafloor (mbsf) on continental rises. The pore spaces of sediments above the BSR are partly filled with gas hydrate, which may increase the sediment density, whereas deeper sediments may contain free gas, resulting in a sharp contrast in acoustic impedance and a strong reflector at the base of the gas hydrate stability zone. The Carolina Rise, particularly along the Blake Ridge, was the area where marine gas hydrate was first identified on the basis of a BSR (Fig. 1) and is an area where gas hydrate appears to be especially extensive.

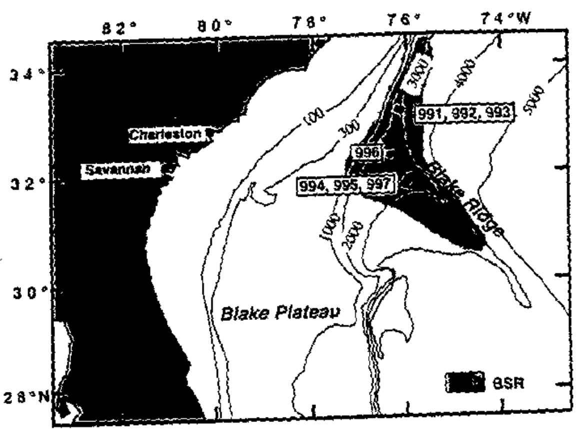

Figure 1. Location map of Leg 164 sites on the southeastern North American continental margin. Contours are in meters. The shaded region along the Blake Ridge and Carolina Rise indicates the area where gas hydrate occurrence has been inferred on the basis of BSRs.

ODP Leg 164 was devoted to refining our understanding of the in situ characteristics and amounts of natural gas hydrate stored in marine sediments. The program involved drilling three sites on the Blake Ridge to 750 m depths, which extend through the zone where gas hydrate is stable and into the sedimentary section below. Short holes (50 m) were drilled at four sites on the crests of two diapirs on the Carolina Rise where gas hydrate-bearing sedimentary sections have been disturbed by the intrusion of diapirs (Fig. 1). Because of the ephemeral nature of gas hydrate, emphasis was placed on downhole measurements and sampling strategies that allow in situ conditions of gas hydrate to be reconstructed.

The objectives of Leg 164 included:

(1) assessing the amount of gas trapped in hydrate-bearing sediments;
(2) understanding lateral variability in gas hydrate abundances;
(3) understanding the relationship between BSRs and gas hydrate development;
(4) investigating the distribution and in situ fabric of gas hydrate within sediments;
(5) establishing changes in physical properties (porosity, permeability, P-wave velocity, thermal conductivity, etc.) associated with gas hydrate formation and decomposition in continental margin sediments;
(6) determining whether gas contained in gas hydrate is produced locally or migrated from elsewhere;
(7) investigating the role of gas hydrate in formation of authigenic carbonates;
(8) determining the chemical and isotopic compositions, hydration number, and crystal structure of natural gas hydrate;
(9) determining the role of gas hydrate in stimulating or modifying fluid circulation;
(10) investigating the potential connection between large-scale sediment failures and gas hydrate decomposition;
(11) establishing the origin of the Carolina Rise Diapirs and their influence on associated sedimentary gas hydrate.

RESULTS

Sites 991/992/993

Short holes were drilled at three sites on the crest and flanks of the Cape Fear Diapir (Fig. 1). The diapir is one of about 20 large structures that originate from deep within the sediments of the Carolina Trough and penetrate through the Carolina Continental Rise. Although the core material of these diapirs is unknown, many investigators believe they are salt cored. The crest of the Cape Fear Diapir breeches the seafloor within the scar of the giant Cape Fear Slide. Although the Cape Fear Diapir occurs within a region where a BSR is present, the continuity of the BSR is lost on the flanks of the diapir. The objectives of Sites 991, 992, and 993 were to investigate the effects of diapir intrusion and large-scale sediment failure on the regional gas hydrate field and on the transport of fluid and gas through the sedimentary sequence. A second major objective was to establish the nature of the core material of the diapir.

Lithologic variations, physical property changes, and nannofossil biostratigraphy indicate that a discontinuous Neogene sediment section was recovered at Hole 991A. Sections of core from 2.05–12.67 mbsf and 18.37–47.66 mbsf are characterized by zones of steeply dipping, discordant and truncated beds and laminae of variegated colors; beds deformed by flowage, folding and faulting; and mud clasts of various sizes, shapes and colors. The portion between 12.67–18.37 mbsf is apparently undeformed. This section is interpreted as a large slide block. A long hiatus, correlating with earliest Pleistocene to late early Pliocene times, was also detected.

The upper portion (0–9.1 mbsf) of Hole 992A is composed of strongly deformed gray nannofossil silty clay beds that appears to represent a mass-transport deposit emplaced by slumping. The bottom portion (9.1–50.75 mbsf) is a homogeneous olive gray diatom-rich nannofossil clay, which appears to be undeformed. Most of the ...

Pleistocene sequence is missing. Another long hiatus corresponding to early Pleistocene to late Miocene times was identified, and the oldest sediment recovered was middle late Miocene in age (CN9a Zone). The lithologies did not reveal the composition of the underlying diapir.

Hole 993A contains one major unit, from 0 to 47.27 mbsf, that is predominantly gray nannofossil clay. The only exception is a short interval from 4.43 to 4.9 mbsf that contains an indurated carbonate and overlies a carbonate silty clay. The entire sequence is of early late Miocene age (Zone CN7).

At all three sites, the methane concentrations increased with depth, ranging from 5 to 29,000 ppm at Site 991, from 2 to 81 ppm at Site 992, and from 6 to 18,000 at Site 993. The methane-to-ethane ratios of most samples indicate a microbial origin for the methane.

Detailed pore-water profiles from Holes 991A and 993A, both of which are located on the flanks of the diapir, show that chloride concentrations increase at a rate of 2 millimolar per meter (mM/m). However, in Hole 992A, located on the crest of the diapir, the gradient is significantly less (about 0.8 mM/m). No significant trend in the Na^+/Cl^- ratio exists. There are several possible explanations for the greater pore-water chloride content at Sites 991 and 993 relative to Site 992. High dissolved chloride content may indicate that the core of the diapir is composed of evaporitic salts. The variations in chloride concentration of the interstitial waters analyzed from these sites may have been modified by fluid-circulation patterns around the diapir. The variations in the profiles also may indicate that major slumps have truncated the sedimentary sections on the flanks of the diapir more recently than those on the crest of the diapir. Thus, the present pore-water profiles on the flanks are still steeper than the pore-water gradients on the crest of the diapir. Alternatively, the variations in interstitial water chloride contents could be produced by ion exclusion associated with gas hydrate formation on the flanks of the diapir. Seismic reflection profiles indicate a strong BSR in the sediments surrounding the diapir. Sites 991 and 993, on the flanks of the diapir, are closer to the saline waters that are generated as a consequence of gas hydrate formation. Conclusions about the cause of the high pore-water chloride content await shore-based analysis.

Dissolved sulfate content in interstitial-water samples from Site 991A decreases linearly with increasing depth, declining to negligible concentrations at ~40 mbsf. At this depth, there is a corresponding alkalinity maximum in the interstitial-water samples. Ammonium contents increase linearly with depth, passing through the base of the sulfate reduction zone without inflection. Active anaerobic methane oxidation is suggested by these profiles.

Both PCS runs at Hole 991B were only partly successful. Core 164-991B-1P was pressurized at ~2500 psi, about 70% of that expected for hydrostatic pressure at the coring depth, but contained only water. Core 164-991B-2P was pressurized at 63 psi, but contained 1.04 m of homogenous nannofossil-bearing clay.

Magnetic intensities are very weak throughout the sedimentary sequence at all three sites, and no consistent magnetostratigraphy can be recognized. Rock-magnetic analysis (saturation isothermal remanent magnetization (IRM), back-field IRM, and partial anhysteretic remanent magnetization (ARM) acquisition) indicate the presence of two magnetic carriers. This paleomagnetic and rock-magnetic behavior is probably caused by dissolution of single-domain magnetite and reduction to magnetic iron sulfides.

In summary, the sediments recovered at Sites 991, 992 and 993 are typical Neogene continental rise deposits and do not directly indicate the composition of the underlying diapir. The sedimentary sequence has numerous stratigraphic gaps. Pre-Quaternary sediments occur between 0.5 and 30 mbsf at all three sites, indicating that the upper Quaternary section has been substantially truncated. Pervasive soft-sediment deformation was observed within the Pleistocene to Pliocene sequences from Sites 991 and 992, especially near the tops of both sections, suggesting that these unconformities resulted from vigorous mass-transport processes associated with sediment failures. The sediments near the surface tend to be over consolidated for their current burial depths. The relative absence of Holocene and late Quaternary age materials in a region where the Holocene and late Pleistocene sedimentation rates are known to exceed 20 cm/ky indicates that the most recent deformation occurred within the late Quaternary and Holocene. The paucity of recent sediments around the diapir suggests that the diapir is still active.

Site 994

Site 994 is part of a transect of holes on the southern flank of the Blake Ridge that extends from an area where a BSR is not detectable to an area where an extremely well-developed and distinct BSR exists (Fig. 2). The transect is situated where variations in the development of the BSR and seismic blanking are especially distinct. However, the geology and topography along this transect are relatively simple (Fig. 3), which provides an opportunity to assess basic properties of hydrate-bearing sediments and to understand lateral hydrate variations caused by local lithologic, chemical, and hydrologic factors. Site 994 is situated at the end of the transect where the BSR is not detectable and, thus, serves as a background or reference site.

At Site 994, we recovered a 700-m-thick sequence that is dominantly composed of clay and calcareous nannofossils (Fig. 3). Three major lithologic units were identified, based on downward decreasing contents of calcareous nannoplankton. The sediments at Site 994 are lithologically homogeneous which makes it an ideal reference section.

The section obtained in Hole 994C contains a continuous record spanning from the Holocene to latest Miocene (~6 Ma) in age. All nannofossil zones and subzones were present, and no obvious hiatuses were identified. Measurement of discrete paleomagnetic samples allowed determination of approximate positions for the Brunhes/Matuyama (40 mbsf) and Gauss/Matuyama (150 mbsf) magnetochron boundaries and for the Olduvai subchron (90–115 mbsf). Estimated sedimentation rates increased consistently downsection, reaching a maximum of 400 m/My.

Sediments in many cores were very gassy. Most cores underwent extensive gas-driven self-extrusion, sometimes splitting the liners near the shoe, and one core burst its liner within the core barrel on the drill floor. Disruption of the cores due to gas expansion began occurring at ~60 mbsf. Poor recovery below 190 m is largely a result of vigorous degassing. The gas is mostly methane with secondary amounts of CO_2. Slight increases in ethane contents with depth were observed; however, the sediments did not reach the zone of thermogenic hydrocarbon production.

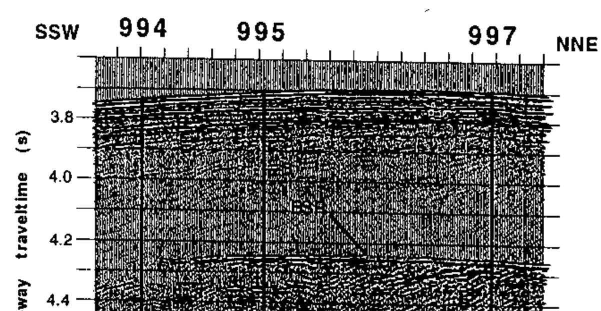

Figure 2. Seismic reflection profile (CH-06-92 Line 31) for the transect of Blake Ridge Sites 994, 995 and 997. The profile crosses perpendicular to the topography of the Blake Ridge. BSR = bottom-simulating reflector.

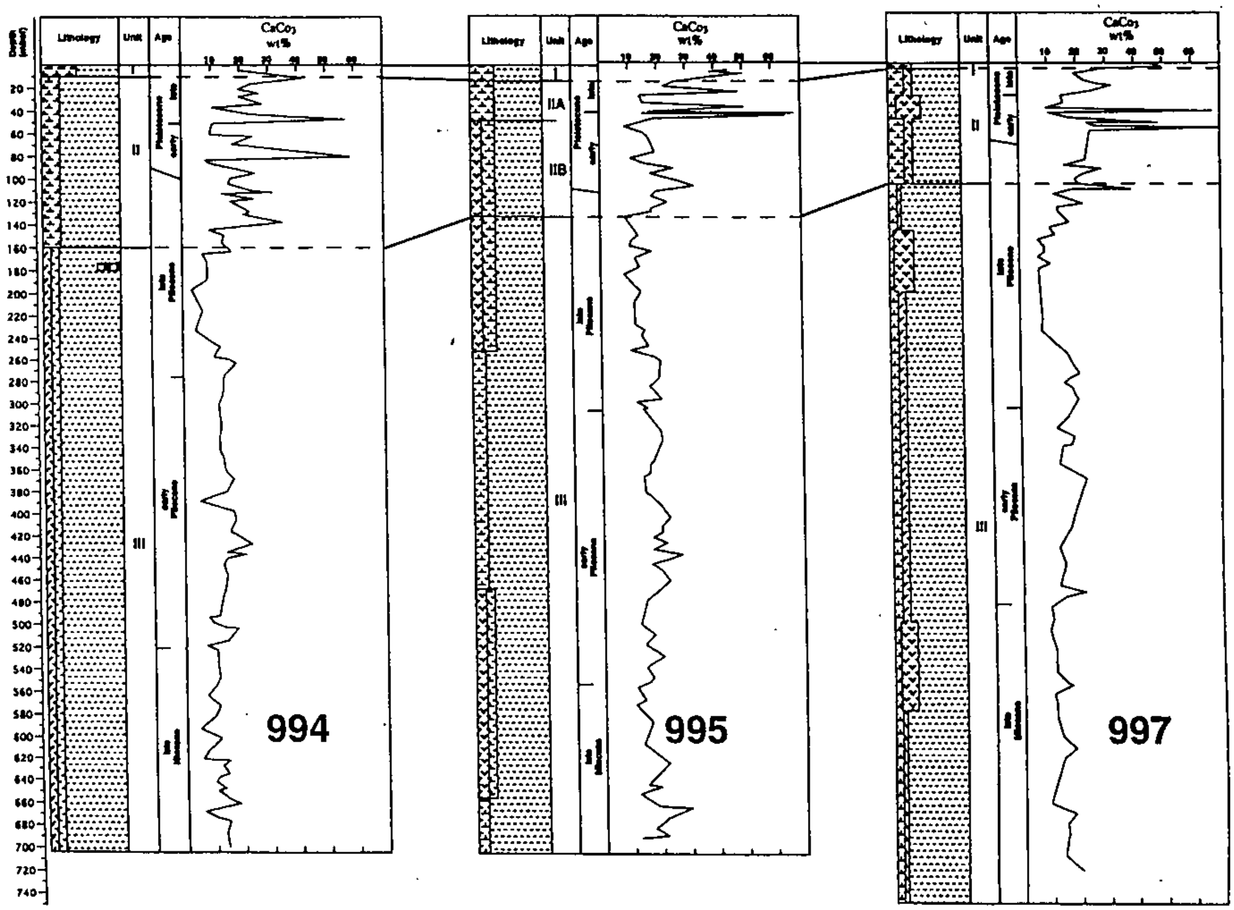

Figure 3. Composite stratigraphic section for Sites 994, 995 and 997 showing simplified lithostratigraphy, depth of lithologic unit boundaries, biostratigraphic ages, and total carbonate contents (wt% $CaCO_3$) of the sediments.

The chloride profiles from Holes 994A, B, and C contain anomalously low-chloride spikes superimposed on a trend of generally decreasing chloride concentration from typical seawater values at the top of the section, to ~90% of seawater at 300–400 mbsf. A slight increase in chloride toward the bottom of the hole is present. The lowest measured chloride concentration is 438 mM. In the interval from 100 to 450 mbsf, chloride anomalies were found in 50% of the interstitial water samples, and they are particularly abundant and well developed at 380–440 mbsf. Detailed studies on cores from Hole 994D revealed that the anomalous low-chloride spikes extend over less than 1.5 m. The spikes are interpreted as evidence for the presence of gas hydrate, which melts and dilutes the interstitial water during coring and processing.

Gas hydrate was sampled from two cores. Section 164-994C-31X-7 (258 mbsf) contained several white nodules of hydrate that ranged in volume from ~4 to 25 cm³. Gas volume, gas composition, and water volume of a solid piece of hydrate were determined. The gas composition of the hydrate was 98.78% methane, 1.22% CO_2, 86 ppm ethane, and 2 ppm propane. Volumetric calculations show that the cage occupancy (percentage of potential gas molecule sites in the hydrate crystal lattice that are actually filled) of the hydrate sample is at least 80%. In Section 164-994D-4X-1 (261 mbsf), a piece of hydrate that was less than 1 cm³ was found. In the region where solid hydrate was recovered from the cores, the physical properties data do not reveal any significant changes in any sediment properties. Many cores recovered from 240 to 430 mbsf contained anomalously cold zones (measured using temperature probes on the catwalk) indicating that gas hydrate had decomposed within these cores, even though hydrate was not visually observed.

Fourteen in situ temperature measurements were attempted between 0 and 445 mbsf in Hole 994C. Based on data from eight successful deployments of the Adara temperature tool and water sampler temperature probe (WSTP) tools, the average geothermal gradient in the uppermost 320 m is estimated at 38.6°C/km. Average heat flow is 35 mW/m² over the entire depth range of the measurements, but 45 mW/m² within the upper 100 m of the hole. Anomalously low temperature measurements (6–8°C) were made at four depths between 300 and 425 mbsf. Although there is no simple explanation for the shape of the equilibration paths associated with the anomalous records, the low in situ temperatures are consistent with those measured close to solid hydrate in the recovered cores. Such anomalously low temperatures might be produced by the endothermic decomposition of solid hydrate.

Rock-magnetic studies indicate two prominent features superimposed on a continuous sequence of magnetite to pyrite reduction. At 260 mbsf, immediately below the hydrate recovery in Core 164-994C-31X, and at 365 mbsf, coincident with an anomalously low interstitial-water chloride content, rock-magnetic signatures are similar to those found on samples from Leg 146 at the base of hydrate concentrations and "fossil hydrate zones."

A suite of wireline logs was run, including neutron density, neutron porosity, resistivity, P-wave sonic, shear sonic, and geochemical logs. In addition, several measurements with the geochemical tool in the inelastic mode were made in an attempt, for the first time in ODP history, to determine carbon/oxygen ratios. Initial analysis of the neutron density, resistivity and sonic logs shows distinct changes in P-wave velocity and resistivity in two important regions. The first corresponds to the zone below 220 mbsf from which gas hydrate was recovered. In this zone, velocity and resistivity have pronounced positive spikes. The second region at 420 mbsf, where velocity and resistivity decrease sharply, is near the predicted base of the hydrate stability field. In contrast, the density log does not show changes at corresponding depths. The formation factor (observed resistivity/seawater resistivity) increases with depth from 220 to 420 mbsf and then abruptly decreases to lower values. The relatively constant density throughout this interval suggests that the rise in resistivity is not entirely due to changes in porosity and may reflect increasing amounts of gas hydrate with depth in this zone.

Vertical seismic profiles were conducted at depths of 110–650 mbsf during five lowerings of the three-component Woods Hole Oceanographic Institution (WHOI) borehole seismometer in Hole 994D. Difficulties with the clamping arm restricted the acquisition to two walkaway VSPs at 650 and 482 mbsf and eight zero-offset clamps over the same depth range. Zero-offset air-gun shots were fired with the tool suspended in the hole at 20 m intervals from 570 to 110 mbsf. A stacked record section shows clear first arrivals from 250 to 650 mbsf. A preliminary P-wave velocity model (Fig. 4) shows elevated velocities (with respect to background levels) in a zone from 320 to 420 mbsf and a pronounced low-velocity zone from 550 to 650 mbsf. The low-velocity zone may be due to the presence of free gas bubbles dispersed in the sediments at this depth.

Estimates of gas hydrate amounts in the sediments before recovery at Site 994 are made by assuming that diffusive equilibration prohibits significant and non-systematic interstitial chloride concentrations from occurring between closely spaced samples. Thus, chloride spikes are only a result of gas hydrate decomposition during sample recovery. To produce an estimate of the interstitial-water salinity through the zone between 200 and 450 mbsf, where erratic chloride values were measured, a polynomial was fit to the relatively smooth chloride data above 200 m and below 450 m. All but one of the measured chloride concentrations in this zone have lower values than the calculated in situ values, with some significantly lower. The differences between the calculated in situ chloride concentrations and the measured chloride concentrations were used to establish the relative chloride anomaly that is associated with each sample. The calculated chloride anomalies enable the amount of gas hydrate that was present in these samples to be estimated. Corrections for the porosity of the samples were made using the shipboard physical properties data. The estimated percentage volume of the samples that was occupied by gas hydrate had a skewed distribution, ranging to as much as 7% (at 391 mbsf), with a mean value of 1.3% ± 1.8% and a median value of 1% for all the interstitial-water samples that were collected between 200 and 450 mbsf.

Calculations of the percentage of gas hydrate that is required to explain the observed change in the well-logging resistivity trend indicate that the general trend through this interval (between 212.0 and 428.8 mbsf) can be explained by the pervasive addition of up to 2.9% gas hydrate. The same calculation indicates that the horizon with the highest concentration (~239 mbsf) contains as much as 9.5% gas hydrate. It is remarkable that independent estimation of the amounts of gas hydrate from different data sets (chloride anomalies and logging data) yield similar values of a few per cent gas hydrate disseminated in the sediments.

In summary, although very little gas hydrate was recovered from Site 994, the interstitial-water chloride anomalies, temperature anomalies in recovered cores, and patterns in the well-log data all indicate that gas hydrate occupies an average of 1% or more of the sedimentary section from 220 to 430 mbsf. The hydrate is inferred to occur as finely dispersed crystals within homogenous sediments. All of the inferred hydrate occurs well above the predicted base of gas hydrate stability at this site.

Site 995

Site 995 was the first site on Leg 164 at which drilling penetrated below the base of the gas hydrate stability zone and through a strong BSR (Fig. 2). The site is located on the southern flank of the Blake Ridge, 3.0 km northeast of Site 994, and within the same stratigraphic interval as Site 994. However, a strong BSR is present at Site 995 at 0.53 s sub-bottom, which is not observed at Site 994 (Fig. 2). Sites 994 and 995 are coupled sites that were intended to establish the nature of the BSR and to understand the causes of profound differences in acoustic characteristics within essentially the same sedimentary sequence.

At Site 995 we recovered a 700 m thick sedimentary sequence that is dominantly composed of clay and nannofossils (Fig. 3). Three major lithologic units were identified, primarily based on downhole variations in carbonate contents and diatom and nannofossil abundances.

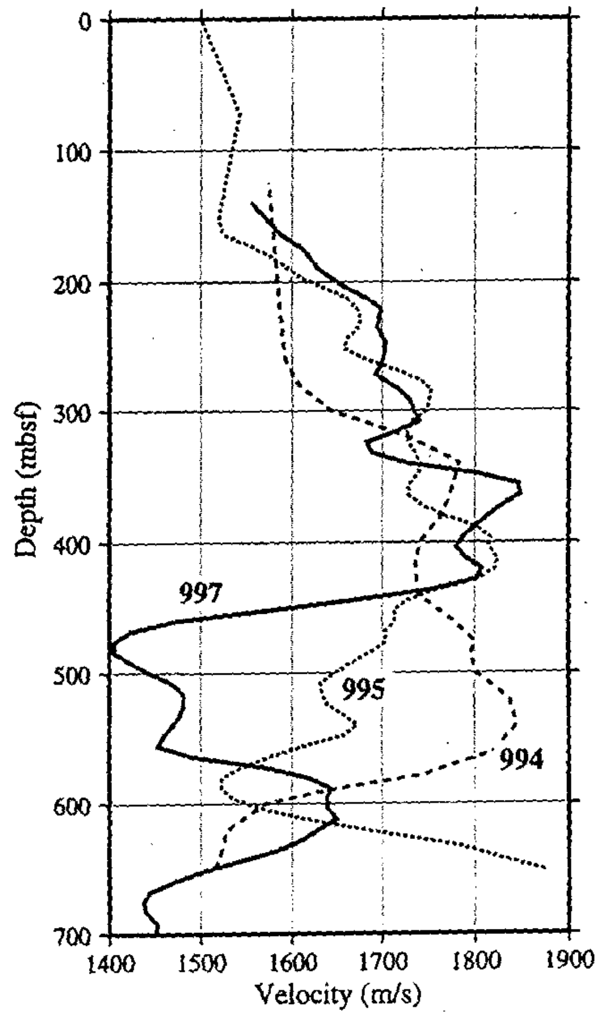

Figure 4. Velocity profiles based on the results of the zero-offset VSP at Sites 994, 995 and 997. From the flank of the Blake Ridge to the crest, the profiles show similar, possibly slightly increasing, velocities above the hydrate stability zone (~450 mbsf) and a significant decrease in velocity toward the crest below this zone. These preliminary velocity–depth functions were produced by inverting the air gun first-arrival times using a weighted, damped, least-squares inversion that weights mean traveltimes by the inverse of their standard error. The velocity–depth curves were produced by assigning equal weight to fitting the traveltime data and to producing a smooth velocity–depth function.

Nannofossil biostratigraphy indicates that the sequence recovered at Site 995 is mostly continuous except for a short hiatus or gap detected within the uppermost Miocene. The sedimentation rates for the Quaternary and lower Pliocene sequences are almost identical to those at Site 994. However, the rate for the upper Pliocene (110 m/My) is about 10% higher than at Site 994. The upper Miocene sequence is estimated to have been deposited at a rate of approximately 260 m/My. The age of the oldest sediments cored at Site 995 (704.6 mbsf) is estimated to be 6.1 Ma. A magnetostratigraphy was determined for Hole 995A, despite remanences of <0.5 milliampere/m (mA/m), and major chron boundaries were recognized as follows: C2An/C2r (Gauss/Matuyama), 125–145 mbsf; C2Ar/C2An (Gilbert/Gauss), 295–320 mbsf; C3n/C2Ar, 320–350 mbsf; C3r/C3n, 545–580 mbsf; and C3An/C3r (Anomaly 5/Gilbert), 620–640 mbsf.

Concentrations of methane in headspace gas samples increase from 0.021 ml/kg of sediment near the sediment–water interface, to a maximum of 114 ml/kg at a depth of 42.7 mbsf. Headspace methane contents then steadily decline to about 10 ml/kg near 240 mbsf and remain at 1 to 10 ml/kg throughout the rest of the hole. Methane-to-ethane ratios decrease with depth and reach a minimum of 146 at 699.4 mbsf. Higher molecular weight hydrocarbons are present in <10 ppm concentrations from 171.2–699.4 mbsf, and heptane occurs in the lower sections of Hole 995A, suggesting a small amount of thermally mature gas has migrated to the site. The total organic carbon contents of the sediments are near 1%, and the organic matter is immature, containing both terrestrial and marine components.

Interstitial-water geochemical data from Site 995 are remarkably similar to those found at Site 994. In particular, anomalously low values of interstitial-water chloride concentrations occur at the same depths at both sites. The low chloride values (as low as 466 mM) occur between 195 and 450 mbsf, coincident with the zone of anomalously low sediment temperatures measured on the catwalk after recovery, indicating that gas hydrate recently decomposed in these cores. These results imply that sites 3 km apart possess similar vertical distributions and amounts of gas hydrate.

Eleven WSTP runs from 78.7 to 200.2 mbsf were made at Site 995. The recovered samples contain 0.1–94% interstitial water, with the proportion of interstitial water decreasing with increasing depth. After correction for the effects of dilution by borehole water, the WSTP water samples indicate that in situ chloride concentrations are generally comparable to those measured for water squeezed from whole-round core samples recovered from corresponding depths.

The PCS was successfully deployed 11 times at Site 995. Gas samples taken from the PCS are methane, with approximately 1% CO_2, that evolves from the tool at pressures below 500 psi (at 0°C). The amount of gas recovered from certain cores exceeds that expected from methane saturation of the interstitial waters at in situ pressures. Because some of these same cores were recovered from above the base of gas hydrate stability in the zone associated with the erratic interstitial-water chloride concentrations, the "excess" gas is probably derived from decomposition of methane hydrate.

Physical properties data for sediments from Hole 995A are nearly coincident with those found at Site 994. The data do not reveal major differences that could account for the remarkable lateral variability in the strength of the BSR between the sites. The data also show a 390 m thick interval (220–610 mbsf) in which the wet-bulk density values are constant as a function of depth, an unusual observation in sediments undergoing normal compaction.

Rock magnetism defines a trend of magnetite-greigite-pyrite conversion in which greigite develops within the first 20 mbsf in response to bacterial oxidation of organic material and is progressively reduced to pyrite downhole. Below this a second generation of greigite extends downward to ~260–300 mbsf, approximately coinciding with the zone of high gas hydrate concentration inferred from interstitial-water chloride values. This sequence of reduction steps is similar to that documented at Site 994.

Twenty in situ temperature measurements were attempted at Site 995 using the Adara and WSTP tools and a new prototype temperature probe, the Davis–Villinger temperature probe (DVTP). Based on 15 successful deployments of the temperature tools, the geothermal gradient is estimated at 33.5 ± 0.9 °C/km between 0 and 381 mbsf. Taking into account vertical variations in thermal conductivity, the average heat flow from 0 to 381 mbsf is 34.2 ± 1.7 mW/m², which is 35% lower than previous measurements from this region. Preliminary extrapolation of the thermal gradient to 440 mbsf, the depth of the BSR at Site 995, yields a temperature of 18.3°C. This is well within the experimentally determined pressure–temperature stability field for methane hydrate.

A complete suite of wireline logs (natural gamma, resistivity, sonic, neutron porosity, lithodensity, geochemistry, FMS, and the experimental shear wave tool) was run in Hole 995B from 130 to 630 mbsf. Preliminary analysis of the acoustic and resistivity logs shows a pattern similar to that at Site 994, with low acoustic velocities (~1600 m/s) in the top of the hole that begin to increase at 220 mbsf to a maximum of 1900 m/s at 450 mbsf before decreasing again to 1600 m/s at 600 mbsf. The zone from 220 to 450 mbsf has higher resistivities than are found either above or below. The resistivity and acoustic velocity measurements are consistent with the presence of hydrate in the zone from 220 to 450 mbsf and with the presence of gas bubbles in the section below 450 mbsf.

VSPs were conducted at depths of 144–664 mbsf during two lowerings of the three-component WHOI borehole seismometer in Hole 995B. Walkaway VSPs were shot by the *Cape Hatteras* and recorded at eight depths from 176 to 680 mbsf. A stacked record section shows clear downgoing first arrivals and upgoing reflections, including a strong reflection from the BSR. The intersection of the downgoing first arrival and the upgoing BSR reflection indicates that the BSR is located at 440 ± 10 mbsf. A preliminary P-wave velocity model (Fig. 4) shows that compressional velocity reaches a maximum of 1850 m/s at 400 mbsf. Velocities decrease below this depth, reaching a minimum of about 1550 m/s at 590 mbsf, suggesting the presence of gas bubbles.

Site 996

Site 996 is located on the crest of the Blake Ridge Diapir, the southernmost in a series of ~20 diapiric structures rising from deep within sediments of the Carolina Trough (Fig. 1). The objectives at this site were to investigate: (1) methane migration and gas hydrate formation in a pockmarked fault zone where methane is leaking out of the continental rise; (2) the source of fluids and gases in a seafloor seep; and (3) the influence of these fluids on the host sediments.

Five short holes were drilled at Site 996 in sediments overlying the Blake Ridge Diapir (Fig. 5). Holes 996A, 996B and 996C are located within a seafloor pockmark that contains an active chemosynthetic community dominated by mussels. Holes 996D and 996E were drilled on the flanks of this pockmark. Overall core recovery was poor. The sedimentary sequence consists primarily of nannofossil-bearing clay and nannofossil-rich clay, both with varying amounts of foraminifers (0–15%) and diatoms (0–25%). Contorted and steeply dipping beds in parts of the sequence provide evidence of soft-sediment deformation that is probably related to diapir uplift. The uppermost 2 m of sediment within the pockmark consist of nannofossil-rich aragonitic clayey silt with abundant bivalve shell fragments. The shell fragments and surrounding sediments commonly show initial stages of calcite and aragonite cementation. Indurated carbonate zones occur from ~5 to 15 mbsf and from 30 to 50 mbsf. Rapid decreases in the calcium and magnesium concentrations of interstitial waters within the upper 10 mbsf and a corresponding increase in the alkalinity indicates the precipitation of carbonate within the uppermost sediments.

All of the sediments recovered at Site 996 are Quaternary in age. The lowermost cores from Holes 996A, 996D and 996E are early Pleistocene, with a maximum age of about 1.0 Ma. Because of poor

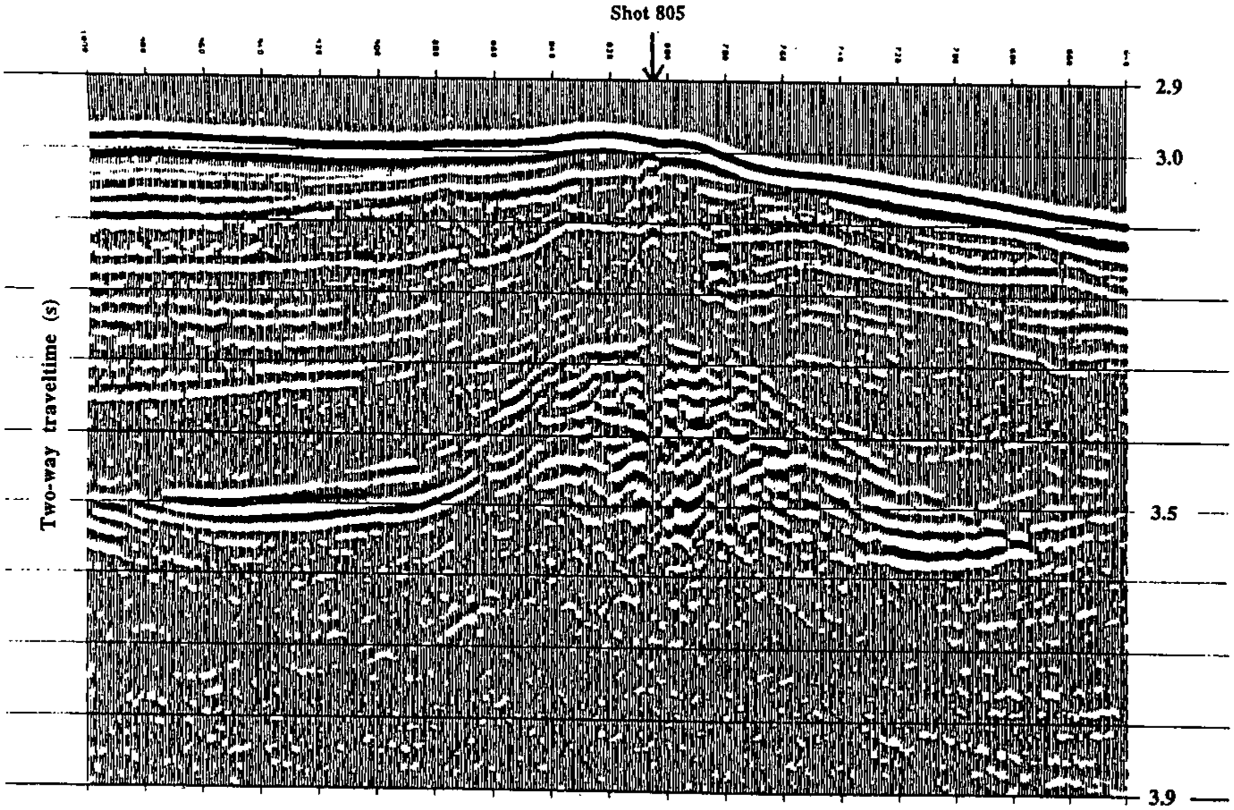

Figure 5. Single-channel seismic line acquired over the Blake Ridge Diapir showing the location of Site 996. Data have undergone constant velocity migration (1500 m/s) and a mild three-trace mix. Note the highly reflective sediments in the center of the figure bounded above by a reversed polarity reflector interpreted as the base of hydrate stability.

recovery, the magnetostratigraphy is very poorly defined. In Hole 996E, the Matuyama/Brunhes boundary is tentatively placed at about 33 mbsf, and the top of the Jaramillo subchron at ~40 mbsf.

Gas hydrate was recovered from all five holes (Holes 996A through E). The hydrate was white and occurred in three different forms: (1) massive pieces, cylindrical to round in shape and as much as 5 to 8 cm long, were found in sediments recovered from the uppermost 9 mbsf; (2) platy, 1–4 mm thick veins that filled wavy vertical fractures; and (3) vertically oriented rod-shaped nodules about 1 cm in diameter and 3–12 cm in length that tapered downcore. Numerous pieces of hydrate were sampled both for shipboard analyses and for storage in pressure vessels for shore-based studies.

Magnetic susceptibility and rock-magnetic studies suggest that the zone of bacterial magnetite authigenesis, present in the uppermost few meters at all other Leg 164 sites, is absent from Site 996. High-resolution gamma-ray attenuation porosity evaluator (GRAPE) data for sediments from Hole 996E indicate little variation in wet-bulk density with depth, with values averaging 1.8 g/cm^3. Porosities decrease from 75% to 50% in the uppermost 12 m of the hole, but water content decreases exponentially over the same interval, which is similar to the pattern observed in the uppermost 100 m at Site 995.

The methane (C_1) content of headspace gases in sediments from Holes 996A, 996C and 996D increases from 1300 to 11000 ppm with increasing depth to 60 mbsf. Ethane (C_2) concentrations ranged from 1 to 10 ppm, yielding C_1/C_2 ratios near 1000. In contrast, near-surface sediments from Hole 996E, which is located outside of the pockmark, were relatively poor in C_1. However, at depths below about 10 mbsf, C_1 concentrations and C_1/C_2 ratios were comparable to those from Holes 996A, 996B, and 996C. The free gases consist almost entirely of C_1 (greater than 90%), CO_2 and H_2S in the upper sections of each hole. H_2S concentrations were as high as 50,000 ppm. Maximum values for C_2 and C_3 were 940 and 25 ppm, respectively.

Chloride concentrations increase to 1.8 times that of seawater with increasing depth (57.7 mbsf) at Site 996, suggesting the influence of evaporites at depth. Increasing Na/Cl ratios and a two-fold increase in K^+ concentrations are consistent with a salt source. Large (20–30%) negative anomalies in chloride concentration also occur, probably due to gas hydrate dissociation. Large decreases in dissolved calcium and magnesium concentrations in interstitial waters from sediments within the uppermost 10 mbsf, and alkalinity maxima at approximately 15 mbsf, indicate precipitation of carbonate within the top 10–15 m of the sedimentary sequence. Sulfate approaches negligible concentrations near the seafloor (Holes 996C and 996D), and together with high levels of interstitial ΣHS^- and methane, suggests active sulfate and methane consumption near the seafloor. Active pore-water advection is also suggested by the wide difference in interstitial waters sampled immediately below the seafloor chemosynthetic community (Holes 996A, 996B and 996C) and sampled at depth in Hole 996E.

Site 997

Site 997 is located on the topographic crest of the Blake Ridge in an area where an extremely well-developed and distinct BSR exists (Fig. 2). It was the last of three sites drilled along the Blake Ridge transect.

The three lithostratigraphic units recognized at Site 997 are very similar to those documented at Sites 994 and 995 (Fig. 3). The 750 m sequence recovered at this site is Holocene to late Miocene in age. Three short hiatuses were detected in the upper Lower Pleistocene and upper Lower Pliocene, and the fourth short hiatus is likely in the Upper Miocene. Sedimentation rates increased with depth throughout the sedimentary sequence. Because of a hiatus and coring gap, the Quaternary sedimentation rate at Site 997 (40 m/My) is only two-thirds of the value observed at Sites 994 and 995. The Pleistocene rates (129–194 m/My), calculated by excluding the hiatuses, are the highest among the three sites. The minimum rate for the upper Miocene is more than 342 m/My, very close to the value obtained for the uppermost Miocene sequence at Hole 994C. The oldest age estimated at Hole 997B is approximately 6.4 Ma.

A well-defined magnetostratigraphy was determined for the upper part of Site 997. The lower boundary of the C1r.1n subchron (Jaramillo normal chron) is at 52 mbsf, the upper and lower boundaries of the C2n (Olduvai normal chron) are at 72 and 84 mbsf respectively, and the C2An/C2r boundary (Gauss/Matuyama boundary) is at 122 mbsf. The C1n/C1r boundary (Brunhes/Matuyama boundary) and the upper boundary of the C1r.1n (top of Jaramillo normal chron) are tentatively defined at 36 and 41 mbsf, respectively.

Sediment physical properties at Site 997 are generally similar to those at Sites 994 and 995. Most notably, all three sites have a well-defined lowermost unit (upper boundary at 610–625 mbsf) in which wet-bulk density increases with depth more rapidly than in the overlying and largely homogeneous unit that makes up most of the sedimentary section. All three sites are also characterized by an interval in which water contents increase with depth in at least one 50 m thick section between 50 and 200 mbsf. At Site 997, the major interval of increasing water content and porosity with depth (approximately 88–177 mbsf) corresponds to a diatom-rich layer.

Rock magnetism defines a similar downhole sequence of reduction steps to that seen at Sites 994 and 995. Magnetite authigenesis from 0 to 2 mbsf is followed by reduction of magnetite to pyrite via magnetic sulfides. Two reduction styles are apparent. The first is a trend of magnetite-greigite-pyrite conversion in which greigite apparently develops within the first 20 mbsf in response to bacterial oxidation of organic material and is progressively reduced to pyrite downhole. A second generation of greigite extends downward to ~260–300 mbsf, as observed at Sites 994 and 995. Rock-magnetic data suggest that the second generation greigite has been largely reduced to pyrite below 300 mbsf.

Seventeen in situ temperature measurements were obtained between 0 and 414.1 mbsf in Hole 997A using the Adara, WSTP, and DVTP. The data indicate that Site 997 is characterized by a linear geothermal gradient of 36.9 ± 0.4 mK/m, which is within one standard deviation of the estimated gradient at Site 994 (36.4 ± 1.3 mK/m), and 9% higher than the gradient at Site 995 (33.5 ± 0.9 mK/m). The estimated temperatures at the BSR are 18.7°C (440 mbsf) at Site 995 and 20.0°C (450 mbsf) at Site 997. At Site 994, where there is no BSR, the temperature at a comparable depth (440 mbsf) is estimated at 20.1°C. On the Blake Ridge, sediments overlying a BSR (Sites 995 and 997) are not uniformly cooler than those at a comparable depth in a location with no BSR (Site 994).

The concentration of methane in headspace gas samples increases from 0.022 ml/kg of sediment near the sediment–water interface to a maximum of 180 ml/kg at a depth of 50.4 mbsf. The concentration steadily declines to about 6.6 ml/kg near 210 mbsf, and thereafter remains at concentrations ranging from 0.4 to 61 ml/kg. Notable spikes in methane concentrations occurred in the same intervals in which gas hydrate was found or inferred by temperature measurements. Methane-to-ethane ratios increase with depth and reach a minimum of 109 at 725.8 mbsf. Higher molecular-weight hydrocarbons are present throughout the hole in <100 ppm concentrations and increase with depth. Heptane occurs from 153.3 mbsf to 750.0 mbsf. The total organic carbon (TOC) contents of the sediments are near 1% above 200 mbsf and ~1.5% in the interval from 200 to 700 mbsf. The amount and composition of volatile and non-volatile organic matter is very similar to that found at Sites 994 and 995.

The interstitial-water chemistry at Site 997 is very similar to that documented at Sites 994 and 995. Downhole profiles of all dissolved species show the same general trends with the same approximate depths for maxima and minima as those seen at the other Blake Ridge sites. Chloride profiles were used as a proxy indicator of the amount of in situ gas hydrate. The chloride excursion zone occurs at approximately the same depths (~200 to 440 mbsf) over the 10 km transect. Furthermore, the two depth intervals showing the largest chloride excursions, at ~250 and 400 mbsf, are also depth correlative. Thus, the similarity of the Cl^- profiles at the ridge sites strongly suggests that gas hydrate is correlative over the expanse of the Blake Ridge.

The PCS was successfully deployed 11 times at Site 997, including one deployment to determine the volume and composition of gas in sediment immediately below the prominent BSR at 462 mbsf. The volume of methane evolved from this particular PCS core suggests that interstitial waters at this depth are 10 times oversaturated with methane. Chemical analyses also show that pore waters at this depth do not have the low chloride concentrations associated with the presence of gas hydrate. Together these observations provide the first direct evidence for significant free gas immediately below a BSR.

Preliminary analysis of the acoustic velocity and resistivity logs shows a pattern similar to that at Sites 994 and 995. Low acoustic velocities (about 1600 m/s) in the top of the hole begin to increase at 186 mbsf to a maximum of 2000 m/s at 450 mbsf, before dramatically decreasing again to below 1200 m/s. The interval from 186 to 450 mbsf also exhibits higher resistivities. In addition, the resistivity log reveals three conspicuous high electrical resistivity intervals near 210, 365 and 440 mbsf. The anomalously high resistivities and velocities measured in the zone from 186 to 450 mbsf are likely to be because of the presence of gas hydrate. Numerous low-velocity zones are observed within the depth interval below 440 mbsf in Hole 997B. These apparent low-velocity zones probably contain free gas.

The VSP program at Site 997 consisted of two lowerings of the three-component WHOI borehole seismometer, each of which provided complete coverage of the hole from ~160–700 mbsf. Preliminary velocity inversions from the two lowerings yield the same background velocity structure, thus verifying the repeatability of the experiment. Stations on the second lowering were interleaved with stations from the first lowering to provide 4 m trace spacing throughout most of the hole. Results show that velocities decrease sharply from 1800 m/s to 1400 m/s at the BSR (464 mbsf) and remain low to the base of the hole. Average velocities beneath the BSR at Site 997 are substantially lower than at Sites 994 and 995 (Fig. 4), providing evidence for increased concentrations of gas beneath the crest of the Blake Ridge.

CONCLUSIONS

ODP Leg 164 was devoted to furthering our understanding of the in situ characteristics of gas hydrates and gas hydrate-bearing sediments and to ground-truthing the nature of BSRs. The Blake Ridge gas hydrate field was targeted for drilling because it is associated with an extensive and well-developed BSR that could be considered the archetypal section for BSRs.

Most of the materials recovered were deposited during the Pliocene and Miocene at very rapid rates (as much as 350 m/My) by the southerly flowing Western Boundary Undercurrent, which sweeps along the Atlantic Margin. The stratigraphic sequence is composed of lithologically monotonous hemipelagic clays; this allows the distribution of gas hydrate and the origin of the BSR to be studied with minimal lithologic complication. The sediments are moderately organic carbon rich (~1.5%) and thus have the raw material to produce quantities of biogenic gas.

The following conclusions were determined for the scientific objectives of this leg.

(1) Amounts of gas trapped in hydrate-bearing sediments
Preliminary analysis from Leg 164 drill sites on the Blake Ridge indicates that gas hydrate occupies 1–2% of the sediment volume in a zone that is 200–250 m thick. In fact, the site without a BSR also contained ~1% gas hydrate through a similarly thick zone. If the rest of the ~26,000 km^2 region around the Blake Ridge where BSRs are present contains as much gas hydrate, rough estimates indicate that about 10 Gt of methane carbon is stored in this region. Given the number of localities worldwide in which gas hydrate occurs, the results of ODP Leg 164 provide further evidence that methane stored as gas hydrate in marine sediments represents a significant component of the global fossil fuel reservoir.

(2) Lateral variability in gas hydrate abundances
Interstitial water chemistry is very similar at the three deeply drilled (~750 mbsf) sites on the transect along the Blake Ridge (Sites 994, 995 and 997). Downhole profiles of all dissolved species show the same general trends with the same approximate depths for maxima and minima. Chloride profiles were used as a proxy indicator for the amount of in situ gas hydrate. When gas hydrate forms in sediment, water and gas are removed from the pore spaces, causing the residual pore waters to become saltier. Over long periods of time the local salinity anomalies produced by gas hydrate formation diffuse away. However, many of the cores that were recovered contained surprisingly fresh interstitial waters, indicating that gas hydrate had decomposed within these sediments during drilling and core recovery. A zone with anomalously low chloride values occurs at approximately the same depths (~200 to 440 mbsf) over the 10 km transect. Furthermore, the two depth intervals showing the largest chloride excursions, at approximately 250 and 400 mbsf, are also depth-correlative. Thus, the similarity of the Cl^- profiles at the ridge sites strongly suggests that gas hydrate is correlative over the expanse of the Blake Ridge, including Site 994 where no BSR is present in the seismic profile.

(3) Relationship between bottom-simulating reflectors and gas hydrate development
Downhole sonic log and vertical seismic profile data indicate decreasing interval velocities near the depth of the BSR. The change in sediment velocity may be related to either changes in the amount of hydrate above the BSR or the presence of gas bubbles below. Both types of sonic data indicate that gas bubbles are present at greater depths, but simple shipboard analyses of the absolute velocities do not require that the gas be present immediately below the BSR at all these sites. This issue can be resolved by combining pressure core sampling data, temperatures of cores measured after recovery, and interstitial-water chloride concentrations. Whereas the pressure core sampler data indicate that there must either be hydrate or gas bubbles present, the temperature and interstitial-water chloride data demonstrate that gas hydrate is not present below the BSR. Thus, there are gas bubbles beneath the BSR at these sites.

(4) Distribution and in situ fabric of gas hydrate within sediments
As anticipated, the recovery of gas hydrate proved to be difficult. The cores were very gassy, causing sediment to extrude from the liners as the cores arrived on deck. Some large pieces of gas hydrate were recovered. Gas hydrate recovered at Site 996 occurred as massive pieces, as veins filling vertical fractures, and as rod-shaped nodules. Fine-grained hydrate was not directly observed in sediments from any of the sites, but proxy measurements, such as the chloride concentration of interstitial pore waters, indicated that fine-grained hydrates had been present prior to core recovery. Calculations indicate that sediments in the zone from 200 to 450 mbsf had a minimum average gas hydrate content of 1% and that some individual samples contained more than 8% gas hydrate.

(5) Changes in physical properties associated with gas hydrate formation and decomposition in continental margin sediments
Well-log measurements show the gas hydrate-bearing and free gas-bearing zones are associated with distinct characteristics, whereas shipboard lithologic and physical properties measurements did not indicate any differences in these sediments. The distinctions between shipboard and downhole measurements are believed to result from the presence of gas hydrate in situ and will be the subject of shore-based research.

(6) Source of gas contained in gas hydrate (local production or migration)
As discussed below, the interstitial-water chemical data at Site 996 suggest that methane is transported upward along faults from underlying gas hydrate-bearing sediments. This is consistent with the occurrence of hydrate as vein fillings. At Sites 994, 995 and 997, constraints on the sources of gas contained in gas hydrate must await shore-based isotopic and organic geochemical studies, as well as detailed analysis of the PCS data that will delineate the distribution of hydrate, free gas, and methane dissolved in interstitial waters.

(7) Role of gas hydrate in formation of authigenic carbonate
Fine-grained, disseminated authigenic carbonate was present in sediments at all sites. Indurated diagenetic carbonate was recovered primarily at Site 996 but also from one horizon at Site 993. At Site 996, intersititial-water chemical data suggest that carbonate precipitation is caused by intense microbial oxidation of methane, which results in high alkalinity and high bicarbonate concentrations. The methane arriving at the seafloor at this site is largely biogenic and has a composition similar to that of the gases from Sites 994, 995 and 997. Fluids and gases venting at Site 996 have probably been transported upward from the underlying gas hydrate-bearing sediment section that slopes up around the diapir.

(8) Chemical and isotopic composition, hydration number, and crystal structure of natural gas hydrate
Gas hydrate decomposition experiments indicate that volumetric ratios of gas:water range from 130 to 160, and show that the gas of the hydrate is ~99% methane. Numerous hydrates were sampled for storage in pressure vessels and will be used for shore-based isotopic and crystallographic studies.

(9) Role of gas hydrates in stimulating or modifying fluid circulation
An intriguing association of pore waters was documented. Pore waters are systematically fresher than seawater within the gas hydrate-bearing sections. One of the potential explanations of such a pattern is that salinity changes associated with gas hydrate decomposition may be stimulating fluid circulation in these sedimentary sections. Other anomalies await shore-based isotopic and modelling studies, including variations in the amounts of free gas and gas hydrate and the sedimentary section, the occurrence of both thermogenic and biogenic hydrocarbon gases, and unexplained patterns of both the major and minor elements in dissolved pore waters.

(10) Connection between large-scale sediment failures and gas hydrate decomposition
Drilling along the top of the Cape Fear Diapir, which breeches the seafloor within the scar of the giant Cape Fear Slide, revealed soft-sediment deformation features and several biostratigraphic gaps. Both are the result of mass-transport processes associated with sediment failure and were caused by the Cape Fear Slide or emplacement of the diapir. The results of drilling did not provide any direct evidence as to whether large-scale sediment failures are related to gas hydrate decomposition.

(11) Origin of the Carolina Rise Diapirs and their influence on associated sedimentary gas hydrate
The chloride concentrations of interstitial waters from sediments overlying the Cape Fear Diapir (Sites 991, 992, 993) and the Blake Ridge Diapir (Site 996) are high; the ratio of Cl^- to other ions suggests nearby sources of evaporitic salts. Thus, it seems likely that both diapirs are salt cored. Presumably the salt has risen from deep within sediments of the Carolina Trough, the base of which is approximately 8 km below the seafloor at these sites.

Bahamas Transect

Science Operator Prospectus Leg 166

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ABSTRACT

Although sea-level fluctuations are known to have occurred throughout the Earth's history, their global synchroneity, amplitude and rate are still largely unknown. A better understanding of global changes in sea level is contingent upon coverage in a variety of tectonic and sedimentary settings, such as the deep sea, carbonate platforms and atolls, and continental margins.

The primary objective of Leg 166 will be to address fundamental questions regarding sea level. To attain this objective, five sites in the Straits of Florida will be drilled during Leg 166, completing a transect through prograding carbonate sequences formed in response to sea-level fluctuations along the western margin of the Great Bahama Bank. Two boreholes drilled previously on the western Great Bahama Bank as part of the Bahamas Drilling Project represent the shallow-water sites of the transect. The primary goal of the transect is to document the platform-margin record of the Neogene–Holocene sea-level changes by determining the ages of the major unconformities and to compare the timing of these unconformities with ages predicted from the oxygen isotopic record of glacio-eustasy. Core borings along the complete transect will document the facies variations associated with oscillations of sea level and, thus, the sedimentary response of the carbonate environment to sea-level changes. The correlation between the two independent records of sea-level changes, sequence stratigraphy and oxygen isotope proxy, has the potential to evaluate rate and amplitude of eustatic vs. relative sea-level changes and to establish a causal link between glacio-eustasy and the stratigraphic pattern.

Leg 166 also will core a number of holes through the sediments on the upper slope to measure the composition of the recharged waters retained in the sediment to assess rate and flow mechanisms through the bank. One of the distal sites of the transect will be deepened to determine the onset of the Florida Current, acquire a low-latitude record of the Paleogene "Doubthouse" and its transition into the Neogene "Icehouse," potentially sample the Cretaceous/Tertiary (K/T) boundary, and core the middle Cretaceous sequence boundary to assess the cause of the platform demise in the middle Cretaceous.

California Margin

Science Operator Prospectus Leg 167

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ABSTRACT

Leg 167 will investigate the evolution of oceanographic conditions in the north Pacific Ocean and will document changes in flow of the California Current system and associated changes in coastal upwelling. These data will be used to reconstruct north Pacific climate conditions through the Neogene, concentrating upon the time period since the advent of northern hemisphere glaciation, from ~2.5 Ma to the present. Approximately one third of the proposed drill sites will also sample lower and middle Miocene sediments to reconstruct a Neogene history of the California Current. The results of Leg 167 drilling will also be used to understand better the links between climates of the north Pacific Ocean and western North America, particularly in terms of temperature change and changes in precipitation.

Thirteen proposed sites and five alternates are organized into three transects across the California Current (Baja Transect, ~30° N; Conception Transect, ~35° N; and Gorda Transect, ~40° N) and one coastal transect extending from northern Baja California to the California/Oregon border (30° to 42°N). Each of the three transects will compare deep-water sites near the core of the California Current to coastal upwelling sites near shore. The coastal transect will examine variations in upwelling and productivity along the California margin, and will also examine intermediate water properties in many of the basins of the California Continental Borderland.

The proposed drill sites were chosen based upon two sites surveys (W9406 (R/V *Wecoma*) and EW9504 (R/V *Ewing*)). Much of the survey data (bathymetric swath maps, seismic profiles, and preliminary physical properties data from the sediment cores), for those sites that require it, can be obtained from the following WWW site: http://kihei.idbsu.edu/EW9504/camargin.html. SEG-Y versions of the seismic reflection data are also available from the National Geophysical Data Center (NGDC) where the digital data have been archived.

Logging Operator Report Leg 161

Mediterranean Sea II

Leg 161 was the second in a two-leg ODP program to address both tectonic and paleoceanographic objectives in the Mediterranean Sea. During Leg 161, the *JOIDES Resolution* drilled a transect of six sites across the Western Mediterranean, from the Tyrrhenian Sea to the Alboran Sea immediately east of the Strait of Gibraltar. Sites 974 (Tyrrhenian Sea) and 975 (South Balearic Margin) were dedicated to paleoceanographic objectives. Sites 976 (Western Alboran Sea), 977, 978 and 979 (Eastern Alboran Sea) focused mainly on tectonic goals, but also involved paleoceanographic objectives.

Five of the six sites drilled during Leg 161 were logged (Holes 974C, 975C, 976B and E, 977A, and 979A) with the following tools: Quad combination (Quad combo), Formation MicroScanner (FMS), Geochemical tool (GLT), Lamont–Doherty Temperature Logging Tool (TLT), and Borehole Televiewer (BHTV). Data recorded (i.e. natural radioactivity, sonic velocity, resistivity, neutron porosity) are generally good to excellent, but in most of the logged holes, caliper measurements indicated a variable borehole diameter over a substantial part of the logged interval in the sedimentary sequence, which affected the quality of some of the measurements sensitive to hole diameter, notably the density log. The main observations made during Leg 161 are the following:

(1) The main log units (identified on the basis of the log response in the sediment) generally show a good agreement with those identified by the sedimentologists from lithologic criteria on core observations. Comparisons between logs and cores, in terms of natural radioactivity for example, will provide a useful core–log integration (identification of organic-rich layers, volcanic ash layers, lithologic unit boundaries, etc.), even if the vertical resolution of the sensor is larger than the generally thin layers observed in the cores.

(2) The XCB coring appears to generate erratic variations in hole diameter and modifications of the sediment lithology ("biscuiting" of the muddy sediments) and physical properties. The APC-cored part of the hole and the lower part of the XCB-cored interval (in harder sediment) showed much less variability in the borehole diameter.

(3) In some cases, the calipers, either from the Quad combo or FMS tools, also detect sudden and local increases in the borehole diameter every 9.0 or 9.5 meters: the main application of this may be to provide a precise comparison of cores and and logs, i.e. a core–log integration. This will be aided by the high core recovery (around 100%) in the holes penetrating the Plio-Pleistocene sediments.

(4) In the metamorphic basement, the logs allow us to reconstruct the entire lithologic section, as core recovery is rather low (between 15 and 30%).

One of the most exciting results obtained during Leg 161 has been the extensive logging through the basement at Site 976. A full suite of logging was carried out in Hole 976B, during three successive passes, due to the instability of the borehole and serious washout; the first two were obtained in the Neogene sediments. For the third pass, the drillpipe was set below the sediment–basement interface (at 696.0 mbsf), to maximize the chances of success in basement logging. Quad-Combo and GLT tool strings were run and obtained excellent results. High quality FMS images and BHTV data (transit time and amplitude) were recorded in the same interval (from 910 to 700 mbsf in Hole 976B), providing a 200 m long high-resolution profile of the high-grade metamorphic basement (metasediments and gneiss). Preliminary analysis of the logging data and FMS images shows three main log units in the basement of Hole 976B, in accordance with core descriptions made on board *Joides Resolution*. Brecciated fault zones (characterized by poor recovery) are clearly identified, with a more conductive pattern. Granitic or migmatitic rocks are also clearly identified, being correlated with higher values in the photoelectric factor and, for the former, increases in the radiogenic potassium concentration due to crystallization of K-feldspar. This will allow the nature of the unrecovered intervals (mean core recovery: 19% in Hole 976B, 29% in Hole 976E) to be partially defined.

Logging operations in Hole 976E covered the transition between basement and sediments, a zone that was not possible to log in Hole 976B. A single run of the Quad Combo from the basement into the sediments and a short repeat run within the sediments were obtained. Twenty meters of sediment fill was found in the bottom of the hole, and the Quad Combo had to penetrate a bridge at the sediment–basement contact. During the logging run upwards out of the hole, the sediments had closed in upon the logging cable above the tool, and the tool was extracted from the basement only with difficulty. The repeat run was only in the sedimentary sequence as it proved impossible to penetrate down to the basement, because the bridge was several meters thicker than during the first run. In the electrical response, there was a smooth transition over about 7m

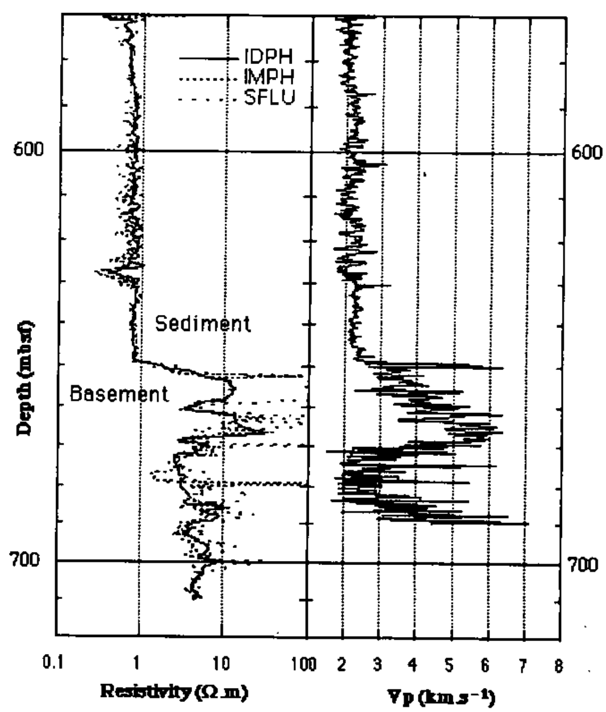


Figure 1. Transition of sediment to metamorphic basement in Hole 976E.

from the sediments to the basement. In other logs (caliper, bulk density, potassium content, neutron porosity, photoelectric factor), the change is more abrupt and places the basement top at 652.0–653.0 mbsf.

In conclusion, the log data are of excellent quality in the basement in Hole 976B, but are degraded by the large borehole diameter found in the two logging sections within the sediments. In Hole 976E, poor hole conditions prevented running the FMS across the transition between basement and sediments, but excellent data have been recorded with the Quad Combo string. Downhole measurements made at Site 976 will provide much data on the lithology, orientation of structures, stress orientation, and the tectonic deformation of the basement in this part of the Alboran Sea. The full suite of measurements will allow extensive analysis and core–log integration of high-grade metamorphic basement.

North Atlantic Arctic Gateways II

Logging Operator Report Leg 162

During ODP Leg 162, the second of two Arctic Gateways expeditions, wireline logging operations were undertaken at four of the eight new sites drilled. Two of these sites (982 and 984) were south of Iceland and were located in eastern N. Atlantic sediment drift sites along the Rockall Plateau and Reykjanes Ridge, respectively. The other two sites (986 and 987) were located along the Svalbard and East Greenland margins, respectively. Logging at Site 985 in the Norwegian Basin, east of the Icelandic Plateau and NE of Iceland, was attempted but unsuccessful due to poor hole conditions following coring operations. For the location of all sites occupied during ODP Leg 162, see the Science Operator report on page 7.

The standard suite of logging tools was used on this leg: the Quad combination which includes the sonic, electrical and nuclear tool strings, the Formation MicroScanner (FMS), and the Geochemical toolstring. In addition, the Geological High-resolution Magnetic Tool (GHMT), which is made up of a total field measuring tool and a magnetic susceptibility tool, was also deployed. The natural gamma tool (NGT) was also run on every toolstring to provide a means for intercalibration.

The quality of logging data during Leg 162 was generally very good for most of the toolstrings. The logs provided important data both for core–log integration, stratigraphy, and potentially for geochronologic control with the GHMT data. The following table and individual site summaries provide information on the type and quality of data available. Any additional questions regarding wireline logging tools or data collected during Leg 162 should be directed to the Borehole Research Group at the Lamont-Doherty Earth Observatory.

LOGGING CONTRIBUTIONS TO SITE OBJECTIVES

Site 982 (NAMD-1)

The objective of drilling at this relatively shallow site on the Rockall Plateau was to provide information on the long-term evolution of North Atlantic Intermediate Water (NAIW) and circulation patterns over the last ~18 My. Wireline logging data from Hole 982B provided stratigraphic control by filling in gaps in the core data through the use of natural gamma ray (NGR) and shallow focused resisitivity (SFLU) logs. These logs also helped identify exact depths of important reflectors seen in seismic records. Interpretation of FMS logs provided additional information on the type of sediments and the internal structure of the reflectors.

Site 984 (Bjorn Drift)

The high sedimention rate (120–170 m/My) area of the Bjorn Drift, on the east flank of the Reykjanes Ridge SW of Iceland, was targeted for high resolution Plio-Pleistocene climate evolution studies. The entire suite of logging tools were run in Hole 984B, and the overall log data quality is probably the best of all the sites. Wireline logging provide improved stratigraphic control and sedimentation rates through integration of core and log natural gamma and magnetic susceptibility data.

Possible geochronologic control for the interval between 2–5 My may come from analyses of GHMT data through the very strong in situ paleomagnetic measurements in these sediments. The GHMT measures both the earth's total field and the magnetic susceptibility within the sediments. The estimated age of sediments at the bottom of the borehole is approximately 4–5.5 My. However, good chronologic control from onboard biostratigraphic markers and paleomagnetic measurements on the cores were limited to the upper 2 My.

Site 986 (Svalbard Margin)

The glacial history of the Barents Sea region was the primary interest in drilling along the Svalbard margin. Previous coastal drilling and seismic work had identified seven main seismic reflectors. In Holes 986C and 986D, several logs including the density, natural gamma, and resistivity logs helped to locate 6 of the 7 main seismic reflectors, which turned out to be large mass flow deposits.

	Site 982	Site 984	Site 986	Site 987
Water depth (m)	Hole B: ~1144	Hole B: ~1660	Hole C: ~2063 Hole D: ~2062	Hole E: ~1682
Depth cored (mbsf)	~615	~503	Hole C: ~408 Hole D: ~965	~860
Interval logged (m)	~80–615	~80–500	C: ~80-408 D ~325–490	~77–495
Toolstrings deployed	Quad*, FMS, NGT	Quad, GLT, NGT FMS, GHMT	Quad, FMS GHMT, NGT	Quad, FMS GHMT, NGT

FMS logs provided a closer look at the structure of these dense mass flows. GHMT data may help to tighten up age control, as onboard measurements were not possible below ~100 m because of poor core recovery and the fractured condition of cores that were recovered in the lower 850 m. Unfortunately, the logging data covers only the upper ~500 m, since poor hole conditions in Hole 986D prevented logging below that level.

Site 987 (East Greenland Margin)
The history and development of the Greenland Icesheet was the primary interest in drilling a thick sediment sequence of ~850 m. This sedimentary sequence was located near the base of the slope off Scoresby Sound fjord, which is a major drainage pathway for the interior Greenland icesheet. Wireline logging in the upper 500 m of this 860 m borehole showed a long sequence of primarily glacial sediments and dropstones, interrupted by a massive 60m mass flow deposit. Resistivity, density, and gamma logs should provide good stratigraphic control and the means for core–log depth integration. GHMT data may help fill in gaps in the already well-developed onboard paleomagnetic stratigraphy, and provide a good testing ground for this tool.

Logging Operator Report Leg 164

Gas Hydrates

Leg 164 was designed to investigate the occurrence of methane hydrates in the sediment section beneath the Blake Ridge. The presence of hydrates in this area has long been suspected due to seismic reflection data showing a strong bottom-simulating reflector (BSR) at the base of a zone of low amplitude reflections (the so-called blanking zone). The primary objectives of the drilling included:

(1) an assessment of the amounts of gas trapped in extensively hydrated sediments;
(2) an investigation of the lateral variability in the extent of gas hydrate development;
(3) an investigation of changes in the physical properties associated with gas hydrate formation (see Leg 164 Scientific Prospectus).

A corollary to these objectives was to establish a quantitative relationship between seismic characteristics and hydrate occurrence in the sediment section. To this end it was necessary to measure the concentration of hydrate with depth and to measure physical properties that influence the acoustic response of the sediment column – in particular density and velocity – at a wide range of scales. A complicating factor in this investigation is that hydrate is not stable at normal shipboard conditions, so measurements at conditions as nearly in situ as possible were required. The various wireline log measurements were, therefore, critical to understanding hydrate occurrence within the Blake Ridge.

SHIPBOARD RESULTS

The geochemical (Aluminum Activation Clay tool (AACT) and Gamma Ray Spectrometry tool (GST)) logs and lithology (sonic, density, resistivity) logs were critical to the Leg 164 effort. In gamma ray spectroscopy well logging, each element has a characteristic gamma-ray that is emitted from a given neutron–element interaction. Specific elements can be identified by their characteristic gamma-ray signature, with the intensity of emission related to the atomic elemental concentration. By combining elemental yields from neutron spectroscopy well logs, reservoir parameters including porosities, lithologies, formation fluid salinities, and hydrocarbon saturations (including gas hydrates) can be calculated. The GST can be operated in two timing modes: inelastic, which mainly measures the neutron reactions in the high energy range (elements quantified: carbon, calcium, iron, oxygen, sulfur, silicon); and capture-tau mode which measures the gamma rays emitted from neutron capture (elements quantified: calcium, chlorine, iron, hydrogen, sulfur, silicon). In ODP wells the GST has historically been operated in capture-tau mode; however, on Leg 164 a selected number of inelastic mode measurements were made (45 stations). Preliminary interpretation of the geochemical logs onboard ship suggests that the inelastic carbon/oxygen data can be used to assess gas hydrate saturations.

In theory the porosity log (compensated neutron log measured by the compensated neutron tool: CNT-G) provides a direct measure of porosity. The sonic and litho-density (HLDT) logs provide the necessary information to determine the acoustic response. However, in reality, because of poor hole conditions and inadequate tool design, the porosity tool provided little immediately useful information, and the sonic and density tools provided data contaminated by noise. Initial onboard attempts to generate synthetic seismograms that bore any resemblance to the observed vertical incidence seismograms in the vicinity of the drilling sites were not satisfactory. Our best onboard estimates of porosity were obtained from the resistivity logs via Archie's Law and calibration with the porosities measured in core samples in the laboratory. Even this estimate of porosity is, however, somewhat suspect since there was very little range in observed resistivity from which to calculate a regression equation, $\ln(FF) = -m*\ln(F) + \ln(a)$, and few or no independent measurements of pore water resistivity from which to determine the formation factor. Shipboard we determined these constants by using core-derived porosity measurements to calibrate the extremes of the observed log resistivity measurements. We assumed seawater resistivity for the pore water resistivity with a correction for the temperature increase downhole.

Preliminary shipboard analyses included estimates of porosity and hydrate saturation from resistivity logs and estimates of elemental content including carbon/oxygen ratios from the geochemical tool string (GLT) measurements. The geochemical data can be used to estimate porosity and hydrate saturation independently from other log measurements.

During post-cruise log analysis the various wireline logs will be more extensively analyzed and integrated with core measurements, including pore water chemistry data and vertical seismic profile (VSP) results in order to obtain more reliable estimates of hydrate concentration, porosity, and a synthetic seismogram. In addition, the acoustic logs obtained with the new shear sonic tool and the Schlumberger sonic tool will be integrated with the results from the VSP and walk-away offset reflection data.

The 1997 ODP Science Plan

The 1997 schedule for the *JOIDES Resolution* was set in December 1995 at the Annual Meeting of the JOIDES Planning Committee. At the completion of ODP Leg 170 (Costa Rica accretionary wedge), the ship will sail from the Pacific Ocean through the Panama Canal and the Caribbean into the North Atlantic Ocean for a series of legs (Legs 171B, 171C, 173, 174A and 174B). The *JOIDES Resolution* will then conduct one leg of drilling in the South Atlantic (Leg 175) before going to the Indian Ocean for Leg 176.

See back cover for the *JOIDES Resolution* schedule to Leg 176.

LEG 171A: PHYSICAL PROPERTIES AT THE BARBADOS ACCRETIONARY PRISM. The Barbados accretionary complex is the best studied of four areas worldwide that have been selected by JOIDES as type examples for studies of active margin processes. Leg 171A represents a continuation of ODP's efforts to understand margin processes at the Barbados accretionary complex by employing Logging While Drilling (LWD), state-of-the art industry standard logging technology, for the in situ evaluation of physical properties, including transient borehole conditions. Leg 171A will acquire more LWD data in four additional holes in the Barbados accretionary prism. In order to determine the characteristics of the negative polarity reflections at Barbados, measure the physical properties of faults, and assess the physical properties of the incoming sedimentary sequence. Extensive previous drilling at the Barbados accretionary prism and 3-D seismic surveys provide a rich framework for log interpretation, seismic calibration and process evaluation. The results will assist interpretation of similar but less active systems in sedimentary basins elsewhere, contributing to the analysis of groundwater, hydrocarbon migration and earthquake processes.

The continuation of ODP efforts to understand active margin processes at the Barbados prism is relevant to the objectives of the US MARGINS initiative, the ION program, and other Japanese collaborative programs, especially those projects focusing on the Nankai Trough.

LEG 171B: BLAKE PLATEAU/BLAKE NOSE. Much recent attention has focused on reconstructing the Cenozoic history of deep water chemistry and carbonate dissolution by drilling depth transects in the equatorial oceans. While sequences of Cretaceous and Paleogene sequences have generally been too deeply buried to be recovered either completely or consistently along depth transects, these sequences are of great interest as they record climates and patterns of water-mass development under conditions very different from those of modern oceans. In order to investigate the chemistry of intermediate to deep-water masses and their circulation in the northern hemisphere during the Cretaceous and early Cenozoic, as well as test the hypothesis of the existence of a "warm saline deep water mass" during this time, ODP Leg 171B aims to drill five holes along a depth transect across the Blake Plateau. Sediments on the Blake Plateau and Blake Nose offer an ideal record for reconstructing water mass chemistry and circulation because the northern subtropical location of the Blake Plateau and its position adjacent to the western opening of the Tethys Seaway place the area in the mixing zone between water-masses of different origins during the Paleogene and late Cretaceous. An additional objective of Leg 171B is the examination of events surrounding the K/T boundary, since it should be penetrated by four of the planned holes.

The 1996 ODP Long Range Plan identifies the study of the ocean's record of past environmental change as a major research initiative that will increase our understanding of the sensitivity of different parts of the climate system, permitting the further refinement of models used to predict future climate change. The objectives of Leg 171B are not only relevant to this goal, but also to the aims of the IMAGES, MESH and MARGINS geoscience programs.

LEG 172: WESTERN NORTH ATLANTIC SEDIMENT DRIFTS. The primary goal of Leg 172 is to obtain a detailed history of late Neogene paleoceanography and paleoclimate in the North Atlantic by drilling Neogene hemipelagic sediments which have been deposited at accelerated rates on western North Atlantic sediment drifts. Specifically, the drilling program aims to investigate the millennial-scale oscillations of stable isotopes (C, O), carbonate and trace metals in drift deposits, the nature of cyclicity of these oscillations, and how these cycles are related to the history of northern hemisphere glaciations during the Late Neogene. In addition, this drilling program will investigate sediment wave migration and drift sedimentation processes, detailed variations of the Earth's magnetic field (secular variations, reversals), and the geotechnical/acoustic properties of deep-sea sediments.

These objectives will be tackled through a series of sites, with multiple APC-XCB cored holes, arranged in a depth transect across the Blake-Bahama Outer Ridge, the Bermuda Rise, and the Carolina Slope. Because of the very high deposition rates in this area, only ODP drilling can recover cores that are long enough to permit investigation of the ocean-climate system at high resolution on Milankovitch (orbital) time-scales and to trace the evolution of this system since the inception of northern hemisphere glaciation. Leg 172 drilling will provide scientists with the first ODP depth transect in the North Atlantic, enabling scientists to monitor the history of North Atlantic Deep Water production, glacial intermediate water production, and changing sediment fluxes with depth.

LEG 173: NORTH ATLANTIC RIFTED MARGINS – THE IBERIA MARGIN. Rifted margins contain the principal record of the break-up that follows continental rifting and the onset of sea-floor spreading. ODP drilling contributes uniquely to rifted margin studies because it provides the only means of directly characterising the nature, age and emplacement conditions of igneous, metamorphic and/or sedimentary rocks formed, deposited or tectonically exposed during margin formation. Non-volcanic margins, in particular, provide opportunities to investigate and understand the tectonic aspects of rifting, since faults which penetrate deep into the crust and uppermost mantle may cause deeper rocks to be exposed at the top of acoustic basement.

The west Iberia margin is an excellent example of a non-volcanic rifted margin. The Galicia Bank and Iberia Abyssal Plain segments of the margin were drilled during ODP Legs 103 and 149 respectively, and have also been extensively studied geophysically. Legs 103 and 149 have revolutionised ideas about rifted margins by demonstrating the existence of mantle along these margins. This information, together with the recognition of low angle faulting and 'core-complexes' provided a new dimension for looking at deformation of the continental crust during break-up. ODP Leg 173 will be a sequel to Leg 149. Leg 173 will aim to drill a small number of holes on basement highs, mainly within the Ocean–Continent Transition (OCT), to characterise the OCT, to test the simple-shear lithospheric extension hypothesis for this probable lower-plate margin, to determine the extent of synrift magmatism, and to determine the existence and nature of the first-formed oceanic crust. These observations in combination with the improved quality and quantity of seismic images, will permit better structural interpretation and allow the time frame and nature of generation of melts from the mantle during break-up and earliest generation of 'normal' oceanic crust to be addressed.

The goals of Leg 173 drilling are closely tied to the objectives of a number of European MAST community programs, the US MARGINS initiative, and many national programs which have funded research on the Iberia–Galicia rifted margin.

LEG 174A: NEW JERSEY MID-ATLANTIC TRANSECT. Determining the age, amplitude, mechanism and stratigraphic response to sea-level change continues to be a fundamental goal of the Ocean Drilling Program. The general goals of the New Jersey Mid-Atlantic Transect (MAT) are to determine the geometry and age of Oligocene to Miocene depositional sequences, and to evaluate the role of relative sea-level changes in developing this record. When completed, the New Jersey MAT will evaluate possible causal links between glacio-eustatic changes inferred from the deep sea $\delta^{18}O$ record and depositional sequences from this "Icehouse World".

Significant progress has since been made towards completing the entire New Jersey sea-level transect through the accomplishments of ODP Leg 150 and the New Jersey Coastal Plain Drilling Project (Project 150X). Leg 174A will drill four sites on the outer shelf and slope, which will address all but the lower Miocene–Oligocene objectives of the overall program. The additional intervening shelf samples that must be drilled to advance the New Jersey MAT project to a meaningful conclusion lie in water depths too shallow for the capabilities of the *JOIDES Resolution* and will have to be drilled with an alternate platform.

The New Jersey margin is one of two study areas recently selected by the US Office of Naval Research for a multi-year initiative that it has termed "Stratal Formation" (STRATFORM). Together with studies of the contrasting margin off Northern California, the goal is to understand the range of factors affecting shelf and slope sedimentation. Clearly, the missions of STRATFORM and the sea level transect coincide off New Jersey. The New Jersey MAT is also directly relevant to the US MARGINS initiative, and will produce a test of oil-industry models of sea-level change.

LEG 174B: CORK 395A. Leg 174B will carry out a selected suite of downhole experiments in Site 395A, which was drilled during DSDP Leg 35 (1975), and then emplace an instrumented borehole seal or CORK with thermistor cable and pressure sensor. Site 395 is located in 7 My old crust in an isolated sediment pond considered typical of the structure and hydrogeological setting of thinly sedimented crust formed at slow spreading rates. Since it was drilled in 1975–76, extensive downhole measurements have been obtained during multiple visits to the site which indicate a strong downhole flow of ocean bottom water into the permeable upper oceanic crust that has continued virtually unabated in over 20 years since the hole was drilled. The primary goal of the CORK experiment at Site 395A is to monitor how the hydrological system varies with time as natural hydrogeological conditions are re-established once the hole is sealed. The experiment will provide essential information about the formation pressure and permeability structure, which are the real keys to understanding the crustal hydrogeology, and which control the active off-axis hydrologic system around Site 395A. The natural thermal regime will allow determination of whether the observed downhole flow is dynamically maintained due to active circulation in the basement, regardless of whether or not a borehole is present, instead of flow induced by the geothermal gradient.

For the past five years, ODP engineers have been involved in a collaborative effort with scientists to establish borehole observatories to collect time-series measurements of parameters such as temperature and pressure. The effective post-drilling use of boreholes represents an expansion of ODP's focus from mainly acquiring samples and downhole geophysical data while the drill ship is present, to making long-term observations or doing active experiments in concert with other earth science programs, including ION. The new 1996 LRP for ODP will emphasise as one of the ODP's three major initiatives the location of geophysical and geochemical observatories in the uniquely quiet environment of sea floor boreholes to provide both a clearer view of earth structure and as a means to monitor earth processes.

Part of Leg 174B will be used to test a hammer drill-in casing system, which, if successful, will replace the time-consuming setting of the current hard rock guidebases.

LEG 175: BENGUELA CURRENT. The goal of ODP Leg 175 is to reconstruct the Cenozoic history of upwelling off Angola and Namibia using data from sites located between 5° and 32°S. The individual transects reflect examinations of specific "end-member" upwelling environments which collectively comprise one of the most concentrated centres of ocean productivity. One of the major aims will be to monitor the evolution of the Benguela Current system and its relationship with the onset of Northern Hemisphere and Antarctic glacial cycles. Many of the proposed sites are expected to have high sedimentation rates, offering an opportunity to develop very detailed paleoceanographic records. Sediments will be largely diatomaceous and carbonate-rich clays with variable, and occasionally very high, organic carbon contents.

Of principal interest is the period since the Miocene, when a pattern of oceanic circulation akin to the modern circulation became established in the Atlantic. The sites of this program have been selected to record the development of the Benguela Current system, productivity variations, seasonal upwelling, pelagic offshore divergence, and provide a detailed correlation between the margin record and the pelagic record. The environment of the Angola/Namibia margin also provides an excellent setting for natural experiments in diagenesis and for the formation of economically important resources such as petroleum and phosphate.

The Benguela Current is linked to the exchange of heat between the South Atlantic and North Atlantic. Today, the extent and intensity of the modern Benguela Current directly influence the South Equatorial Current and its transport of heat from the South Atlantic to the North Atlantic. This energy transport, operating over great distances, is involved in the formation of polar ice caps and influences their magnitude. Undoubtedly, the development of the Benguela Current has had an important bearing on the evolution of the climate of the northern hemisphere, and particularly that of northern Europe.

The ocean's vital role in climatic change, especially through heat transport and control of carbon dioxide, has prompted the initiation of large integrated efforts in physical oceanography (WOCE, TOPEX), chemical oceanography (GOFS, JGOFS), and marine geology (IMAGES, MESH, MARGINS) whose goals are to better understand the mechanisms of climate change. The sites that comprise ODP Leg 175 drilling are intended to contribute information about the paleoenvironment of the Benguela Current and Angola/Namibia upwelling system which will help answer major questions about global paleoenvironments.

LEG 176: RETURN TO 735B. The exposures along the shoal bank at the Atlantis II Fracture Zone offer an unique setting to investigate the composition and structure of the lower oceanic crust. ODP Site 735B, is located on a 15 km long wave-cut terrace 18 km east of the Atlantis II transform fault. It was originally drilled on Leg 118 and represents the only existing deep penetration into plutonic basement in the oceans. The goal of Leg 176 drilling is to deepen Site 735B to a nominal depth of 2 km sub-basement to determine directly the nature of the magmatic, metamorphic, tectonic and hydrothermal processes in the lower ocean crust at a slow-spreading ocean ridge. While it is hypothesised that deepening Site 735B may reach the petrologic MOHO, the recovery of a truly representative section of plutonic crust, will, by itself, be a major breakthrough in understanding the geologic processes occurring beneath ocean ridges.

The new ODP Long Range Plan identifies two major research themes that encompass the vast range of fundamental scientific questions that can be explored by ocean drilling: the dynamics of Earth's environment and the dynamics of Earth's interior. Within the second theme, ODP will emphasise the goal of penetrating hitherto inaccessible regions beneath the sea floor to explore the underlying processes that form continents, rifts, oceanic crust and economic resources (precious metals, ores, energy) as a special initiative. The scientific objectives and technological initiatives of Leg 176 clearly represents a start towards meeting this challenge.

International News, Meetings and Announcements

InterRidge News

Membership

Since our last update, the InterRidge community has continued to grow. At the beginning of 1996, Germany upgraded its membership from Associate to Principal. The German ridge crest research community has energetically undertaken development and coordination of the DeRidge Program, recently publishing the first formal issue of the *DeRidge Newsletter*. InterRidge is also very pleased to welcome Norway as a new Associate Member. Norway announced its intention to become an Associate Member for 1996, 1997 and 1998 at the start of this year. The number of Corresponding Members has also grown with the welcome addition of Denmark. For 1996, InterRidge now counts 6 Principal Members (France, Germany, Japan, Spain, the United Kingdom, the United States), 2 Associate Members (Norway, Portugal) and 11 Corresponding Members (Australia, Canada, Denmark, Iceland, India, Italy, Korea, Mexico, Russia, Sweden, Switzerland).

InterRidge Office Transfer

The University of Durham's 3-year term as host to the InterRidge Office will end in December 1996. In anticipation of the scheduled transfer of the InterRidge Office to another member nation, a call for bids was announced in January 1996 using the e-mail list. Individuals, groups or institutions from any 1997 Principal Member Nation were invited to submit bids to become hosts. Further details are available from the InterRidge Office.

Forthcoming Events

Planning is underway for two large symposia/workshops in conjunction with three international programs.

The Ocean Lithosphere & Scientific Drilling into the 21st Century will be convened by Drs. H. Dick and C. Mével at Woods Hole, MA, USA on 26–28th May. This joint effort of the JOIDES Ocean Drilling Program, the International Association of Volcanology and Chemistry of the Earth's Interior, and InterRidge, aims to plan an integrated program of scientific ocean drilling to evaluate and extend current models for the formation of a laterally complex and heterogeneous ocean lithosphere.

Reykjavik will be the site of a joint *FARA-InterRidge Mid-Atlantic Ridge Symposium* to be held at the Nordic Volcanological Institute of the University of Iceland on 19–22th June. The Symposium will be convened by Drs. C.H. Langmuir and H.D. Needham and is being planned in collaboration with Drs. K. Gronvold, R.C. Searle and H. Sloan. The Symposium marks the end of the five-year FARA Project of Franco-American co-operative study of the Mid-Atlantic Ridge. A carefully planned program of invited and contributed presentations will synthesize the extensive body of work carried out under the auspices of FARA. In addition to two half-day field trips included in the Symposium program, a three-day pre-Symposium field trip is planned, giving participants the rare opportunity to make real-time, direct observations of the ridge.

WWW

The InterRidge World Wide Web home page continues to evolve with the addition of a series of pages announcing Piggy-back Proposals and offers of ship time. There are also newly updated schedules of ridge crest cruises – many thanks to all of the Principal Investigators who sent information on their upcoming cruises. As the Phase 2 Project activities get underway, new pages will appear reporting their progress.

MEETING ANNOUNCEMENT
In the Wake of the Swedish Deep-Sea Expedition: Development of Paleoceanography as a New Field of Science
Commemorating the 50th Anniversary of the Albatross expedition 1947–48

Stockholm and Göteborg, Sweden, August 25–28, 1997

Organized by: **The Royal Swedish Academy of Sciences**
Convenors: **Jan Backman** and **Kurt Boström**, Stockholm University, and **Anders Stigebrandt**, University of Gothenburg, Sweden

A two day international conference will be arranged at the Royal Academy of Sciences in Stockholm. The theme of the meeting will be historical developments and recent advances in paleoceanography, in the spirit of the Swedish Deep-Sea Expedition. Invited talks will be presented by Gustaf Arrhenius, Margaret Delaney, Eystein Jansen, Larry Mayer, Nick Shackleton and Rainer Zahn. Afternoons will be devoted to poster sessions.

The conference will be followed by a one day symposium in Göteborg, organized by the Earth Science Centre. The theme will be paleoceanography of semi-enclosed seas.

A limited number of travel stipends for graduate students/post-docs will hopefully be available.

Expressions of interest to participate/present a poster should be sent to Margareta Wiberg, Royal Swedish Academy of Sciences, Box 50005, S-104 05 Stockholm, Sweden. Telephone: +46 8 673 95 00. Fax: +46 8 15 56 70.
E-Mail: marga@info.kva.se.
Questions can also be addressed to Jan Backman (jbackman@geol.su.se) and Anders Stigebrandt (anst@oce.gu.se).

Please submit your interest before 1 September 1996.

THE OCEAN DRILLING PROGRAM RETURNS TO ITS ROOTS

In Memory of Cesare Emiliani

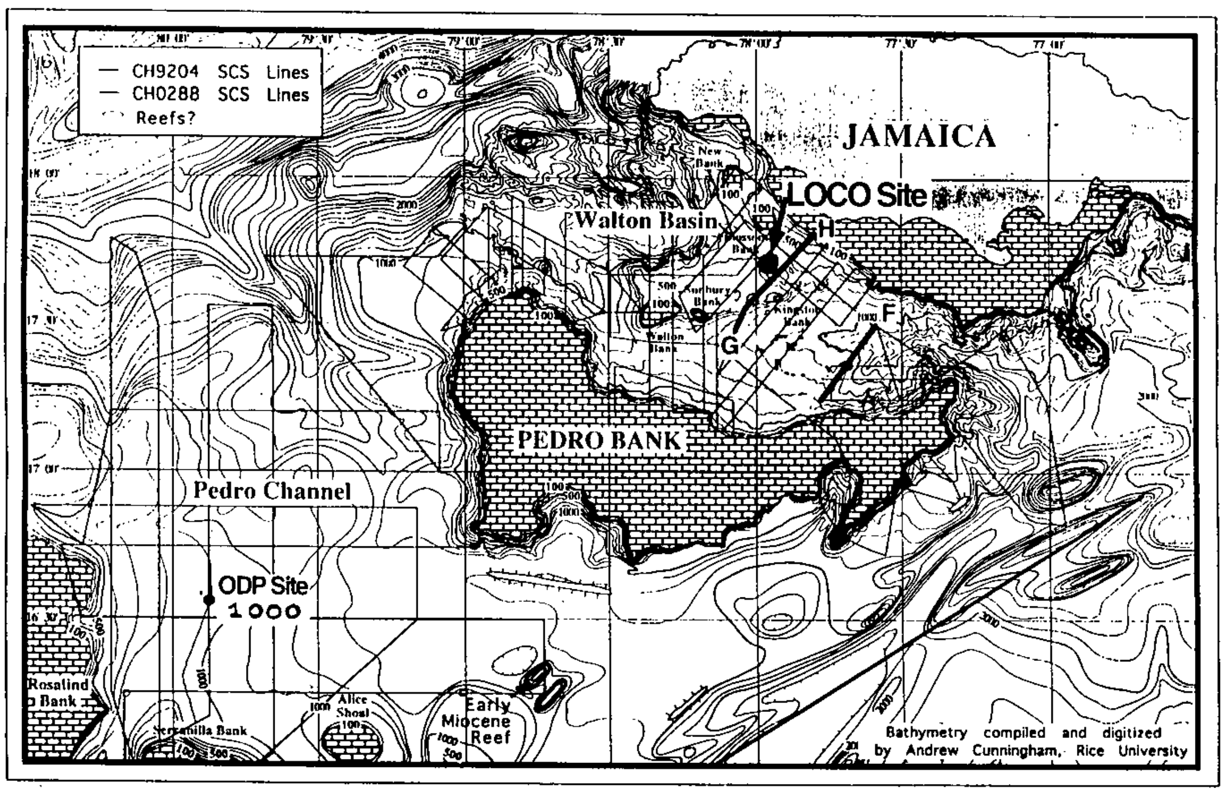
contributed by

ANDRE DROXLER

In January of 1996, the Ocean Drilling Program returned to its roots by drilling ODP Site 1000 on the west side of Pedro Channel, one of a series of channels that dissects the northern Nicaraguan rise, where 30 years ago in December 1963, Cesare Emiliani led a scientific ocean drilling expedition to recover the first ever long core at LOCO Site 1. Cesare Emiliani's LOCO (LOng COres) expedition was the predecessor of the Deep Sea Drilling Project (DSDP) and the Ocean Drilling program (ODP). Moved by the fortuitous location of ODP Site 1000 on the same oceanic feature as LOCO 1, the northern Nicaragua Rise, and in recognition of Cesare Emiliani's outstanding contribution to scientific ocean drilling, the shipboard science party of Leg 165 have dedicated their Initial Results Volume to his memory.

The LOCO drilling was carried out on the D/V *Submarex*, a 174 foot long vessel owned and operated by Global Marine. The vessel was equipped with a skid-mounted Howard Turner drilling rig, capable of drilling in maximum water depths of about 835 meters. The objective of the LOCO expedition was to recover continuous deep-sea sedimentary sections, representing as much of the geological time-scale as possible. Because pelagic sediments usually occur at water depths greater than 2000 meters, however, the restricted range of the D/V *Submarex*, was a severe limitation to the pelagic drilling and coring objectives of the LOCO expedition. This consideration led Cesare Emiliani and his colleagues to attempt the first deep sea drilling of a continuous pelagic sequence in water depths of less than 650 meters in the western Caribbean between Jamaica and Nicaragua/Honduras. Potential drilling targets were selected on the northern slope of the Rosalind Bank and the Walton Basin. Drilling in the Walton Basin was successful and the first ever long core measuring 23 meters (56.4 m of penetration) was obtained at LOCO 1. The core contained a record of the Pliocene–Pleistocene boundary. Prior to the LOCO expedition, pelagic sequences recovered from stratigraphic and paleoceanographic studies had been limited to the length of a 15–20 m piston core.

On Leg 165, coring at ODP Site 1000 recovered a 696 meter thick, almost turbidite-free sedimentary sequence of periplatform sediments and sedimentary rocks, interbedded with volcanic ash layers and intervals of redeposited periplatform/pelagic and neritic carbonate sediment. This excellent record, which spans a continuous 20 million year period, promises to provide many new insights into the history of Caribbean subthermocline (intermediate) water masses, the segmentation and subsidence history of the Northern Nicaragua Rise, the seismic stratigraphy of the region, and a record of explosive volcanism during the Neogene.



Location of the LOCO Site in Walton Basin drilled by Cesare Emiliani in December 1963.

International Conference
Neogene Mediterranean Paleoceanography
Trapani, Sicily, 28–30 September, 1997

An International Conference on Neogene Mediterranean Paleoceanography will be held in Erice (Trapani, Sicily) under the auspices of the International School of Applied Geophysics, c/o "Ettore Majorana Center for Scientific Culture" on 28–30 September, 1997, preceded by a 3-day field trip. The meeting will be sponsored by the Geological Society of Italy and the European Consortium for Ocean Drilling (ECOD).

Convenors are: **M.B. Cita** (University of Milano), representing the Geological Society of Italy; and **J.A. McKenzie** (ETH, Zurich), representing the ECOD-ESCO (ESF Scientific Commitee for the ODP).

The aim of the conference is to discuss and improve our knowledge of the post-alpine orogeny evolution of Mediterranean paleoceanography, taking into account the results of the ODP Legs 160 and 161 which were dedicated in part to unravelling the origins of Mediterranean sapropels.

Session leaders will be appointed to focus discussion on problems related to physical oceanography, inorganic geochemistry, cyclic stratigraphy, sequence stratigraphy, paleoecology, and paleoclimatology and eventually to prepare a synthesis of events related to specific time-slices, e.g. present day, last deglaciation, glacial–interglacial Quaternary, Pliocene climatic deterioration, early Pliocene flooding, the Messinian Salinity Crisis, and Miocene paleoceanographic evolution with special emphasis on the interruption of the connections with the Indian Ocean, and the effects of the onset of monsoon regime conditions.

The field trip will focus on the following themes:
1 – Paleoceanographic conditions leading to cyclic sedimentation in pre-salinity crisis time.
2 – Messinian Salinity Crisis: cyclic sedimentation in basinal and piggy back setting.
3 – Paleoceanographic conditions leading to cyclic sedimentation in post-salinity crisis time.

The number of conference participants is limited to 100 persons. Total cost for the 3-day stay in Erice will be US$400. The excursion will be limited to 50 persons and will cost approx. US$350 for transportation, room and meals.
The 2nd circular will be sent **only** to those who respond to the 1st circular.
Since the total number of participants to both the conference and excursion is strictly limited, we must begin planning well in advance. Deadline for response to the 1st circular is **30 September, 1996.**

Name: .... Institution: ....

Tel: .... Fax: .... e-mail: ....

I plan to attend the meeting yes no (circle one) I plan to attend the excursion yes no

I intend to present a contribution on the following topic: ....

....

....

Oral preferred Poster preferred (circle one)

Please return to: **Mrs. Eva Pour, ETH-Zentrum, Geologisches Institut, Sonneggstrasse 5, Zurich, Switzerland** by **30 September, 1996.**
Tel: +41-1-632 3680, Fax:+41-1-632 1030, e-mail: pour@erdw.ethz.ch

JOIDES PROPOSAL SUBMISSION

There are two options to get your ideas into the system.

A LETTER OF INTENT
A Letter of Intent is a three to four page outline of your idea(s) for scientific ocean drilling. It may be submitted as an alternative to a full proposal and will be forwarded to the panels for comment. Based on panel responses, the preparation of a formal proposal may be recommended.

FULL PROPOSAL
An ODP drilling proposal must contain an abstract (400 words or less) and the following information to be accepted and forwarded to the four thematic panels for review:

- Scientific objectives must be linked to the themes of the *ODP Long Range Plan (LRP)*, which is available from the JOI.
- Drilling sites that are tied to the stated scientific objectives and justified by appropriate site survey data.
- Completed ODP Site Summary Forms. Blank forms are available from the JOIDES Office on disk or hard copy.

In addition:
Ten hard copies of the entire proposal must be sent to the JOIDES Office. The JOIDES Office would also appreciate receiving a copy of the proposal via electronic mail or on floppy disk.

JOIDES PROPOSAL DEADLINES

ALL JOIDES PROPOSAL DEADLINES, FROM JULY 1996, WILL BE ADHERED TO. PROPOSALS WILL BE RETURNED IF RECEIVED AFTER THE DEADLINES.

Please note that if you submit a revision or addendum to an existing proposal in which you have modified the proposed drilling sites or changed their location, you must follow the JOIDES Office Drilling Site Designation Policy (available from the JOIDES Office). Proposals that do not follow this scheme will be returned to proponents before being sent out for review. THERE WILL BE NO EXCEPTIONS TO THIS. Failure to follow the JOIDES Office Drilling Site Designation Policy could delay the review of your proposal by up to six months.

DEADLINES FOR SUBMISSION OF SITE SURVEY DATA PACKAGES ARE JULY 1 AND NOVEMBER 1.

Proposals prioritized by thematic panels as being highly ranked are reviewed by the Site Survey Panel (SSP). Proponents are urged to submit as complete a data package as possible, as early as possible, once their proposals are highly ranked (refer to the Spring 1996 Global Ranking Table in this issue). Site survey data in support of proposals is to be submitted to the JOIDES/ODP Site Survey Data Bank, Lamont-Doherty Earth Observatory, Palisades, NY 10964 (US); Tel: (914) 359-2900; Fax: (914) 365-2312; Email: odp@ldeo.columbia.edu. The guidelines for submission of site survey data are available from the JOIDES Office at any time.

As of October 1, 1996 the new JOIDES Office address will be: JOIDES Office
Department of Geology and Geophysics
Woods Hole Oceanographic Institution
Woods Hole, MA 02543 USA

PROPOSAL REVIEW CRITERIA FOR ODP THEMATIC PANELS (AS OF 1 JAN 1996)

A. Thematic Relevance

- A 1 Highly relevant to top thematic objectives
- A 2 Relevant to thematic objectives
- A 3 Portions are relevant, interdisciplinary approach required
- A 4 Could be relevant with minor revisions
- A 5 Not relevant to thematic objectives
- A 6 Could be relevant to thematic objectives with revisions.

B. Scientific Merit

B 1	Objectives	B 1.1	Well formulated
		B 1.2	Needs revision
		B 1.3	Poorly formulated
B 2	Location	B 2.1	Appropriate
		B 2.2	Not appropriate

C. Scientific Feasibility

- C 1 High probability of achieving scientific objectives
- C2 Needs more supporting data to achieve objectives (e.g. will need other sorts of data to interpret drill results)
- C 3 Insufficient data to assess scientific feasibility
- C 4 Scientific feasibility highly questionable

D. Preliminary Technical Feasibility Assessment

- D 1 Technology in hand and tested
- D 2 Technology in hand, untested
- D 3 Technology under development
- D 5 Recommend proposal be reviewed by DMP, IHP, SMP, or TEDCOM
- D 4 Technology not available
- D 6 Possible safety problems; early PPSP review is recommended.

E. Proposal Completeness (indicate where deficient)

- E 0 No deficiencies
- E 1 Abstract
- E 2 Site location map
- E 3 Survey coverage map
- E 4 Regional geologic setting
- E 5 Balanced cross-section (where appropriate)
- E 6 Site summary forms
- E 7 Reference list
- E 8 Other deficiencies specified in review comments

F. Recommended Action (to proponent)

- F 1 Proposal is of high priority; no further action is necessary
- F 2 Proposal is of high priority, but recommend revision as indicated
- F 3 Proposal is of low priority, but could become high priority
- F 4 Proposal is of low priority, and unlikely to become high priority.
- F 5 Of interdisciplinary interest

Satellite image of the storm at 1201 GMT on 29 September 1995, showing the relative positions of the East Greenland coast and the JOIDES Resolution. *This exceptional storm developed rapidly out of two easterly moving low-pressure systems that merged into a system that was more intense and more northerly-moving than initially forecast.*

1996 Spring ODP Thematic Panel Global Rankings

Rank	LITHP		OHP		SGPP		TECP	
	Number	Title	Number	Title	Number	Title	Number	Title
1	448-Rev	Ontong Java LIP	464	Southern Ocean Paleoceanography	481	Red Sea Deeps	450	Taiwan Arc–Continent collision
2	480	Caribbean Cretaceous Basalt Province	441-Rev	SW Pacific Gateway	445-Rev2	Nankai Trough	447-Rev2	Woodlark Basin
3	481	Red Sea Deeps	465-Add	SE Pacific Paleoceanography	Generic	Antostrat	431-Rev	Western Pacific Seismic Network
4	451-Rev3	Tonga Forearc	367-Rev3	Cenozoic Carbonates in the Great Australia Bight	367-Rev3	Cenozoic Carbonates in the Great Australia Bight	445-Rev2	Nankai Trough
5	Generic	Seismic Boreholes	484	East Asian Monsoon History	484	East Asian Monsoon History	442	Northern Mariana Rift
6	457	Kerguelen LIP	485	Southern Gateway – Australian Antarctica	476	Hudson Apron	484	East Asian Monsoon History
7	472	Izu–Mariana Mass Balance	449 + 488	Mesozoic Weddell Sea & Southern Ocean Circulation	472	Izu–Mariana Mass Balance	451-Rev3	Tonga Forearc
8	426-Rev	Australia–Antarctica Discordance	452-Rev2	Antarctic Glacial History of Sea Level Change	455-Rev	Laurentide Ice Sheets Outlets	Generic	Crust Structure
9	420	Evolution of Ocean Crust	455-Rev	Laurentide Ice Sheets Outlets	453	Bransfield Strait Antarctica	Generic	Mass Balance
10	442-Rev	Northern Mariana Rift	483	ACC – Scotia Sea and Falkland Trough	355-Rev5	Gas Hydrates / Peru Margin	457-Rev3	Kerguelen Plateau

DRILLING SITE DESIGNATIONS

As directed by PCOM in December 1994, and so that each point on the seafloor that has ever been considered for drilling is known by one and only one name, and that name is never used for any other point on the seafloor, the JOIDES Office has adopted and ODP will use the following format henceforth:

AAAAAnnX

AAAAA is up to 5 alphanumeric characters (although 4 is preferable) indicating the area of the proposed drill site. **nn** is two numerals indicating the number of the site within that area.

X is one letter indicating variants (alternates or revisions) of that site. The first time a site is proposed, **X=A**. If alternative sites are proposed in close geographic proximity and sharing scientific objectives, they would have **X=A**, **X=B**, **X=C**, etc. Every time a site is moved, a new value of **X** would be used to identify the relocated site.

The site designator should not attempt to encode information about the priority of the site (i.e. no "alt." designators). Because site priorities often change as the proposal passes through the advisory system, a site name that encodes priority may became obsolete or misleading by the time the site is drilled.

Why are sites moved?
As a proposal moves through the advisory system, it occasionally becomes necessary or advisable to shift the position of a site in response to new data, new hypotheses, safety concerns, international clearance issues, or man-made seafloor hazards.

New Proposals in the ODP System

(reviewed in spring 1996)

Prop. no.	Date received	Abbreviated title	Contact
348-Add4	Nov. 1995	New Jersey MAT: NJ Realism	Ken Miller
334-Add2	Sept. 1995	Galicia Margin S' Reflector	Gilbert Boillot
334-Add3	Jan. 1, 1996	Galicia Margin S' Reflector	Gilbert Boillot
367-Add2	Oct. 1995	Great Australian Bight Site Survey Cruise Proposal	David Feary
367-Rev3	Jan. 1, 1996	Cenozoic carbonates of the Great Australian Bight	David Feary
421-Rev2	Jan 19, 1996	Alkali-acidic rocks of the Volcano Trench	B. I. Vasiliev
441-Rev	Jan. 5, 1996	Southwest Pacific Gateway/Deep Pacific Source	Robert Carter
442-Add	Jan. 2, 1996	Rift Initiation in the Northern Mariana Trough	Robert Stern
445-Rev2	Jan. 2, 1996	Nankai Trough Accretionary Prism	Greg Moore
447-Rev2	Jan. 5, 1996	Woodlark Basin	Brian Taylor
451-Rev3	Jan. 2, 1996	Tonga Forearc	Chris MacLeod
452-Rev2	Jan. 2, 1996	Antarctic Glacial History of Sea Level Change	Peter Barker
455-Rev2	Jan. 15, 1996	Laurentide Ice Sheet Outlets (LISO)	David Piper
457-Rev3	Jan. 15, 1996	Kerguelen Plateau	Fred Frey
461-Add2	Nov. 1995	Return to Iberia	Bob Whitmarsh
463-Add	Jan. 2, 1996	Shatsky Rise Plume Impact Hypothesis	Will Sager
465-Add	Jan. 1, 1996	SE Pacific paleoceanographic depth transects	Alan Mix
472-Rev	Jan. 2, 1996	Marianas-Izu Mass Balance	Terry Plank
476-Add	Nov. 27, 1996	Hudson Apron Submarine Slope	Loncoln Pratson
478-Add	Jan. 2, 1996	Eastern Nankai Multiple Shortening	H. Tokuyama
482	Jan. 2, 1996	Wilkes Land margin	Carlota Escutia
483	Jan. 2, 1996	ACC – Scotia Sea and Falkland Trough	Peter Barker
484	Jan. 9, 1996	East Asian Monsoon History/South China Sea	Pinxian Wang
485	Jan. 2, 1996	Southern Gateway – Australia and Antarctica	Neville Exon
486	Jan. 2, 1996	Paleogene Equatorial Pacific APC Transect	Mitch Lyle
487	Jan. 2, 1996	Palau-Kyushu Ridge and Shikoku Basin	Yasuhiko Ohara
488	Jan. 2, 1996	Southern Ocean Circulation – Weddell Sea	Y. Kristoffersen
489	Jan. 2, 1996	Ross Sea Shelf – Glacial History and Sea Level	Fred Davey
490	Jan. 2, 1996	Prydz Bay – Cooperation Sea/Glacial History	P. O'Brien
491	Jan. 2, 1996	Cyclic Crustal Accretion – Angola Basin	Karl Hinz
492	Dec. 22, 1995	Taiwan Arc-Continental Collision	Serge Lallemand
493	Feb. 7, 1996	Rifting & Crustal Fluid/Okinawa Trough	Naisheng Li
494	Jan. 15, 1996	Deformation and Evolution of South China Sea	Bochu Yao
495	Jan. 1, 1996	Rifting and Isolation of Microcontinents	W.E. Stephens

New LOIs in the ODP System

(reviewed in spring 1996)

LOI no.	Date received	Abbreviated title	Contact
63	Jan. 9, 1996	H_2O Seafloor Observatory *	Ralph Stephen
65	Jan. 9, 1996	Eastern Australia Margin	Ron Boyd
64	Jan. 2, 1996	Dike–Gabbro Transition – Central Cocos Plate	Doug Wilson
66	Jan. 2, 1996	Basement of the Marsili (South Tyrrhenian Sea)	C. Savelli
67	Jan. 2, 1996	W. Pacific ION/OSN Seafloor Observatories*	John Orcutt
68	Jan. 21, 1996	Paleoproductivity of Antarctic coastal waters	Eugene Domack

* Ocean Network (ION).

Active ODP Proposals, Spring 1996

Prop. no.	Date rec'd	Abbreviated title	Contact
079——	28/08/84	Tethyan stratigraphy and oceanic crust, Indian Ocean	Coffin, M.F.
079-Rev	31/07/92	Tethys and the birth of the Indian Ocean	Coffin, M.F.
079-Rev2	28/06/93	Tethys and the birth of the Indian Ocean	Coffin, M.F.
300——	18/02/88	Deep crustal drilling, Site 735B, SW Indian Ridge	Dick, H.J.B.
300-Rev	01/08/92	Return to ODP Hole 735B	Dick, H.J.B.
300-Add2	03 /05/95	Return to 735B	Dick, H.J.B.
300-Rev-Add	03/01/95	Return to ODP Hole 735B	Natland, J.H.
334——	28/07/89	Detachment faults/Galicia margin	Boillot, G.
334-Rev	27/12/90	Galicia Margin S reflector	Boillot, G.
334-Rev2	27/07/92	Galicia Margin S reflector	Boillot, G.
334-Rev3	30/06/93	Galicia Margin S' reflector	Boillot, G.
334-Add2	09/1995	Galicia Margin S' Reflector	Boillot, G.
334-Add3	01/01/96	Galicia Margin S' Reflector	Boillot, G.
348-Add3	05/11/94	TIE: US Mid-Atlantic Transect	Austin, J.
348-Rev	30/06/95	New Jersey TIE: US Mid-Atlantic Transect	Miller, K
348-Add4	Nov. 1995	New Jersey MAT: NJ Realism	Miller, K
354——	18/09/89	Late Cenozoic upwelling system, Angola/Namibia	Wefer, G.
354-Add	30/07/92	Benguela Current and Angola/Namibia upwelling	Wefer, G.
354-Add2	01/07/93	Benguela Current and Angola/Namibia upwelling	Wefer, G.
354-Add3	01/07/94	Benguela Current and Angola/Namibia upwelling	Wefer, G.
354-Rev	30/01/92	Benguela Current and Angola/Namibia upwelling	Wefer, G.
354-Rev2	30/12/93	Benguela Current and Angola/Namibia upwelling	Wefer, G.
354-Add4	03/01/95	Benguela Current	Wefer, G.
355——	18/09/89	Formation of a gas hydrate	Von Huene, R.
355-Rev	04/10/89	Formation of a gas hydrate	Von Huene, R.
355-Rev2	30/08/90	Formation of a gas hydrate	Von Huene, R.
355-Rev3	27/12/93	Formation of a gas hydrate	Von Huene, R.
355-Rev4	30/06/94	Formation of a gas hydrate: Peruvian Margin	Von Huene, R.
355-Rev5	04/01/95	Peruvian Margin/Gas Hydrates	Von Huene, R.
355-Add	03/07/95	Peruvian Margin Gas Hydrates	Von Huene, R.
367——	07/02/90	Cool water carbonate margin, southern Australia	James, N.P.
367-Add	05/10/92	Cool water carbonate margin, southern Australia	James, N.P.
367-Rev	23/12/93	Great Australian Bight cool-water carbonates	James, N.P.
367-Rev2	04/01/95	Cenozoic carbs. of the Gt. Australian Bight	Feary, D.A.
367-Add	10/95	Great Australian Bight Site Survey Cruise Proposal	Feary, D.A.
367-Rev3	01/01/96	Cenozoic carbonates of the Great Australian Bight	Feary, D.A.
376——	07/03/90	Layer 2/3 (and crust/mantle) boundary, Vema F.Z.	Auzende, J.M.
376-Rev	16/09/91	Layer 2/3 boundary and vert. tectonics, VEMA F.Z.	Auzende, J.M.
376-Rev2	27/07/92	Vema F.Z.: Upper mantle, gabbro/dyke, limestone cap	Bonatti, E.
376-Rev3	27/01/94	Vema F.Z.: Upper mantle, gabbro/dyke, limestone cap	Bonatti, E.
404——	11/09/91	Western North Atlantic sediment drifts	Keigwin, L.D.
404-Rev	04/01/95	Late Neogene paleoceanography	Keigwin, L.D.
404-Add2	03/07/95	Western North Atlantic sediment drifts	Keigwin, L.
416——	11/03/92	Glacial history, Svalbard margin	Solheim, A.
416-Rev	27/01/94	Glacial history, Svalbard margin	Solheim, A.
419——	28/07/92	Convergence at Azores–Gibraltar plate boundary	Zitellini, N.
419-Rev	31/12/92	Convergence at Azores–Gibraltar plate boundary	Zitellini, N.
420——	30/07/92	The evolution of oceanic crust	Purdy, G.M.
421——	30/07/92	Alkali-acidic rocks of the Volcano Trench	Vasiliev, B.I.
421-Rev	28/07/93	Alkali-acidic rocks of the Volcano Trench	Vasiliev, B.I.
421-Rev2	19/01/96	Alkali-acidic rocks of the Volcano Trench	Vasiliev, B.I.
424——	31/07/92	To CORK Hole 395A	Becker, K.

424-Rev	31/12/92	To CORK Hole 395A	Becker, K.
425-Rev	01/07/93	Mid-Antlantic Ridge Offset Drilling	Casey, J.F.
426——	20/08/92	Australia–Antarctic Discordance	Christie, D.
426-Rev	30/06/95	Australia–Antarctic Discordance	Christie, D.
430——	31/12/92	Subantarctic SE Atlantic Transect (ghost of 464)	Hodell, D.A.
431——	31/12/92	Western Pacific Seismic Network	Suyehiro, K.
431-Add	01/01/94	Western Pacific Seismic Network	Suyehiro, K.
431-Add2	05/01/95	Western Pacific Seismic Network	Suyehiro, K.
431-Rev	03/07/95	Western Pacific Geophysical Network	Suyehiro, K.
435——	01/07/93	Nicaragua/Izu–Marianas Mass Balance	Plank, T.
435-Add	28/06/94	Mass Balance: Nicaragua Margin (Ghost of 471)	Plank, T.
435-Rev	01/01/94	Mass Balance: Nicaragua Margin (Ghost of 471)	Plank, T.
435-Rev2	01/01/94	Mass Balance: Mariana–Izu (Ghost of 472)	Plank, T.
435-Add2	04/01/95	Mariana–Izu Margin (Ghost of 472)	Plank, T.
436——	20/12/93	Campeche Bank Stratigraphy	Fulthorpe, C.S.
437——	23/12/93	Lau–Havre–Taupo rift to drift	Parson, L.M.
438——	01/01/94	Test of reflecting interfaces in oceanic crust	Mutter, J.
439——	01/01/94	Marquesa Islands, mass budget of hot spots	McNutt, M.K.
441——	27/12/93	Southwest Pacific Gateway I & II	Carter, R.M.
441-Add	05/01/95	Southwest Pacific Gateway	Carter, L
441-Rev	05/01/96	Southwest Pacific Gateway/Deep Pacific Source	Carter, L.
442——	27/12/93	Rift Initiation in Back-Arc Basins: N. Mariana	Stern, R.J.
442-Rev	05/01/95	Rift Initiation in Back-Arc Basins/N. Mariana	Stern, R.
442-Add	02/01/96	Rift Initiation in the Northern Mariana Trough	Stern, R.
443——	29/12/93	Faults, crustal heterogeneity & hydrology at 504B/896A	Alt, J.C.
444——	01/01/94	Joban margin sea level	Soh, W.
445-Rev	05/01/95	Deformation & fluid flow in the Nankai Trough Prism	Moore, G.F.
445-Add	03/07/95	Nankai Trough Accretionary Prism	Moore, G.F.
445-Rev2	02/01/96	Nankai Trough Accretionary Prism	Moore, G.F.
446——	01/01/94	Ocean drilling in the Tonga forearc	Bloomer, S.H.
447——	01/01/94	Continental extension in W. Woodlark Basin	Taylor, B.
447-Rev	04/01/95	Extension in the W. Woodlark Basin	Taylor, B.
447-Rev2	05/01/96	Woodlark Basin	Taylor, B.
448——	01/01/94	History of the Ontong Java Plateau	Kroenke, L.W.
448-Rev	01/07/94	History of the Ontong Java Plateau	Kroenke, L.W.
448-Add	04/01/95	Origin and evolution of the Ontong Java Plateau	Kroenke, L.W.
448-Add2	30/06/95	Origin and evolution of the Ontong Java Plateau	Kroenke, L.W.
449——	01/01/94	Evolution of the Mesozoic Weddell Basin	Wise, S.W.
450——	01/01/94	Taiwan arc-continent collision	Lundberg, N.
450—Rev	05/01/95	Taiwan arc-continent collision	Lundberg, N.
450-Add	03/07/95	Taiwan Arc Continent Collision	Lundberg, N.
451——	01/01/94	Tonga Ridge Island Arc Transect	Tappin, D.
451-Rev	01/07/94	Tonga forearc	Tappin, D.
451-Rev2	05/01/95	Ocean drilling in the Tonga Forearc	Tappin, D.R.
451-Rev3	02/01/96	Tonga Forearc	MacLeod, C.J.
452——	27/12/93	Antarctic glacial history and sea-level change	Barker, P.F.
452-Add	17/02/94	Antarctic glacial history and sea-level change	Barker, P.F.
452-Rev	05/01/95	Antarctic glacial history and sea-level change	Barker, P.F.
452-Rev2	02/01/96	Antarctic glacial history of sea-level change	Barker, P.F.
453——	01/01/94	Bransfield Strait, Antarctica	Fisk, M.
454——	14/01/93	East Australian Current	Jenkins, C.
455——	27/06/94	High res. record of sediment fluxes: NW Atlantic	Occhietti, S.
455-Rev	30/06/95	N.W.A.M.P.	Piper, D.J.W.
455-Rev	15/01/96	Laurentide Ice Sheet Outlets (LISO)	Piper, D.J.W.
456——	28/06/94	Tjornes FZSB: Paleoceanography and Sedimentation	Fridleifsson, G.O.
457——	01/07/94	Large igneous province in Kerguelen Plateau	Frey, F.A.
457-Rev	05/01/95	Kerguelen Plateau and Broken Ridge (LIP)	Frey, F.A.
457-Rev2	30/06/95	Kerguelen Plateau and Broken Ridge (LIP)	Frey, F.A.

457-Rev3	15/01/96	Kerguelen Plateau and Broken Ridge (LIP)	
458—	01/07/94	Southern Ocean Transect (Ghost of 454)	Gersonde, R.
459—	01/07/94	Norwegian Sea overflow	Kuijpers, A.
NARM-Add3	22/12/93	Basement sampling of OCT west of Iberia	Reston, T.J.
461—	01/07/94	Basement of OCT W. of Iberia (former NARM-Add3)	Whitmarsh, R.B.
461-Add	03/01/95	OCT – Return to Iberia	Whitmarsh, R.B.
461-Rev	03/07/95	Ocean–Continent Transition west of Iberia	Whitmarsh, R.B.
461-Add2	11/1995	OCT – Return to Iberia	Whitmarsh, R.B.
461-Add3	15/02/96	OCT – Return to Iberia	Whitmarsh, R.B.
462—	04/11/94	Blake Plateau and Blake Nose	Norris, R.D.
462-Rev	03/07/95	Blake Plateau and Blake Nose	Norris, R.D.
463—	04/01/95	Plume–Impact at Shatsky Rise	Sager, W.W.
463-Add	02/01/96	Shatsky Rise Plume Impact Hypothesis	Sager, W.W.
464—	04/01/95	Southern Ocean Paleoceanography (Transo)	Gersonde, R.
464-Add	03/07/95	Southern Paleoceanography Transect	Gersonde, R.
465—	04/01/95	SE Pacific Paleoceanography	Mix, A.C.
465-Add	01/01/96	SE Pacific Paleoceanographic Depth transects	Mix, A.C.
466—	04/01/95	GAB/Continental Margin	Willcox, J.B.
467—	04/01/95	Sea-level changes in the Western Mediterranean	Droz, L.
468—	05/01/95	Carbonate platforms at the Romanche F. Z.	Bonatti, E.
468-Rev	30/07/95	Carbonate platforms/Romanche Fracture Zone	Bonatti, E.
469—	05/01/95	Argo Abyssal Plain	Symonds, P.A.
470—	05/01/95	Red Sea/Atlantis II Deep	Sichler, B.
471—	01/01/94	Mass Balance: Nicaragua Margin	Plank, Terry
472—	01/01/95	Marianas–Izu Mass Balance	Plank, Terry
472-Rev	02/01/96	Marianas–Izu Mass Balance	Plank, Terry
NARM-Add	30/06/93	Newfoundland Basin	Austin, J.A., Jr.
473	10/04/95	Saanich Inlet	Bornhold, B.D.
473-Add	30/05/95	Saanich Inlet	Nagihara, S.
473-Add	30/06/95	Saanich Inlet	Bornhold, B.D.
474—	30/04/95	Offset Engineering Leg	Pettigrew, T.L.
475—	30/06/95	Physical Properties in Accretionary Prisms	Moore, J.C.
476—	04/07/95	Hudson Apron Submarine Slope Stability Transect	Pratson, L.
477—	04/07/95	Sea of Okhotsk and Bering Sea	Takahashi, K.
478—	04/07/95	Eastern Nankai Multiple Shortening	Tokuyama, H.
478-Add	02/01/96	Eastern Nankai Multiple Shortening	Tokuyama, H.
479—	03/07/95	Felsic Volcanic, East Manus Back-Arc Basin	Binns, R.A.
480—	03/07/95	Caribbean Cretaceous Basalt Province	Driscoll, N.
481—	03/07/95	Red Sea Deeps	Ludden, J.
482	02/01/96	Wilkes Land margin*	Escutia, Carlota
483	02/01/96	ACC – Scotia Sea and Falkland Trough*	Barker, Peter
484	09/01/1996	East Asian Monsoon History/South China Sea	Wang, Pinxian
485	02/01/96	Southern Gateway – Australia and Antarctica*	Exon, Neville
486	02/01/96	Paleogene Equatorial Pacific APC Transect	Lyle, Mitch
487	02/01/96	Palau-Kyushu Ridge and Shikoku Basin	Ohara, Yasuhiko
488	02/01/96	Southern Ocean Circulation – Weddell Sea*	Kristoffersen, Y.
489	02/01/96	Ross Sea Shelf – Glacial History and Sea Level*	Davey, Fred
490	02/01/96	Prydz Bay–Cooperation Sea/Glacial History*	O'Brien, P.
491	02/01/96	Cyclic Crustal Accretion– Angola Basin	Hinz, Karl
492	22/12/95	Taiwan Arc–Continental Collision	Lallemand, Serge
493	31/01/96	Rifting and Crustal Fluid/Okinawa Trough	Li, Naisheng
494	15/01/96	Deformation and Evolution of South China Sea	Yao, Bochu
495	01/01/96	Rifting and Isolation of Microcontinents	Stephens, W.E.

Please note that proposals scheduled for drilling in FY97 retain their active status as proponents continue to make minor modifications to the programs, since these changes must be reviewed by the Thematic panels.

* ANTOSTRAT proposals

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ODP Site Survey Data Bank

Submission of Site Survey Data
Site Survey Data Requests

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Fax: 914-365-8159
email: odp@ldeo.columbia.edu

ODP-TAMU

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ODP/DSDP Samples Requests
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ODP Publications

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College Station, Texas 77845-9547 USA
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Public Information: Aaron_Woods@odp.tamu.edu

Bremen Core Repository

Sample Request Forms*
Sample Information
Availibility of Residues and Thin Sections
(from ODP Leg 151 onward)

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JOIDES - ODP World Wide Web Servers

There are now four on-line ODP-related world wide web servers (though all are still under development) available for the marine geoscience community to browse. These are located at:

JOIDES Office, Cardiff at ***http://servant.geol.cf.ac.uk***
Currently you can look at PCOM and EXCOM Motions, the International Mid-term Review Report, a full JOIDES directory (as per this volume), a calendar of JOIDES panel meetings and the *JOIDES Resolution* schedule (with co-chiefs), Panel Minutes, and an 'on-line' JOIDES Journal.

ODP-TAMU, Texas at ***http://www-odp.tamu.edu***
With an Overview of ODP (including the ship schedule), Publications and Curation, Science Operations, Engineering and Drilling Operations, General News and Information, International Participation and the JANUS project.

ODP-LDEO, New York at ***http://www.ldeo.columbia.edu/BRG/brg_home.html***
These pages contain an Introduction to the Borehole Research Group, and information on the Wireline Logging Services and the ODP Logging database as well as connections to other ODP-related sites on the web.

Joint Oceanographic Institutions, Inc. at ***http://www.joi-odp.org***
This site provides information about ODP, as well as details on funding opportunities available through the JOI/U.S. Science Support Program.

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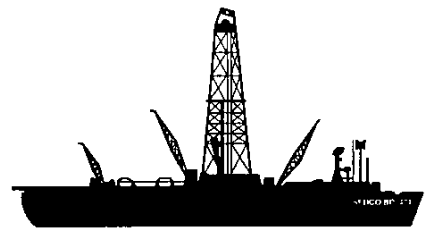

The purpose of the *JOIDES Journal* is to serve as a means of communication among the JOIDES advisory structure, the National Science Foundation, the Ocean Drilling Program, JOI sub-contractors thereunder, and interested earth scientists. Any opinions, findings, conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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Special Issue No. 1: Manual on Pollution Prevention and Safety, 1976 (Vol. II)
Special Issue No. 2: Initial Site Prospectus, Supplement One, April 1978 (Vol. III)
Special Issue No. 3: Initial Site Prospectus, Supplement Two, June 1980 (Vol. VI)
Special Issue No. 4: Guide to the Ocean Drilling Program, September 1985 (Vol. XI)
Special Issue No. 4: Guide to the Ocean Drilling Program, Suppl. One, June 1986 (Vol. XII)
Special Issue No. 5: Guidelines for Pollution Prevention and Safety, March 1986 (Vol. XII)
Special Issue No. 6: Guide to the Ocean Drilling Program, December 1988 (Vol. XIV)
Special Issue No. 7: Ocean Drilling Program Guidelines for Pollution Prevention and Safety, Oct., 1992 (Vol. 18)
Special Issue No. 8: Guide to the Ocean Drilling Program, June 1994 (Vol. 20)

JOIDES Meeting Schedule

Panel/ Committee	Dates	Location
SSP	29 July - 1 August '96	Palisades, New York
PCOM	19 - 22 August '96	Townsville, Australia
IHP	11 - 13 September '96	Kiel, Germany
PPSP	19 - 20 September '96	College Station, Texas
SGPP	3 - 6 October '96	Nancy, France
LITHP	7 - 9 October '96	Kanazawa, Japan
OHP	7 - 9 October '96	Strasbourg, France
TECP	19 - 21 October '96	Sultan Qaboos University, Oman
*DMP	19 - 23 October '96 (3 days)	San Diego, California
*SSP	11 - 13 November '96	Palisades, New York
PCOM	7 - 13 December '96	Biosphere II, Arizona
EXCOM	February '97	Washington, DC
*OHP	Spring '97	Santa Cruz, California
PCOM	April '97	College Station, Texas
PCOM	August '97	Davos(?), Switzerland
EXCOM	10 -12 June '97	Brest, France

* *meeting not yet formally requested or approved*

JOIDES Resolution Operations Schedule

Leg	Destination	Cruise Dates	Port of Origin†		Total Days	Transit	On Site
167	California Margin	21 Apr - 16 Jun '96	Acapulco	20 Apr '96	56	11	45
168	Juan de Fuca Hydroth.	21 Jun - 16 Aug '96	San Francisco	16 - 20 Jun '96	56	4	52
168S	Saanich Inlet	19 - 21 Aug '96	Victoria	16 - 18 Aug '96	2	–	2
169	Sedimented Ridges II	22 Aug - 17 Oct '96	Victoria	21 Aug '96	56	6	50
170	Costa Rica Margin	22 Oct - 17 Dec '96	San Diego	17 - 21 Oct '96	56	11	45
171A	Barbados LWD	21 Dec '96 - 8 Jan '97	Panama	17 - 20 Dec '96	18	7	11
171B	Blake Nose	9 Jan - 14 Feb '97	Barbados	8 Jan '97	36	6	30
172	NW Atlantic Sed. Drifts	19 Feb - 16 Apr '97	Charleston	14 - 18 Feb '97	56	15	41
173	Iberia II	21 Apr - 16 Jun '97	Lisbon	16 - 20 Apr '97	56	10	46
174A	New Jersey Shelf	21 Jun - 19 Jul '97	Halifax	16 - 20 Jun '97	28	3	25
174B	CORK/Engineering	20 Jul - 18 Aug '97	New York	19 Jul '97	29	14	15
175	Benguela	23 Aug - 18 Oct '97	Las Palmas	18 - 22 Aug '97	56	19	37
176	Return to Site 735B	23 Oct - 18 Dec '97	Cape Town	18 - 22 Oct '97	56	16	40
			Cape Town	18 -22 Dec '97			

† Although five day port calls are generally scheduled, the ship sails when ready.