JOIDES Journal

Joint Oceanographic Institutions for Deep Earth Sampling
volume 21, number 3, October 1995

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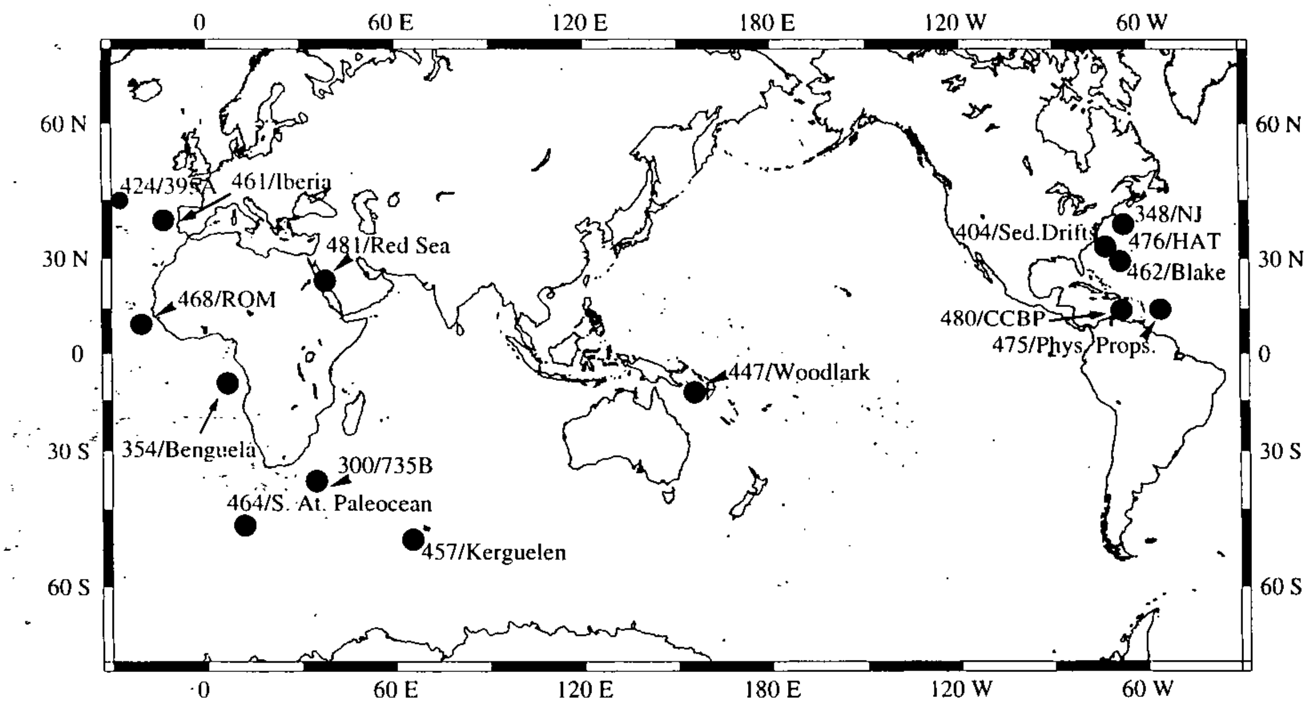

JOIDES Committee Reports, Leg 159 Report

Leg 160 Report, Leg 161 Report

Leg 165 Prospectus, Logging Report Leg 159

International News and Meetings, Proposal News

JOIDES Panel Memberships

COVER :
Schematic map showing the locations of the drilling proposals in the FY97 Drilling Prospectus. The schedule of the JOIDES Resolution for FY97 will be determined by examining the scientific (and taking into account logistical matters) merit of each of the proposals overleaf.

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Joint Oceanographic Institutions for Deep Earth Sampling

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European Science Foundation: Belgium, Denmark, Finland, Greece, Iceland, Italy, The Netherlands, Norway, Spain, Sweden, Switzerland, Turkey

France: Institut Francais de Recherche pour l'Exploitation de la Mer

Germany: Bundesanstalt für Geowissenschaften und Rohstoffe

University of Hawaii, School of Ocean and Earth Science and Technology

Japan: Ocean Research Institute, University of Tokyo

University of Miami, Rosenstiel School of Marine and Atmospheric Science

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University of Rhode Island, Graduate School of Oceanography

Texas A&M University, College of Geosciences and Maritime Studies

University of Texas at Austin, Institute for Geophysics

United Kingdom: Natural Environment Research Council

University of Washington, College of Ocean and Fisheries Sciences

Woods Hole Oceanographic Institution

Introduction

This has been another very eventful quarter for the advisory panels and the JOIDES Office.

At its August 1995 meeting in Oregon PCOM selected eleven proposals to make up the Prospectus of drilling to be scheduled for 1997. At their Fall meetings the Thematic Panels ranked these and have added a further four proposals for PCOM consideration at the December Annual Meeting in La Jolla. The complete proposal list is on page 3 of this issue. A further consideration for PCOM is whether it would be appropriate to conduct a full or part-leg for Engineering testing within the 1997 drilling schedule. A major aim of the December meeting then will be to select around six proposals as drilling legs for this, the penultimate year of the current phase of ODP.

The JOIDES Long-Range Plan (LRP) will be presented in its final pre-publication form at the La Jolla meeting and should be distributed to the community by JOI Inc. early in the New Year. Since the last issue of this Journal the Plan underwent further refinements as a result of EXCOM and ODP Council debate and has now been assessed by the International Review Committee that was set up by NSF and chaired by Dr. Gordon Greve. At its September, New York, and November, Frankfurt, meetings this committee heard presentations from JOI, JOIDES Office, ODP-TAMU, BRG-LDEO and from other leading ODP scientists, and also received documentation from other collaborative global community programmes and from national ODP committees. The Greve Committee meets once more in December at San Francisco but it has already provided constructive criticism that has helped the final revision of the LRP at JOI. We believe that ocean drilling is embarking on a new era, one in which we will realise the potential of our now being able to read the unique record of Earth's history beneath the sea floor at the highest resolution; being able to monitor geologic processes in real time by instrumenting boreholes; and, eventually, being able to drill many kilometers into continental margins and ocean crust.

A hurricane damaged JOIDES Resolution while it was drilling off East Greenland. Fortunately no-one was hurt but Leg 163 was terminated early. Before that there had been significant successes in basalt recovery in the dipping reflector sequences off Greenland but, apart from the repairs that became necessary in Nova Scotia, we have now identified significant problems for operations in shelf areas with JOIDES Resolution. New restrictions on its use in shallow water depths will be presented to PCOM and these will affect sites that are part of a number of proposals in the system at present. PCOM introduced into the post-1998 LRP the notion that JOIDES should form associations with other global programs to accomplish drilling in shelf and polar seas with other platforms. Clearly the need for this kind of planning is already upon us!

The ship is currently carrying out operations in the Western Atlantic to investigate the gas hydrate province around the Blake Ridge. This leg has attracted major interest from the international media, largely because of popular ideas that link catastrophic gas releases to shipping losses in the infamous "Bermuda Triangle"! Hopefully we can turn their attention to the more important effects of gas hydrate release on global warming and their importance as a potential future energy resource.

This interest from the media is sure to extend to the Caribbean leg that follows with its investigation of the K-T meteorite impact and its implications for mass global extinctions. Publicity like this will surely bring home the importance of other aspects of ocean drilling to the "man-in-the-street".

All of us in the Cardiff JOIDES Office wish you a healthy and prosperous New Year.

Robert B. Kidd

Robert B. Kidd
Chair, JOIDES Planning Committee

JOIDES Committee Reports

Executive Committee (EXCOM)

The last JOIDES Executive Committee meeting was held in Edinburgh, coincident with a port-call of the JOIDES Resolution at the end of Leg 161. The port-call itself was a huge success with over 1000 members of the public and press having toured the ship, and both the JOIDES EXCOM and members of the ODP Council having been given a first hand view of the ships facilities and a glimpse into the work carried out whilst at sea.

There were four major items discussed at the meeting, the ODP Long Range Plan and its presentation to an international review panel, two new initiatives on co-operative technology development and re-competing some or all of the science delivery functions, and the association of ODP and the Nansen Arctic Drilling (NAD) program.

The long range plan, written by the Planning Committee (PCOM), projects the future science of ODP into the first decade of the next century. However, it will also be the foundation document of a current international review panel (and will also be used by a number of national review committees) as the basis for consideration of renewal of the program (i.e., continuing membership of ODP). Thus, after obtaining the views of the various funding agencies, EXCOM determined that some parts of the plan required revision before it was seen by the international review committee, the findings of which, and the long range plan itself, will be circulated to the international community.

EXCOM also approved in principle an initiative for co-operative joint technology development programs with private industry, subject to re-negotiation of the current MOU's in regard of the intellectual property rights.

Another opportunity arising from the EXCOM meeting was the decision to issue invitations to all JOIDES members to submit letters of intent for the provision of science delivery services. The services may be single functions such as publications or engineering development, or the complete science operator contract.

Planning Committee (PCOM)

The JOIDES Planning Committee held their last meeting in Portland, Oregon in August 1995. There were a number of items on the agenda of interest to the UK community, including the Prospectus for consideration at the December 1995 ship scheduling meeting, various engineering items, such as the Diamond Coring System (DCS), other engineering development projects, including the proposal for a dedicated engineering drilling leg, the proposed implementation of project management and a decision to ask the thematic panels to consider the question of "legacy holes".

An early item on the agenda was how ODP could improve and formalise its links with other international geoscience projects. In particular the Nansen Arctic Drilling (NAD) program was discussed (NAD have set up an office in the JOI Inc. headquarters in Washington D.C.), and the sense of the discussion was that ODP should try and strengthen its links with these and other similar multinational geoscience programs, especially where they will be mutually beneficial (i.e., the other geoscience program will bring a capability to ODP that it currently does not have). The result was a series of suggestions to EXCOM as to how these links could be formalised in terms of data and sample archives, sample availability policies, proposal reviews, inter-program liaison and operations. The resulting recommendations (which will be discussed by EXCOM in January 1996) were framed so that they may be used as a model for collaboration with a number of different geoscience programs.

In terms of the DCS, a decision on the feasibility of the project will be made after the tests of the secondary heave compensation system have been made in late 1995 - early 1996. This feasibility was explained as essentially trying to control the weight-on-bit to ±500 lbs, equivalent to a heave control of only 1 cm at the bottom of the hole. At present no funds have been earmarked for final development should feasibility be proved. As regards non DCS Engineering, PCOM were told that funding was a severe problem and that only a limited amount of development could be continued; this would be on the Motor Driven Core Barrel and new hammer-driven casing system that should enable easier spud-in on hard-rock sites. ODP-TAMU also presented a case for a dedicated engineering leg during FY97. This was based on a recommendation from an external review body who recognised that many of the advances arising from ODP have been technology led and that technology development must be pursued.

As part of the problem in trying to manage costs more effectively, a project-based management system is being introduced at the Science Operator (ODP-TAMU), although there is still considerable discussion about how far project management can be implemented across ODP (for example, can it be applied to entire legs?). PCOM will consider this proposal again in December when they evaluate which legs to schedule in FY97.

In terms of looking at cost-savings, PCOM decided that in many cases re-entry could be achieved with free-fall-funnels but it is necessary to look to the longer term. Thus the PCOM made the following policy decision: "Cased, re-entry holes have great potential scientific value for seafloor observatories, future drilling, etc. In the past, the decision whether or not to complete a scheduled re-entry hole with casing has been left to co-chief scientists. Rather than lose potential important cased holes to expediency, PCOM directs panels, especially thematic panels, to identify potentially important "Legacy Holes", to be noted in the annual drilling prospectus. PCOM will review the list and decide whether to mandate casing of a possible "Legacy Hole".

Perhaps the most important task of this meeting was to assemble a prospectus of drilling proposals for the thematic panels to evaluate and rank at their autumn meetings. The result of this exercise, and the relevant PCOM watchdogs are outlined below:

As regards ODP Publications, despite having been through an exercise earlier in the year to find ways of reducing costs and increasing their impact, the EXCOM decided that the recommendations from PCOM only represented a first step, and some EXCOM members felt that it may be appropriate to cease publication of the SR series completely at the end of this phase of ODP in 1998. Therefore PCOM decided to look again at their publication policies and moratoriums and ask the JOIDES advisory panels to comment on some new proposals. These will be reported in due course.

Finally, the volume of e-mail traffic to and from the JOIDES Resolution is ever increasing, with serious cost implications. Therefore ODP-TAMU are instigating a policy on the transmission of such traffic so that there will be a limit on the amount of e-mail from any individual of 100kb, with any one message limited to 20kb - charges will levied after these targets are exceeded, so be warned.

Contents of the FY97 Drilling Prospectus

Proposal Number and Area	PCOM Watchdog
Proposal 300 (735B)	H P Johnson (University of Washington)
† Proposal 324 (CORK Site 395A)	R Larson (University of Rhode Island)
Proposal 348 (New Jersey Margin)	G Moore (SOEST, Hawaii)
Proposal 354 (Benguela)	K Suyehiro (ORI, University of Tokyo)
Proposal 404 (NW Atlantic Sediment Drifts)	H Kudrass (BGR, Hannover)
Proposal 447 (Woodlark Basin)	R Carter (James Cook University, Townsville)
Proposal 457 (Kerguelen)	W Sager (Texas A&M University)
Proposal 461 (Iberia)	J McKenzie (ETH, Zurich)
Proposal 462 (Blake Nose)	H Kudrass (BGR, Hannover)
Proposal 464 (Southern Ocean Palaeoceanography)	R Larson (University of Rhode Island)
Proposal 468 (Romanche/Vema)	C Mével (Université Pierre et Marie Curie, Paris)
¶ Proposal 475 (Phys. Props in Accretionary Prisms)	K Suyehiro (ORI, University of Tokyo)
§ Proposal 476 (Hudson Apron)	R Carter (James Cook University, Townsville)
Proposal 480 (Cretaceous Caribbean Basalts)	T Shipley (University of Texas at Austin, Texas)
‡ Proposal 481 (Red Sea Deeps)	T Shipley (University of Texas at Austin, Texas)

Note:

† Proposal 324 (CORK Site 395A)	Added to Prospectus by LITHP
¶ Proposal 475 (Phys. Props in Accretionary Prisms)	Added to Prospectus by TECP and SGPP
§ Proposal 476 (Hudson Apron)	Added to Prospectus by SGPP
‡ Proposal 481 (Red Sea Deeps)	Added to Prospectus by SGPP and LITHP

Science Operator Report Leg 159

THE CÔTE D'IVOIRE - GHANA TRANSFORM MARGIN EASTERN EQUATORIAL ATLANTIC

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

Abstract
Leg 159 drilled a series of four sites (Sites 959-962) within continental crust adjacent to the continent-ocean transition along the transform passive margin of Côte d'Ivoire-Ghana (CIG). This leg represents the first application of deep-sea drilling to the tectonics of transform margin development. A series of tectonized Albian sediments documents an early phase of intra-continental transform motion. The deep-water lacustrine sequence passes into a progressively more marine sequence as break-up continued, probably as part of a pull-apart basin system. The co-existence of compressional and extensional features, as well as rarer strike-slip faults, shows the intense deformation that affected a broad zone of the continental margin at that time. Subsequent inversion of the pull-apart basin into the Marginal Ridge occurred during the Cenomanian-Turonian. The period of maximum uplift of the ridge is shown by the development of shallow-water reefal carbonates and associated high-energy, coarse, clastic sediments of Turonian-Santonian age. Tectonic models of transform margins indicate that, following continental break-up, an active ocean-continent transform phase is ended by the migration of an active oceanic spreading center along the margin. Transfer of heat from the spreading ridge is predicted to cause major uplift and may correspond to this phase of shallow-water sedimentation. Subsequent cooling of the continental lithosphere would produce subsidence. Post-Santonian sedimentation at Site 959, situated on the flanks of the Deep Ivorian Basin, was marked by a deeper water, organic-rich, black shale facies that continued until the late Paleocene. In contrast, Sites 960, 961, and 962, which are located closer to the crest of the CIG Marginal Ridge, show hiatus and condensed claystone facies with glauconitic hardgrounds at this time. This ridge may have acted as a sill to the Deep Ivorian Basin where free circulation with the open Atlantic was restricted. A major unconformity seen at all four sites in the upper Paleocene may mark the end of rapid thermal subsidence of the margin, but may also reflect changes in current activity at that time. Much of the Eocene and Oligocene is represented by pelagic siliceous sedimentation, with slumping off the uplifted ridge crest seen at Site 959. Neogene sedimentation is dominated by a hemipelagic clayey nannofossil sedimentation, except at Site 962, which accumulated clay alone due to its position below the carbonate compensation depth (CCD). Study of the Neogene sediments at Sites 959 and 960 is expected to yield a rare, high-resolution (1,000-10,000 yr) record of the intermediate-water history in the Eastern Equatorial Atlantic, with implications for paleoceanographic changes during glacial/interglacial cycles.

Introduction
The concept of a transform (or sheared/translational) continental margin as a specific type of continent/ocean boundary progressively developed since the 1970's. Geophysical results from several transform margins clearly demonstrate that these continental borderlands are drastically different from divergent margins in terms of crustal structure, deformation, subsidence, and sedimentation history.

During the past 20 years, several marine geophysical cruises (mainly collecting gravimetry data, as well as refraction, and reflection seismic profiles) have been devoted to a few transform margins (e.g., Falklands and Exmouth plateaux). As a result, three main morphostructural features can be recognized as common to most transform margins; these include a) lateral structural continuity between a major oceanic fracture zone and a continental transform margin (e.g., the Romanche Fracture Zone and Côte d'Ivoire-Ghana Margin, b) very steep and narrow continental slope (20-30 km) between a continental shelf and an adjacent oceanic abyssal plain, indicating a very sharp crustal transition between thick or partially thinned continental crust and oceanic lithosphere, and c) morphologically well expressed marginal ridge bounding the transform margin, along an adjacent extensional basin (Côte d'Ivoire Basin).

Formation of a transform margin involves three major stages: an intra-continental active transform phase, a continent-ocean active transform phase, and an inactive continent-ocean transform phase. Such an evolution requires a series of different crustal/lithospheric contacts between the two plates on either side of the transform boundary. Changes in the nature of the lithosphere on either side of the transform would have led to strong thermal and pressure contrasts, which may have been recorded in the sedimentary cover of the margin at various stages in its evolution.

The objectives of Leg 159 were to
(1) determine the tectonic and sedimentary processes involved in the creation of the different main morphostructural features generated at the CIG Transform Margin, with special attention to the formation of the Marginal Ridge. A determination of the lithology and structural history of the acoustic basement underlying the minor en-échelon ridges generated along the transform boundary was also a key objective.
(2) document the type of deformation and the deformation history of the CIG Transform Margin during its successive stages of evolution;
(3) constrain the timing, rate, and degree of vertical motion (subsidence and uplift) occurring on the CIG Transform Margin;
(4) investigate the thermal evolution of a transform margin, and compare this with the progressive westward migration of an actively spreading oceanic ridge along the southern side of the transform

boundary. The thermally-driven processes to be addressed included diagenesis within the transform margin, as well as heating, hydrothermalism, and possibly magmatism occurring along the margin in response to the vicinity of the spreading center;
(5) collect data on the history the Cretaceous and Cenozoic oceanic gateways across the Equatorial Atlantic and on the sedimentation of specific facies during the opening phase. Periods of oceanic anoxia were a specific target for investigation, with the intention of applying new chronometric techniques, such as the Rhenium/Osmium (Re/Os) evolution of the Cretaceous seawater, in the reconstruction of the paleoenvironment, and
(6) document Plio-Pleistocene changes in the character and origin of intermediate waters flowing through the Eastern Equatorial Atlantic.

Regional Geology of the Côte d'Ivoire-Ghana Transform Margin
The CIG margin results from major transform motion between plate boundaries. This motion is still active today along the Romanche Fracture Zone, which offsets the Mid-Atlantic Ridge by 945 km. The area of particular recent investigation along this margin is the CIG Marginal Ridge which corresponds to a transition between a laterally thinned continental crust and an adjacent oceanic crust (Fig. 1). The setting of the present-day Marginal Ridge includes a fossil ridge that connects laterally with the extinct Romanche Fracture Zone.

The seismic stratigraphy and tectonics of the area drilled during Leg 159 are primarily based on investigations by in excess of 6 research cruises.

Seismic Stratigraphy
The seismic stratigraphy is defined on the basis of angular relationships between several sedimentary units, especially along the northern slope of the CIG Marginal Ridge. Six main seismic units, A to F, are recognized (Fig. 2).

The relationships between basal Unit A and the underlying acoustic basement are unclear. This unit is deformed in both the extensional Deep Ivorian Basin and the transform Marginal Ridge. It has been divided into Subunits A0, A1, and A2, based on the presence of sequence boundaries defined on the seismic lines. A0 seems to be ante-rift in the whole area. A1 is syn-rift in the extensional Deep Ivorian Basin. A2 is post-rift in the Deep Ivorian Basin, but appears deformed within the transform margin domain.

Unit B corresponds to post-rift sediments, and is not deformed within the transform margin. It unconformably overlies both the A sequence of the extensional Deep Ivorian Basin and the A2 (syn-transform) sequence of the transform margin.

Units C to F lie conformably on the previous units, within and along the eastern side of the transform margin. However, they lie unconformably on the B and A2 sequences that constitute most of the northern Marginal Ridge slope. All units lie almost horizontally in the Deep Ivorian Basin, but may progressively pinch out against the Marginal Ridge, possibly due to coeval ridge uplift.

Sedimentary units C and D have been deposited both by aggradation within the Deep Ivorian Basin (i.e., distal detrital sedimentation from the African coast) and by progradation originating from the marginal ridge summit (i.e., proximal detrital sedimentation). Such mechanisms imply that the ridge top was near sea level at the time of their deposition, which was unknown prior to drilling. The upper part of the C sequence onlaps the ridge top, whereas the lower D sequence is restricted to the deepest part of the Ivorian Basin. Such progressive restriction of the sedimentation area also characterizes the E and F sequences.

Results

Site 959
Site 959 is located in 2100 m water depth on a small plateau on the southern shoulder of the Deep Ivorian Basin (DIB). This plateau extends just north of the top of the CIG Marginal Ridge (CIGMR). Both features, the CIGMR and DIB, were generated as a consequence of Early Cretaceous rifting of the northern South Atlantic. Drilling at Site 959 penetrated seismic stratigraphic units F-B, and was designed to document the sedimentary and structural evolution of the CIG Marginal Ridge since early in the process of continental breakup. The sedimentary depositional environments and the state of tectonically induced deformation were key factors addressed by the drilling. In addition, triple recovery of the upper, less lithified sediments, was intended to provide a high-resolution paleoceanographic history of the Neogene of the central Atlantic intermediate waters, and a record of climatic change, such as desertification onshore Africa.

Four lithologic units were recognized.

Unit I (Holocene to early Miocene; 0-208.0 mbsf) is composed of a mixture of nannofossil ooze and foraminiferal ooze, which alternates from laminated to bioturbated intervals; Unit II (early Miocene to late Paleocene; 208.0-812.3 mbsf) is composed of 599.3 m of alternating siliceous and calcareous sediment, divided into three further subunits; Unit III (late Paleocene to Late Cretaceous (early Coniacian); 812.3-1043.3 mbsf) is composed of 231.0 m of black claystone. The Cretaceous/Tertiary boundary could not be identified by using microfossils, nor was it marked by any notable change in the sedimentary facies; Unit IV (Cretaceous (early Coniacian to late Albian and older); 1043.3-1158.9 mbsf) is composed of 115.6 m of sandstone, silty claystone, and limestone.

Site 959 recovered Pleistocene to Albian and older deposits. A nearly complete Neogene section with diverse calcareous microfossils is present in the upper 300 m, and Oligocene rocks were recovered between 303-428 mbsf. It is likely that an unconformity spans most of the Paleocene.

Most of the sediments cored in Holes 959A, B, and C are shallow dipping. A slight increase in dip value with depth (from 2°-4° at 48-70 mbsf to 4°-15° by 400 mbsf) was observed in Hole 959A and in Hole 959D, bedding dips increase to 20°-30° between 960 and 1000 mbsf, before decreasing to 6°-15° between 1035 and 1044 mbsf. This change corresponds to the top of lithologic Unit IV. An abrupt increase in bedding dip (51°-83°) was recorded over the interval 1112-1140 mbsf. Geographically oriented bedding dip directions from Holes 959A and B indicate trends toward the north-northwest and northwest, respectively. Microfaults appear at 92 mbsf in Hole 959A and occur within most of the sequence below this level. Anastomosing normal faults, with seams of fine-grained material along fault planes and minor associated reverse faults, are a distinctive structural feature of the diatomites of lithologic Unit II. These faults are post-dated by sharply defined planar normal faults. Reorientation of the cores in Holes 959A and 959B reveals a series of northeast-dipping normal faults and a conjugate set dipping northwest and southeast, respectively. Several types of vein geometry and infills were observed in Hole 959D, including barite, calcite, quartz, dolomite, and kaolinite, and two or three generations of vein growth are observed. Veins occur as tension gashes, irregular veinlets, septarian-type networks, and along faults, with many displaying evidence of shearing.

Whole-core magnetic susceptibility measurements show a low susceptibility from the seafloor to about 50 mbsf in Holes 959A, B, and C, then a gradual increase from 50 to 162 mbsf. The low susceptibility from about 162 mbsf to the bottom of each hole, corresponds to an increase in clay content. Reversals in declination, from which a preliminary magnetostratigraphic interpretation could be made to the base of the Matuyama reverse polarity chron and more tentatively to the base of the Gauss normal polarity chron, indicates a

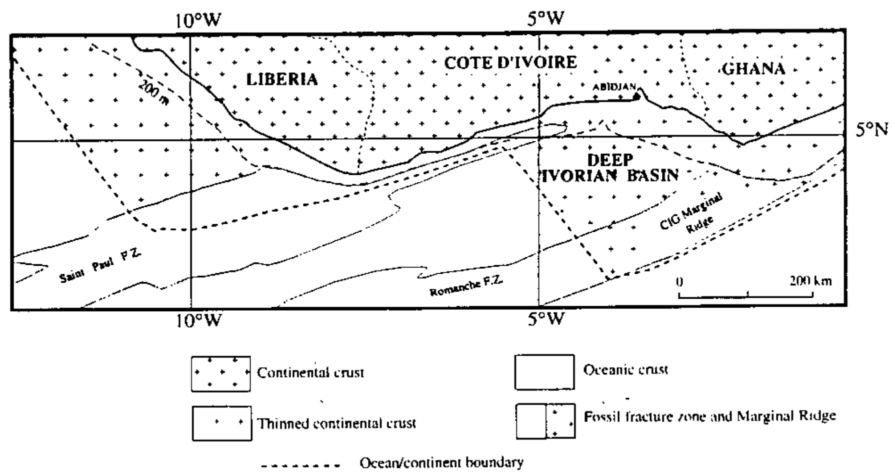

Figure 1. Geodynamic sketch of the Côte d'Ivoire Ghana Margin and the different ocean/ continent transitions. Shaded areas are oceanic fracture zones and marginal ridges

sedimentation rate of about 7 m/m.y. since 3.5 Ma.

Interstitial water analyses indicate organic matter degradation at 0-200 mbsf, with methanogenesis seen below the sulfate-reducing zone. Profiles of Ca, Mg, Mn, and alkalinity indicate carbonate precipitation within the zone of sulfate reduction. Carbonate dissolution and recrystallization are suggested by Sr, Ca, and alkalinity trends below 150 mbsf. Dissolved silica concentrations are high where sediments rich in biogenic silica are dissolving, and exhibit minima in portions of the section with negligible silica content. Uptake of potassium by clay minerals is likely to be responsible for a systematic decrease in pore-fluid potassium concentrations with increasing depth in the sediment.

Fluctuations in organic carbon and carbonate carbon correlate with lithology, although within lithological units, highly variable organic and carbonate carbon patterns demonstrate changes in paleoenvironmental conditions and/or different stages of diagenetic overprint. Continuous input from terrestrial sources during the Pliocene-Pleistocene is indicated by generally intermediate to low carbonate contents and elevated organic carbon vs. total nitrogen ratios.

The physical properties data at Site 959 are heterogeneous, reflecting variations in consolidation, age, and lithology. The most important discontinuities occur at 150 mbsf where there is no change in lithology, at 456 mbsf the change coincides with a change from nannofossil chalk and clay to chert, and at 750 mbsf the discontinuity occurs in an interval with no change in lithology, but a noted increase in clay and decrease in opal.

Downhole measurements were successfully conducted in Hole 959D (395- 1077 mbsf). The logs are of generally excellent quality despite borehole washout near the top (405-425 mbsf) and bottom (1025-1045 mbsf). Initial comparison between log and core data shows good correlation for natural gamma ray and velocity measurements, and preliminary interpretation of the formation microscanner (FMS) data shows bedding planes dipping consistently toward north-northwest with increasing dips downhole (from 20° at 550 mbsf to >40° at 850 mbsf).

Site 960

Site 960 is located 3 miles south of Site 959 in 2061 m water depth, on a small plateau that
occupies the summit of the CIGMR at 2000 m. The sedimentary cover above seismic unit A is much reduced, and Site 960 was drilled to sample this lowermost unit.

Five lithologic units were identified from Holes 960A and 960C.

Unit I (Pleistocene to early Miocene; 0-111.2 mbsf) is composed of Pleistocene nannofossil/foraminifer ooze and nannofossil/ foraminifer chalk; Unit II (early Miocene and early to middle Eocene; 111.2-179.0 mbsf) is characterized by radiolarian/nannofossil chalk, claystone, and porcellanite of early Miocene and middle Eocene age, and chert of early to middle Eocene age. A large stratigraphic break is inferred between these two subunits; Unit III (early Eocene; 179.0-198.8 mbsf) is a 20.5 m (Hole 960A) to 18.7 m (Hole 960C) thick unit, distinguished by its bluish-green color and abundant authigenic barite; Unit IV (Masstrichtian to Turonian; 198.8-329.0 mbsf) is subdivided into lithologic Subunit IVA, a condensed (<10 m) interval with fish debris, hardgrounds, glauconitic claystones, and micritic chalks (Maastrichtian-Coniacian) and lithologic Subunit IVB (Turonian and older), a <144.9 m thick unit composed of quartz sand and skeletal packstones and grainstones; Unit V (Turonian and Albian and older; 329.0-451.2 mbsf) is a 122.2 m thick unit of carbonate-cemented sandstones and siltstones, changing to silty sandstones, siltstones, and clayey siltstones of possible lacustrine origin.

Pleistocene to early Eocene nannofossils were identified in the first 20 cores of Hole 960A, a sequence interrupted by two barren intervals (and probably at least two major hiatuses, as Middle Miocene Zone CN5 is missing and nannofossils representing the time interval from middle Eocene Zone CP14 through to the top of late Oligocene Zone CP19 are missing). A barren interval is also identified at about the Neogene/Paleogene boundary and the lower/middle Eocene section also contains a barren interval near its base.The youngest hiatus separates sediments of late Miocene age from those of early middle Miocene. The oldest hiatus is between assemblages assignable to the early Eocene and Coniacian to Santonian age.

Bedding dips at 0-150 mbsf in Hole 960C are largely due to slumping. The unconformity at the lithologic Unit IV/V boundary is characterized by fissuring, veining, and brecciation. The bedding dip data collected from Unit V range between5°-60°, with the steeper dips measured directly below the unconformity where the majority of faulting and veining observed also occurs. Calcite and kaolinite veins are abundant, with quartz veins appearing at 450 mbsf in the bottom of Hole 960A. Complex microfaulting, with associated asymmetric microfolds, display both normal and reverse senses of motion, possible evidence for strike-slip flower structures. Oblique slickensides/mineral lineations in kaolinite-filled faults also indicate strike-slip.

Magnetic measurements indicate three distinctive transitions in magnetic properties, which can be correlated between Holes 960A and 960C, and Site 959. A sharp increase in NRM intensity and in bulk susceptibility occurs at the upper/lower Pliocene boundary. A drop in intensity of magnetization and in susceptibility at 92 mbsf and 74 mbsf in Holes 960C and A corresponds to a major hiatus between the upper Miocene and lower middle Miocene. An unconformity was found at 329 mbsf in Hole 960A, where both the intensity of magnetization and the bulk susceptibility increase significantly.

At 0-100 mbsf, microbial degradation of organic matter drives the sequential reduction of manganese, iron, and sulfate respectively. Below 100 mbsf, alkalinity and ammonium data indicate that the deeper sediments at Site 960 are less influenced by organic matter degradation. Profiles of dissolved Ca, Mg, and Sr reflect major differences between pore-fluid chemistry at Sites 959 and 960. At Site 960, no minimum in dissolved Ca occurs. An increase in Mg and an increase in Sr downhole suggest carbonate recrystallization but not carbonate precipitation.

Intermediate carbonate contents (35-55 wt%), elevated C/N ratios (10-14), and low hydrogen indices (<100 mgHC/gTOC) are seen in the upper Pliocene to Pleistocene, and an increase in organic carbon (5.6 wt%) correlates to a drop in carbonate (0 wt%) at the Miocene/Pliocene boundary. Early Eocene to early Miocene chalks and claystones indicate a mixed marine/terrestrial source for the organic matter, while the underlying limestone unit has no organic carbon.

Poor hole conditions (960A) seriously affected the quality of the sonic, density, and porosity data collected by the tool string, though resistivity and gamma ray data were affected to a much lesser degree. In Hole 960C, a natural gamma, resistivity, and sonic tool string was run again, but poor hole conditions again resulted in poor quality sonic data. The FMS was run but only covered the interval 354.5-173.7 mbsf.

Site 961

Site 961 lies in 3303 m water depth on the last significant morphologic expression of the CIGMR just before its burial, toward the west, beneath the thick sedimentary cover of the Deep Ivorian Basin. In the area, a multichannel seismic (MCS) line recorded along strike of the CIGMR shows that the progressively deepening pre- and synrift basement consists of a series of rotated structural blocks and bordering half grabens, each about 5 km across. Detailed structural mapping clearly indicates that these extensional structures are bounded by north-south- trending fault zones and are rather similar, in trends and in size, to second order extensional blocks detected within the northern adjacent rifted Deep Ivorian Basin.

In Hole 961A, 308.7 m of stratigraphic section was cored. In Hole 961B, the top 216.3 mbsf, and the intervals 239.0-259.9 mbsf and 264.9-267.5 mbsf, were drilled without coring.

Three lithologic units were identified at Site 961.

Unit I (Pleistocene to early Miocene; 0-129.5 mbsf) is composed of nannofossil ooze with foraminifers, which grades downhole into clayey nannofossil chalk and claystone. Lithologic Unit I at this site can be correlated with lithologic Unit I at Sites 959 and 960; Unit II (early Miocene, early Eocene, late Paleocene and older; 129.5-188.5 mbsf) is divided two subunits, one of early Miocene nannofossil chalk with radiolarians and glauconite, claystone with glauconite and the other of chert interbedded with clayey porcellanite with micrite and zeolite, palygorskite/zeolite claystone, and glauconite-rich porcellanite. Lithologic Unit II correlates with Unit II at Site 959 and with Units II and III at Site 960; Unit III (unknown age in upper part; below 303 mbsf, Maastrichtian to Bajocian; 188.5-374.6 mbsf) consists of dark gray to black silty sandstone, sandy siltstone, clayey siltstone, and silty claystone, with local pyrite and siderite. This unit is correlated with Subunit VA at Site 960. Age is constrained poorly,

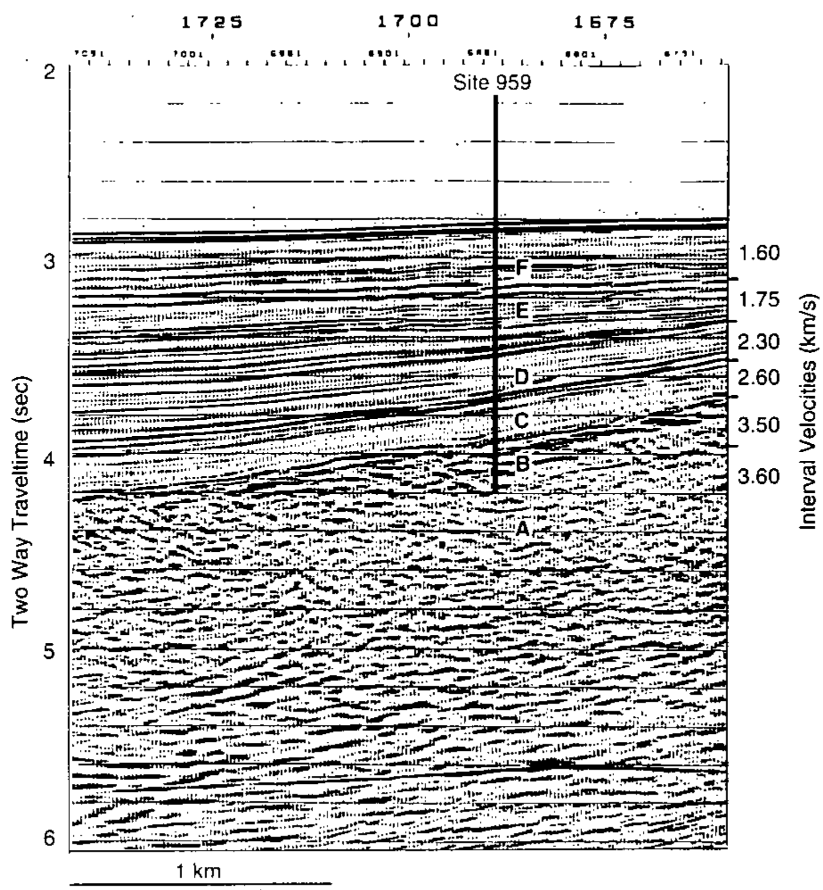

Figure 2. Enlarged section of MCS line MT02 and location of Site 959. The six main seismic units A - F are marked.

being some time during the Maastrichtian to Bajocian.

Below a middle to upper Miocene interval that extends to 148.1 mbsf, an unconformity has removed most or all of the Oligocene and the middle to upper Eocene and there may also be an unconformity or condensed interval in the upper middle Miocene at 81-100 mbsf. The lower Eocene is present from 157.8 to 167.4 mbsf, and the upper Paleocene from 177.0 to 186.7 mbsf. Calcareous microfossil preservation generally deteriorates downsection, and planktonic foraminifers are absent below the lower Miocene.

In Hole 961A, very little bedding data were recorded due to poor recovery and drilling disturbance with only a few normal faults observed in Hole 961A. Variable dips in Hole 961B can be attributed, at least partly, to synsedimentary disturbances (convolute bedding, slump fold) and faults. Sets of conjugated normal faults, steeply dipping shears, finely laminated bedding affected by microfolds (associated with small-scale shear planes), calcite veining infilling fractures and breccia are all observed at this site. Soft sedimentary deformations were observed in both Holes 961A and B and include a water-escape structure, a sand pipe, slump folds, and wavy to convolute bedding.

Changes in magnetic susceptibility mirror lithological changes, and the variation of the intensity of NRM downhole shows a similar pattern as at previous sites.

Eight interstitial water samples were taken during coring operations at Site 961. In spite of the discontinuous sample suite, the data demonstrate a set of diagenetic reactions analogous to those documented at Sites 959 and 960. Sulfate, potassium, and magnesium concentrations decrease with increasing depth, while the concentrations of calcium and ammonium increase with increasing depth in the sediment.

The generally lower carbonate and organic carbon contents in Holes 961A and B compared to Sites 959 and 960 are related to the more pelagic depositional conditions. Pliocene to Pleistocene deposits display highest carbonate contents (up to 50 wt%). In the upper 70 mbsf, evidence for intense organic matter degradation was found by a continuous exponential decrease in organic carbon content with depth. Paleocene through Miocene sediments have low carbonate and organic carbon contents, whereas intermediate organic carbon contents (about 0.4 wt%), but low carbonate contents, characterize the underlying sandstone and siltstone below 220 mbsf. The few maxima in organic carbon within these lithologies were probably caused by an enhanced supply of terrigenous organic matter.

General correlation between different sets of physical properties data at Site 961 is good, but the low density of measurements does not permit more detailed studies. All physical properties data collected at Site 961 show a very distinctive change in trend at the boundary between lithologic Units II and III at 188 mbsf, attributable to significant lithological differences.

Site 962

Site 962 is located in 4650 m water depth, on a small topographic bench which extends toward the southwest, in the same direction as the CIGMR southern slope. A MCS line and the crossing single channel line, reveal that this small bathymetric high is in fact the subdued topographic expression of a narrow "basement" structural high, which lies between a thick pile of undeformed sediments to the south, and a fault-bounded and rather deformed basin and wedge system to the north, comprising sedimentary reflectors. A dense set of single channel seismic lines reveals a similar feature just a few kilometers to the southwest. These two acoustic basement ridges, buried by sediments, are elongated (2-3 km wide and 12-15 km long), almond-shaped, and trend southeast-northwest. They lie at the boundary between the southwesternmost extension of the CIGMR and the flat-lying sediment cover of the adjacent oceanic crust to the south. The minor ridges are arranged en échelon, and lie at the transition between the main continental transform Marginal Ridge and the oceanic fossil Romanche Fracture Zone, which is expressed in a series of aligned, still exposed, acoustic basement highs just a few kilometers toward the west-southwest.

Drilling in four holes at Site 962 penetrated 393.5 mbsf. The recovered sediment has been divided into three lithologic units.

Unit I (late Pleistocene to early Miocene; 0-47.0 mbsf) is composed of 47 m of hemipelagic silty clays and clays, subdivided into two subunits; Unit II (early Miocene, unknown, and late Albian; 47.5-123.5 mbsf, Hole 962D) is composed of siliceous pelagic components, radiolarians and diatoms, palygorskite, and chert and porcellanite, divided into three subunits; Unit III (late Albian; 123.5-393.5 mbsf, Hole 962D) is composed of normally graded siliciclastic sandstones, siltstones, and claystones intermixed with micritic limestones, containing planktonic foraminifers and nannofossils of late Albian age. Numerous fining-upward sequences are apparent.

The Cenozoic is greatly condensed compared to Sites 959 and 961, and preservation of calcareous microfossils is generally poor. The upper Pleistocene is relatively expanded and lies disconformably on about 5 m of upper Pliocene nannofossil claystone, which, in turn, disconformably overlies 4 m of lower Pliocene claystone. Between 26.5-36.4 mbsf it is essentially barren, although a few isolated specimens of planktonic foraminifers suggest an early Pliocene to latest Miocene age. Silicoflagellates and radiolarians at 50-64.0 mbsf indicate a late early Miocene age. A disconformity at 65.8 mbsf separates Cenozoic deposits from Albian-(?)Cenomanian cherts and mudstones. A distinctive palygorskite clay-bearing sequence immediately overlying this disconformity suggests, by lithologic correlation, that lower Eocene sediments may be present. Upper Albian to Cenomanian radiolarians and silicified planktonic foraminifers are present at 71.3 mbsf, although the microfossils may have been reworked during a later slumping event. This sequence is underlain by more than 300 m of deformed upper Albian turbidites.

In Hole 962B, the few bedding measurements recorded in Units I and II range from 1° to 18°, whilst in Hole 962D (lithological Unit III), the wide range of bedding dip values is mostly due to folding and faulting. Vertical dips, related to tectonic deformations, were recorded between 180 and 185 mbsf and between 386 and 393 mbsf. Unit III shows rare convolute bedding and slump folding throughout, with normal faulting common. At 123 mbsf, conjugated normal faults are seen to have been formed prior to the tilting of the bedding. Reverse microfaults, both alone or associated with asymmetrical folds, are observed at various depths. Microfolding is widespread in Hole 962D, showing various morphologies from rounded to incipient kink folding. Most of the folds are asymmetric, except where associated with pop-up structures. Rare evidence of strike-slip motion includes low pitching slickensides along fault planes and flower-type structures where normal and reverse faults are associated. Brecciation and veining occur as infilling of extensional features.

In Hole 962B, the magnetic susceptibility is low, increasing slightly, then at about 25.5 mbsf remains level to about 45 mbsf and, below this, generally falls again except for an interval between 65-70 mbsf. Susceptibilities throughout Hole 962D are low, and NRM intensities show a similar pattern to that of the susceptibility.

Five water samples taken from 0 to 80 mbsf in Hole 962B reflect the relatively low abundances of calcium carbonate and reactive organic matter, compared to Sites 959 and 961. Gradients associated with sulfate reduction and ammonium generation are less steep than at shallower sites, indicating that organic matter degradation is less vigorous, although organic carbon contents are relatively high. Therefore, the bulk of the organic carbon in the upper portion of the sediment pile at Site 962 must be refractory and not readily degraded, in agreement with its anomalously high hydrogen values. The downhole increase in dissolved strontium concentrations is comparable to that at Site 959, implying that dissolution/recrystallization reactions may be more intensive at Site 962. Carbonate contents are generally low, due to the site being below the CCD, except during

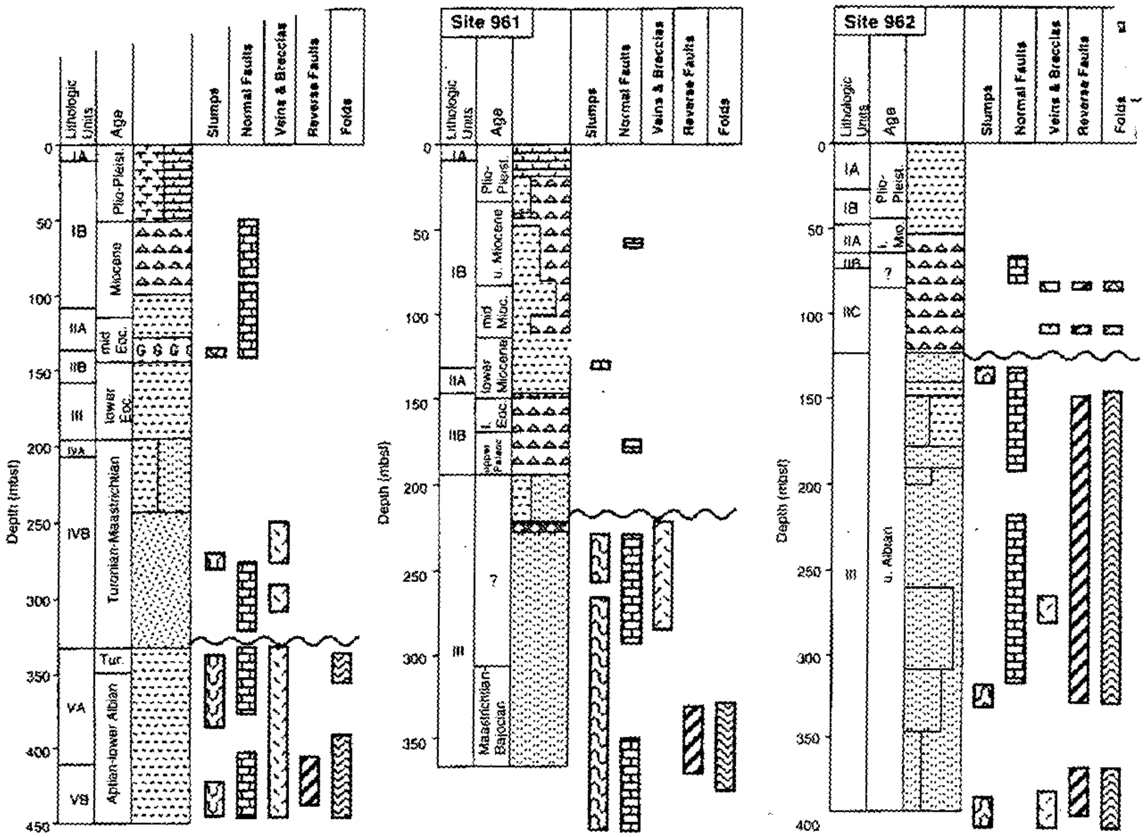

Figure 3. Summary of the structures observed at Sites 960, 961, and 962 along the strike of the Marginal Ridge. Note that the most pervasive deformation and compressional deformation are confined to the Lower Cretaceous, the lower parts of each drill site.

the early Pliocene. Upper Albian porcellanites (70-100 mbsf) have high organic carbon and low carbonate contents. High C/N ratios and intermediate hydrogen indices suggest a mixed terrestrial and marine origin of the organic matter. Between 150 and 195 mbsf, peaks in organic carbon (up to 3.5 wt%) probably indicate periods of high productivity. Decreasing hydrogen indices downcore show a stronger terrestrial influence earlier in the late Albian. The pyrolytic character does not reflect changes in lithology.

Physical properties reflect variations in lithology, consolidation, and composition of sediments. Good GRAPE and NGR measurements were made in Hole 962B. The boundary between lithologic Units II and III, at 123 mbsf, is reflected in discrete velocity measurements. Greater lithification below 90 mbsf is shown in index properties data as lower porosity (<30%).

Summary

The initial results suggest an Early Cretaceous history of restricted intra-continental sedimentation, followed by a progressive marine transgression, presumably reflecting the advancing rifting. Strong deformation observed in the oldest sediments at each of the drill sites (Fig. 3) testifies to the continuous shearing that the margin suffered during the period of intra-continental transform. At the two shallowest sites (Sites 959 and 960), located in approximately 2100 m of water, a period of shallow-water shelf sedimentation during the Turonian-Santonian marks a departure from the normal subsidence pattern of a rifted passive margin, which would predict more rapid thermal subsidence shortly after continental break-up. The development of a reef near Sites 959 and 960 provides firm evidence for the uplift of the ridge at this time (Fig. 4). At Sites 961 and 962, the Turonian-Santonian, with the subsequent younger part of the Cretaceous sequence, is noted as probably one of unconformity, although the biostratigraphy does not prove this conclusively at Site 961. The tilting and uplift inferred from the sediments are believed to reflect generation of the Marginal Ridge due to transform deformation, causing flexural uplift and/or crustal thickening. In addition a thermal rejuvenation, and thus uplift, of the crust adjacent to the transform margin is expected due to the close proximity of an oceanic spreading center, which abutted against the margin at this time during its progressive westward migration.

The sedimentary sequences recovered provide a rare opportunity to examine the evolution of what was an important oceanic gateway region between the Southern and Central Atlantic basins, when the Equatorial Atlantic was still a narrow seaway in this region. Most recently, the sedimentary cover to the marginal ridge, and thus Sites 959 and 960, have acted as a record of the evolution of intermediate waters in the eastern Equatorial Atlantic, as they lie at around 2100 m water depth. Through carbon and oxygen isotopic studies of the foraminifers from Sites 959-960, a high-resolution record of the intermediate waters of the equatorial oceans can be reconstr[illegible] will have strong implications for models [illegible] tion and how this evolved [illegible] ciation.

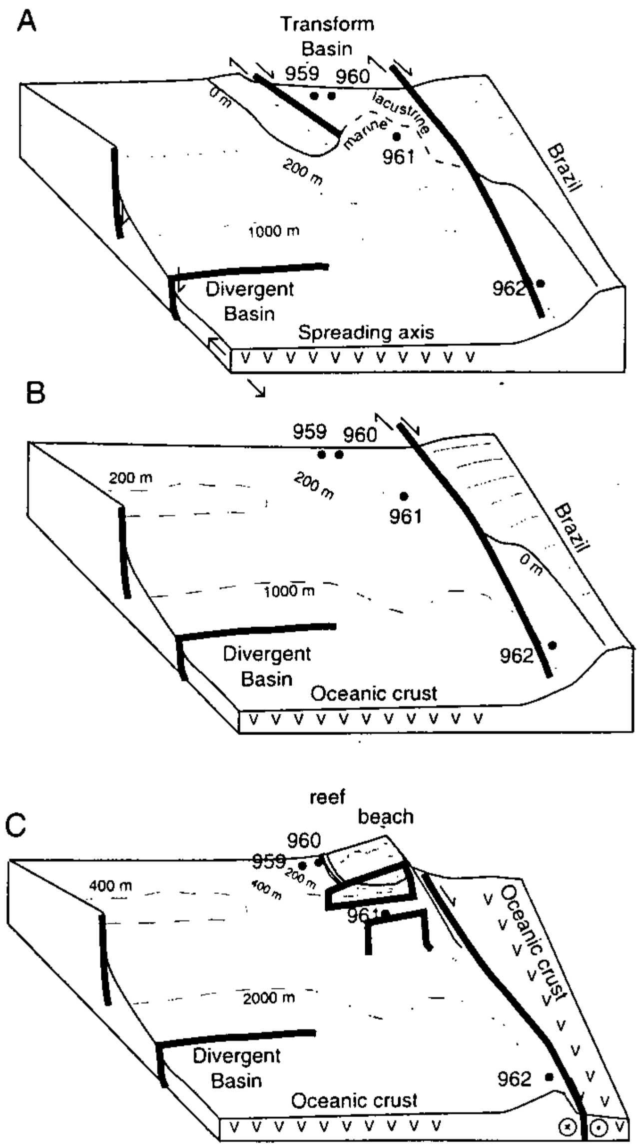

Figure 4. Three main stages in the evolution of the Côte d'Ivoire-Ghana Margin (view from the west-northwest). Stage A - stippled areas show syn-rift basins (divergent basins and marginal ridge). Stages B and C - shaded belt includes main transform domain.

JOIDES - ODP World Wide Web Servers

There are now three on-line JOIDES/ODP 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 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.

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

Abstract
Leg 160 was the first in a two-leg program to investigate the tectonic and paleoceanographic history of the Mediterranean Sea. One focus of this leg was on accretionary and collisional processes associated with the convergent boundary between the African and European plates. The other focus was on the origin and paleoceanographic significance of sapropels, organic-rich layers that are intercalated in the Plio-Pleistocene sediments of the Mediterranean Basin.

One focus of drilling concerned collisional processes related to the tectonic history of the Eratosthenes Seamount. This is a crustal fragment in the process of collision with a convergent margin to the north, including Cyprus. A transect of four holes was drilled across the Eratosthenes Seamount, extending from the crestal area of the seamount, to its upper and lower slopes, and on the lower Cyprus margin. On the lower slope, an intact Upper Cretaceous and middle Eocene section was drilled, overlain by Plio-Quaternary deep-sea sediments. Shallow-water limestones, including corals and algae, and evidence of faulting and rapid subsidence, were recovered at the crestal site. Matrix-supported breccias, with a matrix of lower Pliocene microfossils, accumulated in rapidly deepening seas. Water depths increased during the early to late Pliocene, to a maximum depth today of around 2000 m. The Messinian(?) and Plio-Pleistocene sediments on the Cyprus margin record contrasting paleoenvironments and tectonic settings. The results from the Eratosthenes drilling are interpreted in terms of flexural faulting and collapse related to loading by an overriding Cyprus plate. The drilling has therefore documented a process of initial collision that is of fundamental importance to the interpretation of many mountain belts.

A further tectonic-related objective was the drilling of a transect of holes across the Milano and Napoli mud volcanoes. These are located on the northern margin of the Mediterranean Ridge accretionary complex in an area where the Mediterranean Ridge is believed to be thrust over a backstop of continental crust to the north. Drilling revealed that both volcanoes are well over 1m.y. old and showed that much of the flank and crestal regions are composed of debris flows. These include clasts of mainly Miocene lithologies that were transported within the debris flows. The Milano volcano shows evidence for the existence of clathrates (solid methane hydrates) close to the seafloor. Gas (mainly methane) was detected at both mud volcanoes. Pore-fluid compositions indicate the presence of evaporites beneath. Drilling has thus shed important new light on the origin of the mud volcanoes, and will form a basis for future exploration.

More than 80 individual sapropels were recovered in distinctive packets and time intervals, which are separated by yellowish-brown, oxidized and carbonate-rich sediment. Individual beds in the packets were correlated between holes, separated by several hundred meters, and packets of sapropels could be matched between sites up to several hundred kilometers apart. Many individual sapropels are extraordinarily rich in organic carbon (up to 30% by weight and of predominantly marine origin) and display highly unusual magnetic properties. Sapropel occurrences mark periods when the Mediterranean catchment area experienced increased humidity and relatively high average temperatures. Once such conditions became established, they profoundly changed processes in the biologically active surface layer and at the seafloor. Our findings suggest that the development of deep-water anoxia in the eastern Mediterranean was an essential prerequisite for sapropel formation. The development of anoxia may be triggered by a reduction of deep-water formation, which is dependent on the salinities and temperatures in the surface layer. At the same time, sapropels indicate a dramatically increased carbon flux in the Eastern Mediterranean, which today is oligotrophic.

Introduction

The African/Eurasia plate boundary in the Eastern Mediterranean region (Fig. 1) reflects tectonic settings ranging from effectively steady-state subduction to incipient collision and more advanced collision in different areas. The Eastern Mediterranean is thus an ideal area in which to investigate the transition from subduction to collision, processes that may be recorded on land in orogenic belts but that are still poorly understood. Tectonically oriented drilling on Leg 160 focused on relatively shallow objectives (mainly <600 m). The first objective was to study the collision of the Eratosthenes Seamount with the Cyprus margin in the easternmost Mediterranean, by drilling a north-south transect of four sites. The second objective was to study the origin of mud volcanism by drilling at both crestal and flank locations of an active and an inactive mud volcano on the Mediterranean Ridge.

The third objective was to study subduction and accretion in an area where subduction is still taking place, by drilling on the inner deformation front of the accretionary wedge. The information obtained by drilling will be combined with other data (e.g. land studies) to synthesize the Neogene-Holocene subduction/accretion history of the Eastern Mediterranean.

Sediment cores from the Mediterranean Sea and land sections in southern Italy and Crete contain numerous dark-colored layers that are rich in organic carbon and often laminated. These layers, termed sapropels, are intercalated with carbonate-rich and organic-carbon-

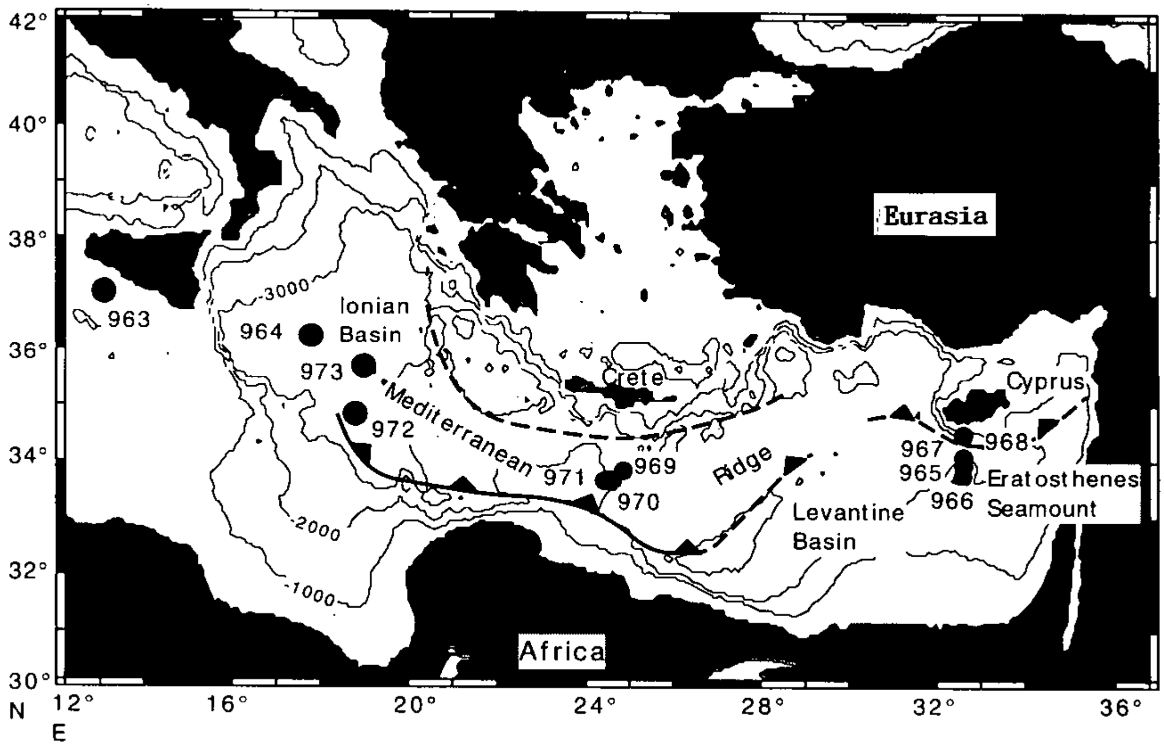


Figure 1. Location of Leg 160 sites in the Eastern Mediterranean. Bathymetry in meters.

poor hemipelagic sediments of Pliocene to Holocene age. They appear to be a characteristic deposit of many silled marginal seas (e.g., the Japan and Red Seas). In all cases it seems that the deposition of organic-rich sediments in the geological past occurred in response to dramatic changes of climate, circulation, and biogeochemical cycling. The Mediterranean sapropels of late Pleistocene to Holocene age have been particularly well studied, and a series of - in part contradictory -hypotheses on their origin and significance have been published in the last three decades. A broad consensus is that sapropels represent a paleoceanographic showcase, because they contain high-resolution records of key processes leading to enhanced burial and preservation of carbon at the seafloor.

Leg 160 made an effort to fully develop this showcase. Drilling on a transect of sites recovered several complete Pliocene to Holocene sediment sequences that represent a range of depositional environments, water depths, and oceanographic and biological characteristics in the modern Mediterranean.

Results

Site 963

The site is located on the unstable foreland of North Africa close to the deformation front of overriding thrust sheets (Gela nappe); movement last occurred prior to the early Pleistocene, allowing subsequent tectonically undisturbed sedimentation. Recovery and core quality in the four APC holes was excellent (average 101%) and yielded a complete sediment section that spans the early Pleistocene to the Holocene.

The sediments of the one sedimentary unit recognized are olive-green nannofossil oozes with minor quartzose silt, volcanic ash, and clay. Six discrete and thin-bedded (<18 cm) ash layers were recognized in the upper 100 m. Below 100 mbsf in Holes 963A and 963B scattered small (cm offset) soft-sediment normal faults were noted, and below 125 mbsf, a series of increasingly darker colored zones of 10 to 50 cm thickness occur, the two darkest of these zones are distinctly laminated on a millimeter scale. In the section below 125 mbsf the amplitudes of cyclic variations in the physical properties increase significantly.

The sequence at Site 963 spans the time interval from the early Pleistocene (1.5 Ma) to the Holocene at an extraordinary resolution. According to the preliminary shipboard assessment, the sediment section is complete and was deposited at rates between 70 m/m.y. in the section below 150 m and up to 230 m/m.y. in the upper part of the section.

The paleomagnetic record of Site 963 extends into the Matuyama Chron and clearly shows the Jaramillo Subchron. In addition, several short intervals of reverse polarity are evident in the Brunhes Chron.

Site 963 achieved both objectives: We recovered a complete and highly resolved sediment record with high stratigraphic potential (physical properties, biostratigraphy, magnetostratigraphy, and stable isotope stratigraphy), and we were able to recover lower Pleistocene sapropels that shore-based research will tie to the occurrences of sapropels in land sections.

Site 964

Site 964 is located at the foot of the Calabrian Ridge on a small bathymetric high. The high is interpreted as being on the toe of the accretionary prism near the Ionian Abyssal Plain (Figs. 1 and 2). Our objectives were (1) to recover a deep-water sedimentary sequence that records the history of sapropel deposition in the Ionian Basin and the variations in deep-water formation from the Pliocene to the Holocene, and (2) to establish a high-resolution stratigraphy based on paleontological, geochemical, magnetic, and lithological properties and to correlate it with coeval sequences in Calabria.

Six holes were drilled at Site 964 to a maximum depth of 112 mbsf. Recovery and core quality was excellent (average recovery 102%) and a complete sediment section was recovered that spans the lower Pliocene to the Holocene. Each hole contained locally discontinuous and tectonically attenuated sedimentary sequences.

Outstanding features of the sequence recovered at Site 964 are; more than 50 distinct sapropels in the composite section (Fig. 2), numerous ash layers and ashy turbidites, and marked color banding of the sediments. The host sediments comprise clayey nannofossil ooze, nannofossil ooze, and nannofossil clays. Some of the lighter-colored intervals are interpreted as being normally graded turbidites (decimeters to meters thick). Limited intervals of foraminifer sand were recovered in the lower parts of the sequence. The sapropels, which are centimeters to decimeters thick, are enriched in pyrite, plant material, and amorphous organic matter. Individual sapropels display a wide range of depositional and post-depositional features that include laminations, bioturbation, and oxidation fronts ("burn-down"). Together, sedimentological and physical features in sapropels, ash layers, and turbidites permitted detailed correlation between the holes and the construction of complete sections despite erosional hiatuses at the bases of turbidites, high-angle extensional faults, and possible fault-like drilling artifacts.

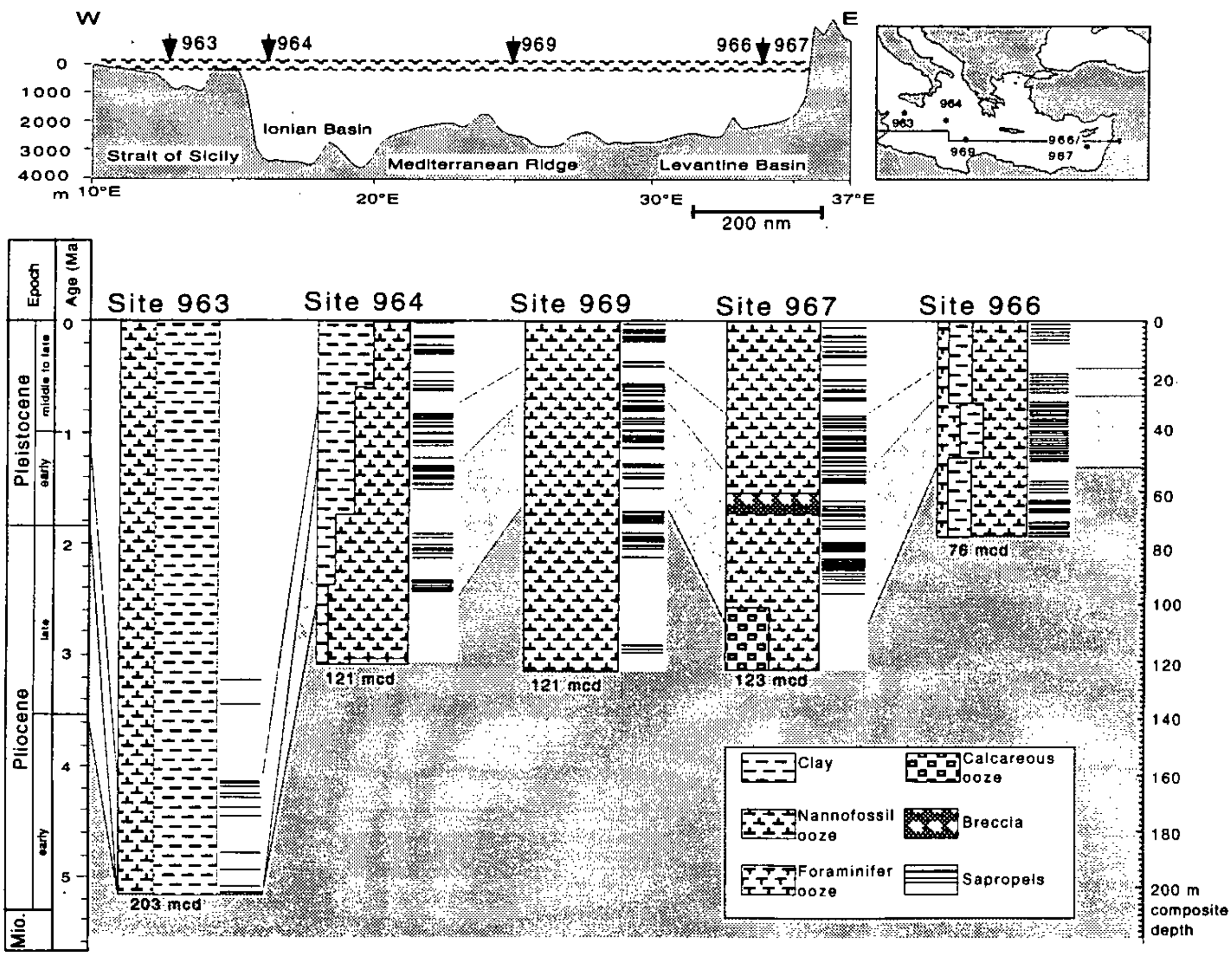
Organic carbon concentrations in the sapropels reach up to 25 wt%, values that prior to Leg 160 were known only from Mesozoic black shales and sapropelic coals. Based on the amount of hydrocarbons liberated by pyrolysis, the organic matter is interpreted to be of mixed marine and terrigenous origin with a more strongly pronounced marine character in the older sapropels.

A total of 18 biostratigraphic events were recognized (using calcareous nannofossils and planktonic foraminifers) in Hole 964A ranging from the late early Pliocene to the late Pleistocene, and the occurrence of sapropel S1 in the uppermost section demonstrates that the Holocene is present. Based on composite depth, the resulting age vs. depth relationship reveals that the sedimentation rate at Site 964 varied between 10 and 64 m/m.y., with an average of 30 m/m.y.

Constructing the magnetostratigraphic record at Site 964 was hampered by suspected overprints, however, the detailed records of individual holes hold promise for successful shore-based work on a composite section.

The setting of the site at the toe of the Calabrian accretionary wedge carries significant tectonic information concerning the processes of final closure of the Ionian Basin, a Tethyan remnant. The "cobble-

Figure 2. Lithostratigraphic profiles, age, and sapropel occurrences of the paleoceanographic transect drilled during Leg 160.



stone topography" at Site 964 is clearly tectonically influenced in view of the evidence of high-angle normal faulting observed in the cores and inferred from the sedimentary record.

Site 964 was a success allowing a compilation of the complete sequence of sedimentation since the late early Pliocene, which includes more than 50 sapropels and numerous discrete layers of tephra. The sequence recovered is calcareous and contains evidence for cyclic variations of conditions in the bottom water, an assumption that will be tested by benthic isotope and faunal analyses. The sapropels will undoubtedly help answer questions related to the origin and significance of black shales in the Mesozoic oceans.

Site 965

Site 965, located on the fault-controlled upper northern slope of the seamount, was the first of a north-south transect of holes designed to test the tectonic hypothesis that the Eratosthenes Seamount is a continental fragment that is in the process of collision and underthrusting along the Cyprus active margin to the north (Figs. 1 and 3). Specific objectives were (1) to determine if there is evidence of tectonically induced subsidence during the Plio-Quaternary, possibly related to collision; (2) to determine the lithology, age, and paleoenvironments of a prominent reflector beneath the Plio-Quaternary succession; (3) to determine the timing, magnitude, and rate of any tectonic subsidence at this site.

Three lithological units are recognized at Site 965:

Unit I (Pleistocene to late early Pliocene, 0-23 mbsf) comprises 23 m of unconsolidated, extensively bioturbated nannofossil muds and nannofossil oozes, with sporadic sapropels and sapropelic layers. Bedding ranges from horizontal to subhorizontal and is locally tilted. Microfaults range from moderately to steeply inclined, with measurable throws of up to 15 cm. Two hiatuses are present, the first has an estimated duration of 0.95 m.y., the second, at 0.75 m.y., extends from the middle Pliocene to the late early Pliocene. Sediments below 23 mbsf are only sparsely fossiliferous and are provisionally dated as no older than 6 Ma (late Miocene).

Unit II (23-29.3 mbsf) comprises ca. 6 m of sticky to firm clays, with scattered small (centimeter-sized), angular carbonate clasts, with abundant evidence of soft-sediment deformation and reworking by gravity processes (e.g., as debris flows).

Unit III (29.3-250.4 mbsf) is a 200-m-thick interval of medium- to coarse-grained, parallel- to cross-laminated packstones and grainstones (i.e., limestones), with calcareous algae, ooids, echinoderm remains, pelecypods, benthic foraminifers, gastropods, and rare coral of poritid type. Some limestones grade into poorly cemented gray marls, possibly indicative of the lithology of nonrecovered intervals, and are cut by sporadic carbonate veins. The deepest core showed evidence of penecontemporaneous tectonic brecciation and reworking of clasts.

Formation microscanner (FMS) records, combined with other logs, reveals that (1) dips are nearly horizontal throughout; (2) the lower part of the succession includes apparent cross-lamination, whereas the upper part is more planar bedded; (3) A mainly muddy succession is interbedded with thin intervals, interpreted as the cored limestones); (4) scattered high-angle faults are present.

The preserved stratigraphic record at Site 695 began in the early Pliocene (possibly late Miocene), with accumulation of shallow-water carbonates in a muddy, current-influenced, probably lagoonal setting, adjacent to reef buildups and subject to tectonic instability. This was followed by accumulation of calcareous clays in possibly low-salinity to hypersaline settings (Messinian?). Concomitantly with, or immediately following deposition, the muds were redeposited downslope into an open-marine setting (younger than 6 Ma). Subsequent, Plio-Quaternary deep-marine sedimentation took place on a tectonically unstable slope, subject to slumping, nondeposition, and/or reworking.

In summary, at Site 965 on the Eratosthenes Seamount, a mainly shallow-water carbonate succession has subsided during the last 5 Ma, accompanied by tectonic instability and faulting. Later faulting has produced the present fault-controlled bathymetry of the site. Drilling at Site 965 was clearly successful and constituted an important part of the test of the collision-related hypothesis for the evolution of the Eratosthenes Seamount.

Site 966

Site 966, the second of the transect holes drilled, is located on a broad high on the fault-bounded northern margin of the seamount plateau area (Fig. 3). Objectives here were (1) to recover a Plio-Quaternary succession with abundant sapropels, (2) to determine the nature of the Miocene-Pliocene paleo-environments and tectonic setting, (3) to elucidate the earlier history of the Eratosthenes Seamount, and (4) to infer the subsidence history of the site in relation to the Eratosthenes collision hypothesis. Seismic data show that a distinct (but complex) reflector at the base of the Plio-Quaternary succession is underlain by several deeper, westward-inclined reflectors, of which the uppermost was penetrated by drilling. Four lithologic units were recognized in the recovered sequence, within Holes 966A-F, as follows:

Unit I (0-66 mbsf) is composed of nannofossil ooze, clay-rich (turbidites) toward the top and increasingly foraminifer rich deeper in the section. Volcanic ash is disseminated through the entire intensely bioturbated interval. The succession includes scattered evidence of both high-angle normal and reverse faulting, together with isolated small (<3 cm) clasts of limestone.

Within Unit I, more than 90 discrete sapropels and sapropelic layers were identified, varying up to 60 cm thick, and mostly strongly bioturbated. The number of sapropels increases dramatically toward the base of the section, and organic carbon concentrations range from 2% to 11%. The source of the organic matter is assumed to be mainly marine, based on shipboard organic geochemical data. The preliminary assessment of paleo sea-surface temperatures, based on alkenone ratios in lipids from sapropel extracts, indicates a fairly stable and warm climate in the Pliocene.

18 datum levels have been established in the composite section, representing the early Pliocene to the Holocene, that imply deposition at nearly uniform rates of around 15 m/m.y.

Unit II was reached at different depths in the five holes drilled (Hole 966A-65 mbsf; B-120 mbsf; C-95 mbsf; D-125 mbsf; F-105 mbsf), with the top of the unit marked by some debris flows and evidence of faulting. The remainder of the unit is mainly a matrix-supported breccia, of angular, soft carbonate, or well-cemented limestone clasts (up to 5 cm in size) in a matrix of micrite. The uppermost breccia clasts are indicative of reworking under high-energy conditions, whereas breccias lower in the section are locally cemented by sparry calcite. A few mud clasts yielded calcareous nannofossils of early Pliocene age, while one of the clasts is provisionally dated as late Miocene. Numerous small high-angle normal faults were observed. The five holes drilled into Unit II at this site allowed an irregular paleotopography to be inferred beneath the Plio-Quaternary succession.

Unit III (105-298.5 mbsf in Hole 966F) contains well-cemented packstones and grainstones, with cyclical variations in grain size and sedimentary structures. Individual zones include variable abundances of red and green calcareous algae, coral, benthic foraminifers, bivalves, and bryozoans. Benthic foraminifers are locally abundant and suggest a Miocene age. Several limestone zones are strongly cemented by sparry calcite and minor dolomitization was also noted. Various trends in the log data (e.g., uranium spikes and other features) correlate with primary sedimentary variations (e.g., grain size), or diagenesis (e.g., secondary porosity and cementation). A relatively small number of high-angle faults and fractures were noted in the cores and FMS data.

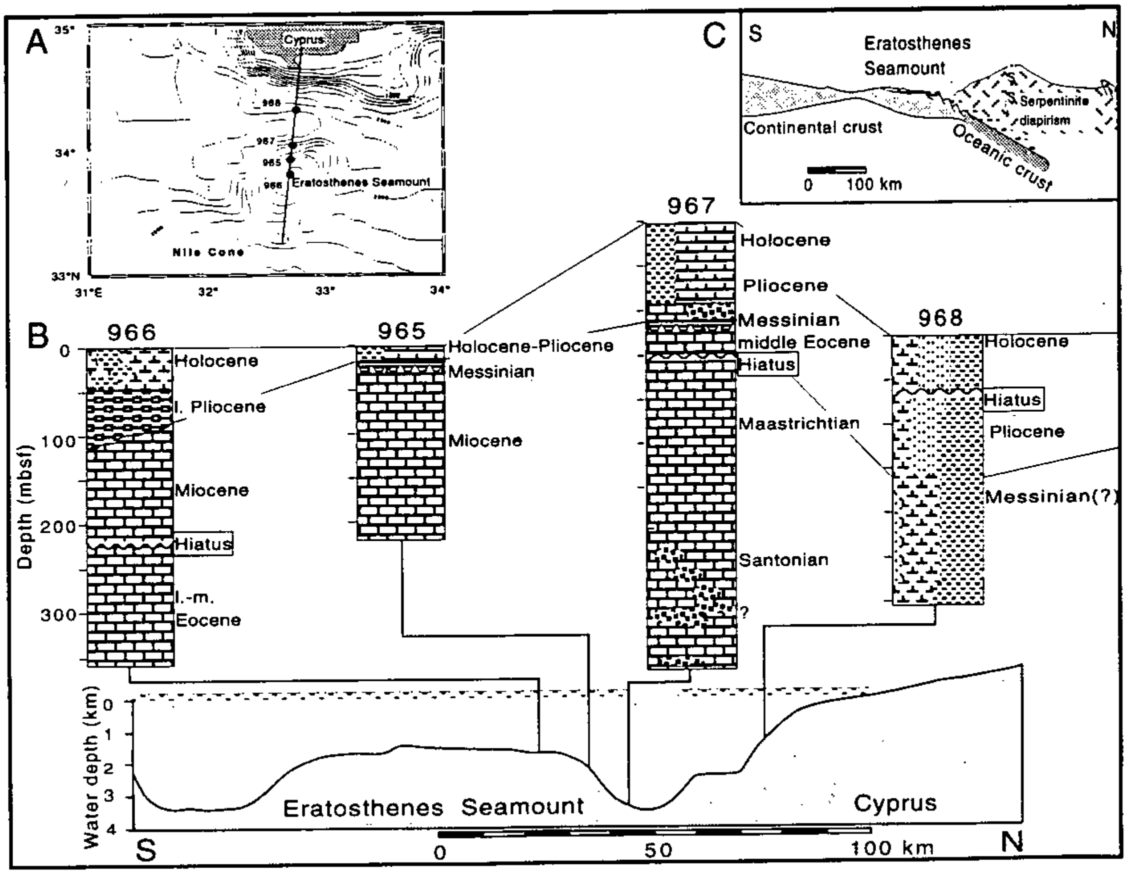


Figure 3. Eratosthenes Seamount transect. A. Location of Sites 965 through 968. B. Lithostratigraphic profiles, age, and location of Sites 965 through 968. C. Tectonic model.

Unit IV (298.5-356.0 mbsf) comprises an interval of finely laminated, highly burrowed, well-cemented chalky limestones (with scattered nodules of black vitreous chert) rich in middle Eocene planktonic foraminifers . There are also several intervals (each tens of centimeters thick) that are composed of thermally immature, finely laminated bituminous limestone. The organic matter is hydrogen rich, has a low sulfur content, and is mainly marine in origin. The lowermost cores exhibit a well-developed tectonic fabric of mainly low-angle veins and shear planes cut by later high-angle normal faults and fractures. Individual burrows within the limestone indicate shear displacement prior to lithification.

The preserved sedimentation history of Site 966 began in the middle Eocene with accumulation of deep-water pelagic carbonates, similar to the coeval Lefkara Formation of southern Cyprus. Both these units experienced silica diagenesis and chert formation. The black, laminated sediments, reflect an interval of enhanced organic-matter deposition under low-oxygen conditions. Deep-water sedimentation was terminated by regression (dominantly driven by tectonic uplift), and was followed (unconformably) by accumulation of Unit III as a shallow-water coralgal facies, in an inferred near-reef setting of probable Miocene age. Lithologically similar limestones were cored at Site 965. After a second unconformity, matrix-supported breccias were shed from a rugged (fault-controlled) paleotopography into an open-marine setting in the lowermost Pliocene. The local existence of this mass-wasted unit may explain the irregular and rather diffuse nature of the seismic reflectors directly below the semi transparent Plio-Quaternary at this site. Marine nannofossil ooze and sapropel deposition followed, with local evidence of minor syn-depositional faulting, and derivation of limestone clasts from inferred active faults. Bioturbation and partial oxidation of the sapropels is in keeping with the relatively condensed nature and shallow setting (<1000 m) of sedimentation on the Eratosthenes Seamount plateau area. Fine-grained mud turbidite deposition increased upward. This, together with the evidence of a hiatus in the early Pleistocene, may record tectonic disturbances of the Eratosthenes seamount plateau area.

In summary, drilling at Site 966 was clearly successful: an extensive record of Pliocene sapropels was retrieved, the nature of the upper Miocene-Pliocene transition at this locality identified, and light shed on the earlier, Tertiary history of the Eratosthenes Seamount: Tectonically induced collapse of the seamount, inferred from evidence at Site 965, was identified to have occurred, in part, in the early Pliocene.

Site 967

Site 967 is located on a small ridge near the foot of the northern slope of the Eratosthenes Seamount (Figs. 1 and 3). The ridge had been inferred to be a compressional feature related to thrusting beneath the Cyprus active margin to the north. Drilling results support this hypothesis; coring at Site 967 further provided a Plio-Pleistocene sapropel record, and a remarkable window into the history of the Mediterranean Sea as far back as the Late Cretaceous.

Five lithological units were recognized in the sequence at Site 967.

Unit I (0-100 mbsf) is composed of intercalations of bioturbated nannofossil ooze, nannofossil clay, mud turbidites, and sapropels. An important interval of slumping with an overlying debris-flow unit (1-7 m thick) was noted in all holes between 50 and 60 mbsf. Bedding of the host sediment is horizontal to subhorizontal throughout, and is cut by sporadic high-angle faults. Eighty discrete sapropels were identified, in which organic carbon values typically range from 3%-10% (maximum 17%). Sapropels were also imaged in the highest part of the section logged, using the FMS. Many of the sapropels are finely laminated; in the upper three cores, some occur with intercalated mud turbidites. The source of the organic matter may be dominantly marine, with fine plant material in some sapropels, while in others the organic matter is present as amorphous matter and dark brown aggregates. Estimates of paleo sea-surface temperatures based on alkenone indices indicate cyclic variations in the Pleistocene between 21° and 25°C, and average temperatures that are 2°-3°C higher in the Pliocene, but with less pronounced fluctuations.

Over several intervals in the Pliocene, the pattern of sapropel occurrence and lithological and physical properties resemble those encountered at Site 966 on the top of Eratosthenes Seamount.

Paleontological studies recognized 15 datum levels within the Pleistocene and Pliocene, including the lowermost Pliocene. A possible hiatus was identified from 1.75 to 2.0 Ma in Hole 967A (but not in Hole 967C), coinciding with the debris flow and slump. The average sedimentation rate over the entire Unit I is 26 m/m.y., ranging from 5 to 57 m/m.y. Benthic foraminifers indicates forms typical of middle mesobathyal depths (i.e., 1800-2500 m) in the late Pliocene, giving way to possibly lower mesobathyal (2500-3000 m), indicative of somewhat deeper water, in the Pleistocene.

Several polarity zones were recognized by measuring discrete samples. These compare well with the biostratigraphic data.

Unit II (100-125 mbsf in Hole 967A, and 109.5-125 mbsf in Hole 967E) consists of intercalations of well-consolidated nannofossil mud and nannofossil ooze, with both micritic and recrystallized carbonate rock fragments. A mixed microfossil assemblage was noted at ca. 130 mbsf in Holes 967A and E, of middle Eocene, Oligocene, Miocene, and late Miocene-early Pliocene age. FMS and other log data suggest the presence at 120-124 mbsf of an interval thought to be gypsum. Upward flow of relatively warm water through limestones at depth, possibly along fault conduits is suggested by heat-flow. The flow was then constrained by relatively impermeable Plio-Pleistocene clay-rich sediments above.

Unit III (125-446 mbsf) is well-lithified bioturbated nannofossil chalk, with several thin (tens of centimeter-thick) intervals of dark organic-rich, laminated calcilutite. Deformation structures include a small (cm-offset), shallow-dipping suite of normal and reverse faults, and a pervasive fabric of steeply-dipping normal faults with slickensided fault planes. The upper part of Unit III is middle Eocene in age, while the lower part is Late Cretaceous (late Santonian-late Maastrichtian), based on well-preserved planktonic foraminifers and less well-preserved calcareous nannofossils. The Cretaceous-Tertiary transition is estimated to lie at ca. 170 mbsf, and appears to have some expression in the log data. The FMS and other log data allow the Eocene and Cretaceous pelagic intervals to be distinguished (together with subunits) and also reveal bands of highly resistive material (inferred to be chert) in the Eocene succession. FMS data indicate a large number of deformed intervals of both low and high angle, interpreted as representing several generations of faulting, within which marked conductivity variations are indicative of rheology contrasts (e.g., open vs. cemented fault zones).

Unit IV (446-504 mbsf) consists of well-cemented shallow-water limestones (calcarenites), with calcareous algae, shell fragments, and peloids. Recrystallization and secondary porosity development have destroyed much of the depositional fabric, except within scattered chert nodules. Fossils have not been identified. The limestone is fractured, with an interstitial clay-bearing matrix and a finely crystalline carbonate cement.

Unit V (504-600.3 mbsf) is restricted to recovery of a small number of clasts of calcarenite, calcilutite, and breccia that are cut by well-developed slickensides. The FMS and other log data reveal evidence of a breccia-like tectonic fabric, in addition to other features (e.g., bedding).

In summary, Site 967 exhibits a long and diverse geologic history. The site once formed part of a shallow-water carbonate platform, later inundated, ushering in a 40-m.y. period of deep-water pelagic carbonate deposition punctuated by low-oxygen episodes in the Late Cretaceous, and times of high-silica accumulation, both in the Late Cretaceous and in the middle Eocene. Derived microfossils of middle Eocene, Oligocene, Miocene, and late Miocene-early Pliocene age shows that some open-marine sedimentation took place at, or in the vicinity of, Site 967 during the middle Eocene-early Pliocene time interval. Evaporites apparently accumulated in the late Miocene (i.e., Messinian), followed by erosion of carbonate clasts and turbidite deposition of well-oxidized muds and carbonates, followed by open-marine sedimentation and sapropel deposition. Water depths increased after the late Pliocene in response to dominantly tectonic subsidence.

Interpretation of the site-survey seismic data support the interpretation of Site 967 as a dominantly south-verging thrust structure. The site appears to have experienced mainly extensional deformation prior to the late Pliocene, followed by reverse faulting and minor uplift in a compressional setting at the base of the Eratosthenes Seamount slope. This uplift possibly began in the late Pliocene-early Pleistocene at the time of the inferred depositional hiatus and slumping.

In conclusion, drilling at Site 967 has charted the kinematic history of a collision-related structure and revealed part of the Mesozoic history of the Eratosthenes Seamount.

Site 968

Site 968 is located on the crest of a small ridge that projects southward from the base of the Cyprus slope at a depth of 2000 m (Figs. 1 and 3). Based on the interpretation of seismic profiles, the site is assumed to lie on the upper plate over a downgoing slab that includes the Eratosthenes Seamount. The site geophysical survey confirmed that the ridge at Site 968 is an intact block relative to adjacent parts of the Cyprus slope that are more deformed. Three units were recognized based on lithological criteria.

Unit I (0-143 mbsf) comprises calcareous nannofossil ooze and nannofossil clay, some thin ash layers (above 55 mbsf), and in total, more than 80 sapropels were recovered. The upper portion represented the most complete record of upper Pleistocene sapropels so far cored during Leg 160. Mainly below 30 mbsf, many of the individual sapropels are expanded by the deposition of thin (millimeter to centimeter thick) mud and clay turbidites. Sedimentary structures within these turbidites are well preserved within sapropels, while those in nannofossil oozes and clays are mainly highly bioturbated. The sapropels (up to 12% organic carbon) are, in general, not as rich in organic matter as at other Leg 160 sites. The Pliocene sapropels are consistently richer in organic carbon and exhibit better preservation of marine organic matter than the Pleistocene sapropels.

Unit II (143-167 mbsf) comprises nannofossil clay, clayey nannofossil ooze, clay, and calcareous silty clay, and was recognized as a discrete unit mainly based on the abundance of kaolinite and smectite.

Unit III (167-301 mbsf) is dominated by interbeds of silty clay, silt, and fine sand (up to tens of centimeters thick), with relatively low clay content (ca. 30%) and some dolomite. The presence of grading and erosional bases indicates a turbiditic origin. Gypsum is present at ca. 215 mbsf, as millimeter- to centimeter-thick layers (i.e., gypsarenite) within muddy sediments, and a 5-m-thick gypsum interval was recognized on the resistivity, sonic, and gamma-ray logs (212.5-217.5 mbsf). The logs also reveal cyclical variation that is interpreted as possible sedimentary grading.

Extensive reworking of microfossils has taken place throughout all three units, however, 10 datums could be recognized from the Holocene to the lower/middle Pliocene boundary (ca. 3.57 Ma). A hiatus was identified from the late Pliocene to the earliest Pleistocene with a possible further hiatus at around 145 mbsf. Sedimentation rates increased from relatively low values of 3.5 m/m.y. in the Pleistocene, to ca. 80 m/m.y. in the early Pliocene.

Structural observations were restricted to the APC cores, where a suite of high-angle faults was observed around 30 and 70 mbsf, together with a few small, low-angle faults especially within sapropels (at 30 mbsf). Discrete small-scale (several centimeters) low-angle features around 30 mbsf were probably caused by downslope sediment motion in the early to middle Pleistocene.

In pore-water samples taken at Site 968, salinity rises to four times seawater values at the bottom of the hole; this trend, together with increases of chloride and sodium, suggests the existence of halite at relatively shallow depths (beneath approximately 600 mbsf).

The section recorded at Site 968 (of Messinian age?) began with accumulation of calcareous turbidites and fine-grained sediments that locally include brackish ostracodes that may have accumulated in a lacustrine setting. The provenance of the thick calcareous turbidites was apparently mainly from the Miocene Pakhna Formation, and the Troodos Ophiolite of southern Cyprus following its initial stages of uplift. Detrital gypsum could also have been derived from up-paleoslope, where gypsum is locally developed in small silled basins. Deep-marine deposition ensued in the early Pliocene. The inferred hiatus in the late Pliocene-earliest Pleistocene corresponds to the time when land-based evidence indicates that southern Cyprus was experiencing intense tectonic uplift. The subsequent demise of all but the thinnest bedded mud turbidites could reflect tectonic uplift of Site 968 from a deep basinal setting in the Messinian/early Pliocene to its present position on the lower slope of the Cyprus margin.

Site 969

Sedimentary Unit I of the sequence at Site 969 (Fig. 1) consists of nannofossil ooze and nannofossil clay with sapropels of early Pliocene to Holocene age. It unconformably overlies calcareous silty clay of indeterminate age (Unit II) of which a total of 5.45 m was recovered. Holes 969A, B, and C contain locally faulted and thinned sedimentary sequences. Hole 969D recovered a tilted sequence containing small reverse faults. This hole appears to have yielded a more complete sedimentary sequence than the others, which contain numerous normal faults.

Over 80 sapropel beds were recovered from the lower Pliocene through Holocene section at Site 969 . The sapropels clearly stand out in a number of continuously logged physical properties: their density is lower (1.4 g/cm^3) than that of carbonate oozes; their water content is higher, and their natural gamma-ray emission is distinctly higher and correlates with organic carbon concentrations. The sapropels occur in five distinct groups, separated by intervals of sediment that are commonly oxidized, and have no preserved sapropels. The lowermost sapropel occurs near the transition of Units I and II, presumably directly after the establishment of marine conditions. The darkest black sapropels, of middle Pliocene age, possess a fine, bedding-parallel parting, which may be a primary lamination. Their organic carbon content reaches 30%. The organic matter is interpreted as degraded marine material with admixtures of terrigenous origin. Preliminary assessment of paleo sea-surface temperatures (SST) suggest that the surface mixed layer was significantly warmer during the Pliocene as compared to the Pleistocene. 18 biostratigraphic events were recognized in Hole 969A, ranging from the earliest Pliocene to the late Pleistocene. The clay-rich unit at the base of the recovered sequence yielded only reworked marine specimens and ostracodes indicative of brackish water. The age vs. depth relationship reveals that the sedimentation rate in Hole 969A averaged 22 m/m.y. (range 6 to 86 m/m.y.) since the early Pliocene.

Pore-water concentrations of dissolved ions imply that solutions characteristic of late-stage brine, possibly derived from dissolving evaporites at depth, are present below the cored sediment interval. The ratios of ammonia and alkalinity show that some carbonate diagenesis occurs in the sediment.

As was expected, Site 969 yielded a sedimentary sequence that includes the uppermost Messinian(?), a well-developed basal Pliocene, and a Pliocene to Holocene section with abundant and extraordinarily organic-rich sapropels. Tectonic overprinting has resulted in considerable variation between holes that are within a few hundred meters distance. Detailed post-cruise inter-hole correlation will have to establish if the sequence is complete and if a composite section can be constructed for high-resolution studies.

Site 970

An east-northeast - west-southwest transect of four holes was drilled from the flank to the crest of the Milano mud volcano, within the Olimpi mud diapir field (Fig. 1). Hole 970A (to 200 mbsf) sampled the mud volcano's outer flank. Hole 970B (to 50 mbsf), ca. 600 m farther from the volcano, examined the most distal effects of mud volcanism; Hole 970C (50 m) characterized the nature of the upper flank of the mud volcano; and, finally, Hole 970D (to 30 mbsf) examined the crestal area (Fig. 4).

At the outermost hole (Hole 970B), the sediments comprise interbedded nannofossil oozes, nannofossil clays, and sapropels, typical of the regional hemipelagic sedimentation. There are also poorly consolidated thin- to medium-bedded sands and silts. Some intervals are tilted, and small normal and reverse faults were noted. This section is dated as early-late Pleistocene.

The outer flank hole (Hole 970A) comprises alternations of mud debris flows and normal hemipelagic sediment (younger than 0.26 Ma) underlain by thick clast-rich mud debris flows and a thin interval of pelagic sediment (1.5 Ma to < 0.99 Ma), followed finally by normal pelagic sediments dated at 1.75 Ma.

The inner flank and crestal holes (Hole 970C and the top of Hole 970D) recovered mainly
"mousse-like" muddy and silty sediments, with evidence of gas hydrates (see below).

Overall, a number of different mud volcanic facies are present. The clast-supported facies in the lower part of Hole 970A are interpreted as turbidites and minor debris flows. The predominant extrusive sediment type, however, is well-consolidated, matrix-supported, clast-rich debris flows (the well-known "mud breccias"), in which the matrix ranges from silty clay to rare sandy silt, with nannofossils, foraminifers, clay, quartz, and rock fragments. The clast lithologies include poorly consolidated sandstone and siltstone, weakly to well-consolidated calcareous claystone and mudstone, together with calcite (or locally quartz)-cemented sandstone and siltstone.

Numerous sandstone clasts are mostly litharenites, derived from mainly plutonic igneous and metamorphic source terrains, admixed with shallow-water carbonate (e.g., calcareous algae and polyzoans and pelagic carbonate). Lithoclasts of pelagic carbonate include foraminifers of middle Miocene (Burdigalian-Langhian) age. In addition, some clasts contain nannofossils and planktonic foraminifers of Eocene and Oligocene age, and rare nannofossils of Cretaceous age again within clasts of Miocene pelagic limestone; brackish-water ostracodes (Messinian or early Pliocene?) were also observed in a few clasts.

Pore-water salinities in Holes 970A and B show a linear increase with depth to approximately twofold seawater values. By contrast, in Holes 970C and D, pore-water salinities decrease with depth, which is explicable by the decomposition of clathrates (methane hydrates). Very low sulfate levels in this hole may relate to intense bacterial sulfate reduction. In Hole 970D, bubbles generated in the mud by decompression contained pure methane in the upper 30 m, but with several orders of magnitude lower concentrations beneath this (to 50 m).

The Milano mud volcano became active around 1.75 Ma, or earlier. Stratified debris flows and turbidites record relatively early mud volcanism. Mudflows were localized around the eruptive center on the transect studied. Seismic reflectors around the mud volcano dip inward and imply progressive subsidence, perhaps resulting in ponding of the mud debris flows. Normal pelagic sediments accumulated around the mud volcano during the Pleistocene, interbedded with turbiditic silts and sands, possibly shed from the crestal area. Hemipelagic sediments interdigitate with mud debris flows on the flanks, while more silty and mousse-like sediments with clathrates characterize the crestal area.

Site 971

The mud dome is an asymmetrical flat-topped mound structure, with a well-defined peripheral moat and underlying inward-dipping reflectors. Hole 971A (106 m) was drilled just beyond the moat to investigate the margin of the mud volcano; Hole 971B (203 m) was drilled within the moat; Hole 971C (17 m) was drilled at the same site to recover unusual diatomaceous muds; while Holes 971D (46 m) and 971E (29 m) were drilled to investigate the crestal area (Fig. 4).

In Hole 971A the sediments comprise interbedded nannofossil oozes, nannofossil clays, and turbidites, in which 11 combined nannofossil and planktonic foraminifer datums were noted, ranging from middle-late Pleistocene to middle Pliocene in age. This sediment is underlain by calcareous clast-rich, matrix-supported mud debris flows (16.5-71.0 mbsf). The matrix of the mud debris flows contains Pleistocene, middle Miocene, Oligocene, and Eocene nannofossils. The pelagic sediment above the mud debris flow is dated at more than 0.46 Ma, while that beneath the mud debris flow is younger than 1.5 Ma. In addition, the lower part of the debris flow is within the *Gephyrocapsa* zone of 1.25-1.5 Ma. Clasts in the mud debris flows were dated as Burdigalian to Langhian in age.

Within the moat (Hole 971B) an upper unit of hemipelagic sediments with sapropels (0-20 mbsf) is underlain by mud debris flows that are older than 0.26 Ma, but younger than 0.46 Ma. Clast-poor mud debris flows alternate with more homogeneous silty clay. The matrix and the clasts in the mud debris flows are similar to those in Hole 971A; however, Pleistocene species are more abundant in Hole 971B.

Downhole logs (especially natural gamma and resistivity) indicate the presence of a number of thin layers that correspond to relatively sandy cored intervals. Intervals with unusual compaction trends may correspond to recovery of soupy sediment. The logs also distinguish clast-rich and clast-poor intervals.

Hole 971C recovered an expanded section. A 3.3-m-thick S5 sapropel is composed of laminated diatom ooze, with well-preserved diatom species characteristic of upwelling, as well as mat-forming varieties. Some radiolarians are also present.

Hole 971D recovered mousse-like silty clay with scattered small (<5 cm) clasts of mudstone and siltstone. In addition, angular fragments of coarsely crystalline halite (up to 3 cm in size) are concentrated in thin, more silty layers, together with a small number of subrounded halite-cemented mudstone clasts (<5

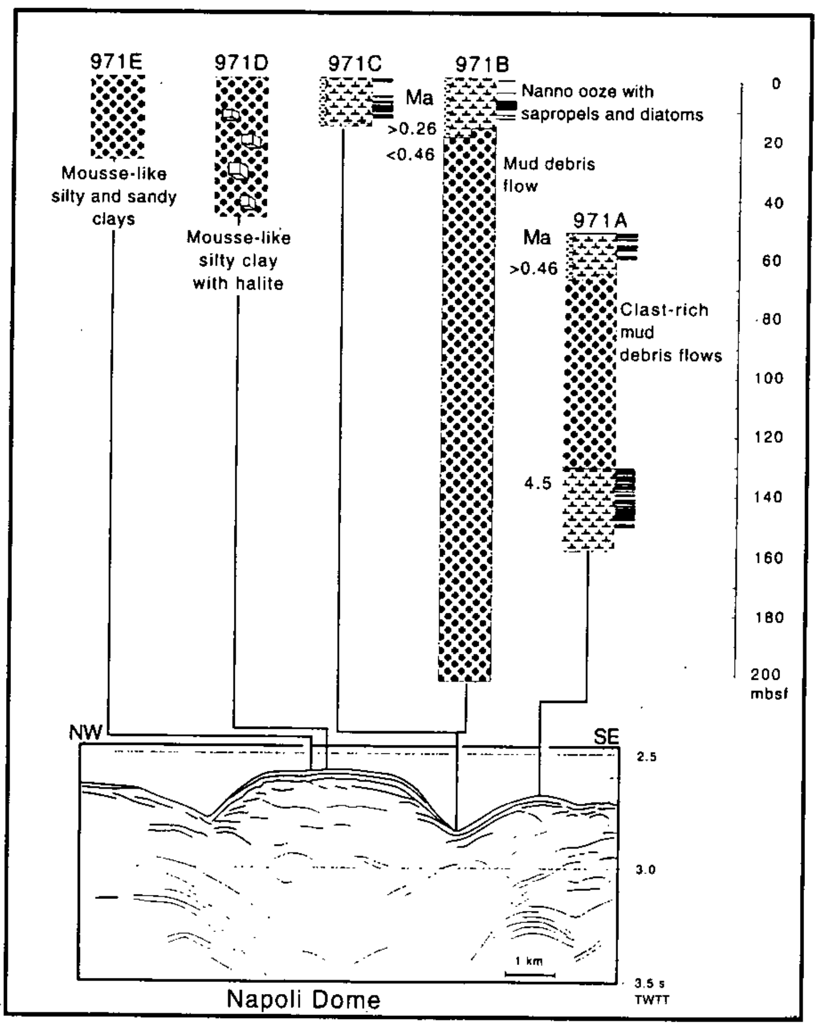


Figure 4. Lithostratigraphic profiles of Holes 970A through 970D at the Milano mud volcano. The location of each hole is shown on a simplified seismic profile.

24%) sapropels. Again in contrast to the Milano mud volcano, pore waters from the crestal holes are saturated with respect to halite in all five holes. Brines in the lower part of Hole 971A are unusually rich in potassium, suggesting that brine of more than one source may be present. A single ADARA temperature measurement obtained in Hole 970D at 45 mbsf gave a temperature of 16.1°C, which is 2°C above normal bottom-water levels.

The sediments cored from the Napoli mud dome all show clear evidence of sedimentary layering. The well-developed moat contains layered muddy debris flows with few clasts, compared to the thick clast-rich mud debris flows recovered at the Milano mud volcano (Hole 970A). More clast-rich mud debris flows interfinger with hemipelagic sediment on the flanks, as observed in the Milano mud volcano. The presence of more silty sediment in the crestal holes may relate to a contrasting mode of eruption, or the effects of current winnowing. Solid halite in the crestal holes (Hole 971D) was introduced both as crystalline aggregates and as halite-cemented clasts. Hydrocarbon gas is continuously flowing to the surface in the Napoli mud volcano, and clathrates are absent (both in contrast to the Milano mud volcano), perhaps because of the effects of higher pore-fluid temperatures and salinities. The Napoli mud volcano apparently first erupted between 1.5 and 1.25 Ma and has been episodically active to the present time, in contrast to the Milano mud volcano, which is probably now dormant.

Site 972

Site 972 is located on a small topographic high on the lower slope of the Hellenic accretionary prism (Fig. 1). Seismic data indicate that the section is folded and faulted. The main objective of drilling was to infer the structural history of the toe of the accretionary wedge, in particular any evidence of subduction/accretion processes, or vertical tectonics. Drilling reached only 100 m due to mechanical problems, and was unable to achieve all its objectives.

Only one lithological unit was recognized, composed of alternations of nannofossil clay, clayey nannofossil ooze, and nannofossil ooze. Minor ash layers are present in the upper part of the section. There are also sporadic thicker beds of turbidites up to a meter or more, with thin (1-2-cm) graded silt layers at their base, and sporadic intervals of fine sand up to 50 cm in thickness are visible. Three main types of turbidites are recognized: (1) white nannofossil ooze, (2) green-yellow clayey nannofossil ooze, and (3) silt or fine sand, fining upward to gray-green nannofossil clay. In addition, 24 discrete sapropels were noted, all of which are enriched in pyrite, amorphous organic matter, volcanic glass, quartz, and fragments of higher plant material.

Micropaleontological studies reveal a large degree of reworking and poor preservation of assemblages. Only 4 first-occurrence datums and 1 last-occurrence datum could be recognized, indicative of a late Pleistocene to latest Pliocene age.

Pore-fluid analysis indicates that salinity increases up to 7 times normal seawater values from the top of the hole downward. The pore-water data point to the existence of a late-stage evaporite at depth, of presumed Messinian age.

In summary, drilling at Site 972 confirmed that turbidites of heterogeneous origin are present on the toe of the Hellenic accretionary complex. There is some evidence of tilting and reverse faulting. Also, evaporites are assumed to exist at depth, and brines have permeated upward.

Site 973

The objective of drilling at Site 973 was to investigate the structure, sedimentation, and geochemical environment of the lower toe of the Hellenic accretionary prism. The site is located on a broad high slightly higher on the slope relative to Site 972. Two units were recognized.

Unit I comprises 84 m of nannofossil ooze and nannofossil clay of late Pliocene to Holocene age with more than 27 intercalated sapropels, and interbeds of sands, silts, and nannofossil clays, and a single 14-m-thick interval of sand, grading upward into nannofossil clay. Three thin ash layers are present in the upper part of the section. Pleistocene planktonic foraminifers are generally common to abundant, while Pliocene forms are less diverse and moderately to poorly preserved. Reworking is common throughout.

Unit II is made up of ca. 68-m clayey nannofossil ooze and an underlying calcareous silty claystone with a thin black layer almost completely replaced by gypsum that is interpreted as a relict sapropel. The unit is dated as early to late Pliocene. Planktonic foraminifers are rare or absent. Downhole logs of this poorly recovered interval suggest the presence of alternations of relatively coarse- and fine-grained sediments. High uranium levels in the downhole logs may indicate the presence of organic-rich layers (e.g., sapropels) above 112 mbsf.

The upper part of the APC section was correlated between holes based on the nature and occurrence of sapropels, turbidites, and distinctive ash beds. High-resolution color reflectance data were used to check visual correlations. Incomplete stratigraphic records were attributed to coring gaps, and erosion and removal of some sapropels, possibly by the turbidity currents responsible for sand deposition.

Bedding in the upper part of the section generally dips shallowly to the south or southwest. Some steeply inclined normal faults occur locally with small offsets. Elsewhere, sub-vertical faults with offsets of up to 44 cm in length were noted. Between 140 and 152.6 mbsf, microveins and small-scale reverse faults are infilled with fibrous gypsum. Several generations of cross-cutting gypsum veins can be observed, and the gypsum was also deformed by tension gashes, linked with small-scale en-echelon fractures. In addition, discrete beds of angular to subangular clasts were noted near the base of the recovered section. The structural features and changes in bedding dips within the section indicate a downward increase in deformation toward a décollement beneath the toe of the Mediterranean Ridge accretionary complex.

Pore-water analyses record a sharp increase in salinity, chloride and magnesium with depth, and, together with the trends in sulfate, calcium, and alkalinity suggest the existence of a late-stage evaporite brine.

Conclusions

Leg 160 included the study of geological responses to collisional processes in three contrasting tectonic settings. The first of these settings, in the east, is the collision of an inferred continental fragment, the Eratosthenes Seamount, with the Eurasian continental margin to the north, represented by the Cyprus active margin. The second objective concerned processes related to the formation of mud domes, resulting from both mud diapirism and mud volcanism on the Mediterranean Ridge, within the Olimpi area south of Crete. Some additional information on the regional tectono-sedimentary setting of the Plio-Pleistocene of the Mediterranean Ridge was obtained by drilling nearby for sapropels at Site 969. The third objective, in the west, was to examine the Ionian deformation front by sampling the incoming sediments and then to compare them with the accreted material, in which fluids may have been affected by salt tectonics associated with the Messinian desiccation event.

In conclusion, the tectonic component of Leg 160 was conceived as a contribution to the understanding of incipient collision-related processes in the Eastern Mediterranean, with a major focus on the tectonic history of the Eratosthenes Seamount and the mud volcanoes of the Mediterranean Ridge. The aim in both cases was to shed light on fundamental processes that operate on a global basis.

In the sediments recovered from the Pliocene to Holocene hemipelagic sequence, more than 80 individual sapropels were found. Preliminary shipboard investigations suggest that the pattern of sapropel occurrences marks periods when the Mediterranean catchment area experienced increased humidity and high average temperatures. These conditions resulted in cyclical and dramatic changes of conditions both in the biologically active surface layer and at the seafloor. A general dependence on global climate is evident in the pattern of sapropel frequency during the Pliocene: before the onset of glaciations in the northern hemisphere (at approximately 2.5 Ma), sapropels occurred frequently, simultaneously, and irrespective of paleo water depth at all sites. After the onset of glaciations, their occurrence was less frequent, the concentrations of organic carbon vary with water depth, and periods of sapropel deposition are separated by well-oxygenated reddish sediment intervals. When sapropel bundles occurred during this later interval, they coincided with times when the global climatic background was warm and ice volume was at a minimum. The initial interpretation from shipboard study is that anoxic conditions in the deep water were a primary contributor to sapropel formation. The link to the climatic background implies a dependence on deep-water formation rates, which may be amplified by simultaneous changes in physical water-mass structure and characteristics, and processes in the biologically active surface layer.

Aside from their paleoceanographic significance, the sapropels recovered during Leg 160 represent a rare and excellent opportunity to study the mechanisms and conditions of organic-carbon-rich sediment formation in the marine environment. Together with detailed stratigraphic work, questions concerning the nature of the environment during sapropel events will be the focus of land-based research.

Science Operator Report Leg 161

MEDITERRANEAN SEA II

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Abstract

Leg 161 was the second in a two-leg ODP program to address both tectonic and paleoceanographic objectives in the Mediterranean Sea. The paleoceanographic program concentrated on reconstructing Atlantic-Mediterranean water exchange and the paleoceanography of the western Mediterranean during the late Cenozoic. Tectonic studies focused on the origin and tectonic evolution of the Alboran Sea as a well-defined example of an extensional basin developed in a collisional setting.

The main focus of the paleoceanographic program during Leg 161 was documentation of the timing of sapropel formation in the Tyrrhenian Sea and of circulation patterns in the western Mediterranean, as well as monitoring of the Atlantic-Mediterranean water exchange. Secondary objectives were to determine environmental conditions during the onset of evaporitic conditions and the reestablishment of open-marine conditions during the earliest and latest Miocene, and the evolution of the Mediterranean's hydrography during the onset of Northern Hemisphere glaciation, about 3.0 m.y. ago. Because the Mediterranean is a semi-enclosed, landlocked basin with only restricted water exchange with the open ocean, the composition of these sediments is especially sensitive to climate change, and environmental signals are preserved in great detail. To achieve these goals, three drill sites where chosen: Site 974 in the Tyrrhenian Sea, Site 975 on the Menorca Rise, and Site 976 in the western Alboran Sea. Sites 977, 978, and 979 in the eastern and southern Alboran Sea were primary tectonic sites but also included paleoceanographic objectives.

APC and XCB drilling at multiple offset holes ensured continuous recovery of Pliocene-to-Pleistocene sequences at these sites. In the Alboran Sea, major unconformities were observed in the Pliocene and Miocene sections. Sedimentation rates varied between 3 and 4 cm/k.y. in the Tyrrhenian and southern Balearic seas, and 15 and 30 cm/k.y. in the Alboran Sea. At Sites 974 and 975, up to 38 organic-rich layers (ORL's) were recovered, which resemble the sapropels found in the eastern Mediterranean in that they are discrete, dark layers with sharp upper and lower boundaries. Total organic carbon concentrations of these layers varies between 0.8% and 2.5%; maximum concentrations of >6% are reached in the Tyrrhenian Sea. At the Alboran sites, more than 40 ORL's were found, but here they are more dispersed and have gradational upper and lower contacts. In addition, some are more than 3 m thick, reflecting higher sedimentation rates. Interstitial water profiles show that brines were present in the deepest parts at all sites. In the Tyrrhenian and Balearic seas, these brines are likely derived from dissolution of evaporites that are inferred to occur below the cored sediments. No

major evaporite series are known in the Alboran Sea, however, and the brines there are preliminarily interpreted as a paleo-fluid of Messinian age or represent a lateral flow of brines resulting from dissolution of evaporites in other parts of the area. At Site 975 on the Menorca Rise, an upper Miocene evaporite sequence was retrieved that consists of finely laminated gypsum, limestone, and marls. This sequence, together with sediments from the Miocene/Pliocene transition in the Alboran Sea, is important for establishing the transition from restricted to open-marine conditions.

The prime tectonic objective of the Alboran Sea sites was to develop a better understanding of the dynamics, kinematics, and deformation of continental lithosphere margins. The following problems were explored: the origin of extensional basins developed on former collisional orogens; the dynamics of the collapse of collisional ridges which result in extensional basins surrounded by arc-shaped orogenic belts; and a determination of the actual or partially-understood collisional processes.

Sites 976, 977, 978, and 978 in the Alboran Sea focused on the tectonic goals. Site 976, in the western Alboran Basin, penetrated through the Pleistocene and Miocene sedimentary cover and recovered 258.97 m of high-grade metamorphic basement, yielding information on the origin and evolution of the Alboran Sea. Metamorphic conditions indicate that these rocks underwent a significant decrease in pressure, accompanied by constant, or possibly increasing, temperature. Sites 977 and 978, in the eastern Alboran Basin, yielded information on the late Miocene to Holocene subsidence history and rifting evolution of the basin. Site 979 penetrated a zone of syn-and post-sedimentary folds on the flank of the Alboran Ridge (the main compressional feature of the Alboran Sea), yielding information on the age and nature of the later stages of compressional tectonic reorganization of the Alboran Basin.

Introduction

During Leg 161, *JOIDES Resolution* drilled a transect of five sites across the western Mediterranean (Fig. 1) from the Tyrrhenian Sea to the Alboran Sea, immediately east of the Strait of Gibraltar. Sites 974 and 975 in the Tyrrhenian Sea and on the Menorca Rise, respectively, were dedicated to paleoceanographic studies. Sites 976, 977, 978, and 979 in the Alboran Sea focused on tectonic goals, but also involved paleoceanographic objectives.

The ODP Leg 160 paleoceanographic investigation in the eastern Mediterranean was devoted to obtaining Pliocene-Pleistocene records containing a detailed record of sapropel deposition. Leg 161 was designed to retrieve time-equivalent sedimentary sequences that would allow documentation of the Miocene-through-Pleistocene paleoceanography of the western Mediterranean and a determination of the Mediterranean-wide circulation patterns at times of sapropel formation in the east. Site 974, in the Tyrrhenian Sea, was chosen, as it represents the westernmost documented occurrence of sapropels in the Mediterranean. Site 975, in the southern Balearic Sea, was selected to document the hydrography of western Mediterranean surface and deep waters. The paleoceanographic goals at the Alboran Sea sites included study of the late Cenozoic history of Atlantic-Mediterranean water exchange and the development of biological productivity patterns. The paleoceanographic and tectonic objectives in the Alboran Sea are related in that the paleo-geographic evolution of the western Mediterranean gateway is a central theme for understanding the Messinian desiccation and circulation in the western Mediterranean Sea.

For tectonic studies in the western Mediterranean, the Alboran Sea was chosen as the optimum area to study the origin of Neogene extensional basins in collisional settings. Among the Mediterranean convergent boundaries, the collision between the Eurasian and the African plates at the western-most Mediterranean Sea has resulted in a broad region of distributed deformation rather than a discrete plate boundary. This broad region comprises the Betic, Rif, and Tell cordilleras, which are linked across the Gibraltar Arc, and includes the extensional basins that form the Alboran and South Balearic seas. The apparent paradox of extensional basin formation and crustal stretching during the collision of the Eurasian and Africa plates has been a long-standing problem in Mediterranean tectonics.

The Alboran Basin was formed during the early to middle Miocene by extension at the site of a former collisional orogen. The basin, which is floored by extended continental crust and surrounded by a thrust belt that was tectonically active during basin extension, closely resembles the northern Tyrrhenian Sea or the Panonnian Basin in that there is no geological or geophysical evidence that oceanic lithosphere subduction was associated with basin extension. The extension directions in the basin, and those of the coeval thrusting in the surrounding orogenic arc, are not clearly related to the Eurasian-African relative motion.

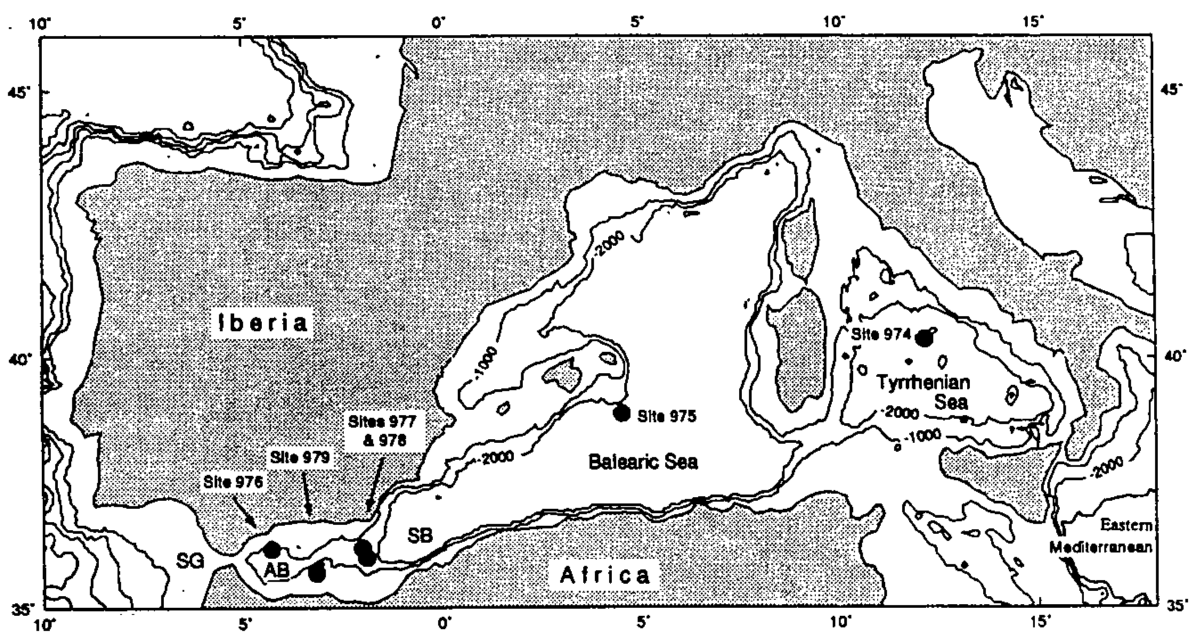

Figure 1. Leg 161 drill sites in the western Mediterranean. SG: Strait of Gibraltar; AB: Alboran Basin; SB: South Balearic Basin.

The prime tectonic objective of the Alboran Sea drill sites was to determine the response of the crust to compressional and extensional forces, and to better understand the kinematics and deformation of the Mediterranean continental lithosphere. Furthermore, the continental rift system that led to the development of the Alboran Basin provided an opportunity to examine the nature of brittle and ductile deformation of the crust, the role of magmatism in rifting processes, and the role of upper mantle in crustal modification and lithosphere evolution. The young, and tectonically active Alboran Sea is an ideal natural laboratory where these active tectonic processes can be investigated. The Alboran Sea drilling results are expected to have immediate applications in establishing geodynamic models for the origin and evolution of Mediterranean-type backarc extensional basins.

RESULTS

The objectives of Leg 161 required recovery of a continuous sedimentary sequence.

Site 974

Site 974 is located in the central Tyrrhenian Sea on the lowermost eastern continental margin of Sardinia. The site lies in a north-south trending, small, deep basin, between the Tyrrhenian Central Fault and the De Marchi Seamount. The basin is underlain by thinned continental crust, which surrounds areas of Pliocene and Pleistocene oceanic crust (the Vavilov and Marsili basins) to the south and southeast. Site 974 lies about 300 m west-northwest of Site 652, which was drilled during ODP Leg 107 in 1986. The objectives at Site 974 were to obtain a complete Pleistocene-through-Pliocene sedimentary sequence with a continuous record of organic-rich depositional events (sapropel intervals) in the Tyrrhenian Sea, and to retrieve a comprehensive record of the coeval volcaniclastic deposits within this sequence.

Cores recovered at Site 974 contain abundant, mostly well-preserved Pleistocene to earliest Pliocene/latest Miocene calcareous nannofossil and foraminiferal assemblages. Abundance and preservation of nannofossils and foraminifers are poor in sediments at the base of Holes 974B and 974C; this may reflect a transition from nonmarine to marine environment during the latest Miocene (Messinian). Benthic foraminifers were rare to absent. The biostratigraphic data indicate that sedimentation rates at this site steadily increased with age, from 30.7 m/m.y. during the early Pliocene to over 34.1 m/m.y. during the late Pliocene to 45.4 m/m.y. during the Pleistocene/Holocene.

Sediments at Site 974 are subdivided into four lithostratigraphic units, based primarily on nannofossil (carbonate) content. Unit boundaries were clearly correlated among Holes 974A, to 974D.

Unit I (Hole 974B, 0-88.9 mbsf; Hole 974C, 0-90.1 mbsf; Hole 974D, 0-89.8 mbsf) consists of Pliocene-to-Pleistocene nannofossil-rich clay, locally bioturbated and exhibiting thin to medium color banding.

36 sapropels, ranging in thickness from 2 to 20 cm, were identified within Unit I. Total organic carbon (TOC) contents of the sapropels reach up to 6.4%. Some of these layers are thin beds (1-2 cm) with less than 2% TOC. At the base of Unit I, some sapropels have been faulted and deformed; reverse faulting has repeated some of these intervals in Hole 974D, normal faulting may have removed others in Holes 974B and 974C. Numerous crystal-rich and vitric ash layers are present in Unit I, with the ash and volcaniclastic layers ranging from a few millimeters to about 12 cm in thickness.

Unit II consists of Pliocene nannofossil clay and nannofossil ooze, with minor amounts (1%-5%) of foraminifers. Ash beds are few and are locally altered to clay minerals and zeolites. A few sapropels are present in the lower part of Unit II.

The sediments of Units I and II correspond to deposits that accumulated in an open-marine environment with periodic influx of pyroclastic material. The shift from more pelagic deposits in Unit II to more hemipelagic sediments in Unit I may reflect greater terrigenous input during the Pleistocene.

Unit III is a very thin, variegated, transitional unit that separates Pliocene marine sediments from the Messinian sequence. The unit is characterized by horizontally laminated to cross-laminated(?) silt to silty clay with local clay interbeds. The Unit II/Unit III boundary was placed at the Miocene/Pliocene age boundary, based on the last occurrence of in-situ planktonic foraminifers.

Unit IV consists of a single graded(?), gray, siliciclastic interval, comprising a basal coarse-to-medium sand that grades upward into cross-laminated, very fine sand to cross- or parallel-laminated silt.

Structural features include changes in bedding dips and the presence of microfaults and slumps, which suggest that the area was tectonically active during the Pliocene and Pleistocene.

Physical property measurements (thermal conductivity, index properties, and natural gamma radiation) all showed good hole-to-hole correlation, and profiles of GRAPE density, magnetic susceptibility, and color reflectance were used to construct a composite depth section from Holes 974B to D.

Evaporites, especially halite, anhydrite, and gypsum are known to occur below the sediments cored at Site 974.

Logging in Hole 974C included the quad-combo, formation microscanner (FMS), and geochemical tool (GLT). Two main log units were identified in close correspondence with lithostratigraphic Units I and II.

Site 974 successfully achieved its goals in obtaining a continuous sequence of Pliocene-Pleistocene sediments that recorded sapropel deposition in the Tyrrhenian Sea. Within this sequence, substantial volcaniclastic deposits have been found. Further studies will focus on developing a latest Cenozoic-to-Holocene paleoceanographic model at this site.

Site 975

Site 975 is located on the South Balearic Margin between the Balearic Promontory (Menorca and Mallorca islands) and the South Balearic-Algerian Basin. The site was drilled at the edge of a small basin perched on the east-dipping slope of the Menorca Rise, at a water depth of 2415 m.

The primary objective at Site 975 was to continuously core the Pliocene-Pleistocene sedimentary sequence on the Menorca continental rise to obtain a complete stratigraphic section. Site 975 is located in a key position to monitor the history of eastbound inflowing Atlantic waters, and of westbound outflowing Mediterranean waters, and will allow correlation of environmental conditions in the eastern Mediterranean and western Mediterranean.

The stratigraphic sequence at Site 975 ranges from uppermost Pleistocene/Holocene to uppermost Miocene. The sediments contain abundant and well-preserved Pleistocene to lower Pliocene foraminiferal assemblages. Upper Miocene samples contain poor to moderately well-preserved foraminifers. The biostratigraphic data indicate that sedimentation rates at Hole 975B were 70.5 m/m.y for the Pleistocene/Holocene, 48.9 m/m.y. for the upper Pliocene, and 53.8 m/m.y. for the lower Pliocene.

Sediments at Site 975 have been divided into three lithostratigraphic units, based on downhole changes in lithology and sedimentary facies.

Unit I consists of Pliocene-to-Pleistocene nannofossil or calcareous clay, nannofossil or calcareous silty clay, and nannofossil ooze. Nannofossils are the major component of the carbonate fraction; locally, foraminifers and micrite may each constitute up to 30% of carbonate sediments. Graded and/or laminated foraminiferal-rich sandy or silty layers were found throughout the unit.

In Unit I, there were 38 sapropels of Pleistocene-to-Pliocene age, containing up to 2.8% TOC. These sapropel layers are well correlated between all holes at Site 975.

Unit II consists of Pliocene/Miocene(?) and the carbonate-rich, finely interlaminated to thinly interbedded micrite and micritic, silty clay.

Unit III is composed of an upper Miocene evaporite sequence of gypsum, nodular, finely laminated, and coarse crystals in a micrite matrix.

Unit I was deposited in an open-marine environment, with a shift from dominantly hemipelagic to pelagic conditions from the Pliocene to the Pleistocene. The boundary between Units I and II likely marks the change from a shallow, intertidal environment during the latest Miocene(?) to open-marine conditions during the Pliocene. Unit III is consistent with deposition in a supratidal environment, which can be correlated with the top of the Messinian evaporite sequences (just below the M reflector) that are known elsewhere in the Mediterranean. Slumping may have been related to the very gentle east-northeast dip of the entire Neogene and Pleistocene sequence. The lack of tectonic deformation and the paucity of slump structures suggest that Site 975 was tectonically inactive during Pliocene-Pleistocene times.

Samples containing at least 1% TOC from Hole 975B indicate sea-surface paleotemperatures which have fluctuated over a 7°C range in the Balearic Sea during the Pleistocene.

Site 975 achieved three significant results. A continuous Pliocene-Pleistocene sedimentary sequence was retrieved, and 38 sapropel layers were recovered at this site. Site 975 thus extends the geographic limit of documented sapropel occurrence farther west, from the Tyrrhenian Sea to the central western Mediterranean Basin. A well-preserved sequence of uppermost Messinian evaporites and early Pliocene hemipelagic-to-pelagic sediments was retrieved in two holes at Site 975.

Site 976

Site 976, the first of three sites planned to address tectonic objectives in the western Mediterranean Sea and the westernmost site of the trans-Mediterranean transect, designed to refine paleoceanographic models for sapropel formation, located in the western Mediterranean (Alboran Sea), 60 km off the southern Spanish coast and about 110 km east of the Strait of Gibraltar, is situated on the lower part of a gentle slope that dips to the south from the Spanish margin toward the western Alboran Basin. The site is located in a water depth of 1108 m and is 8 km northeast of DSDP Site 121 (Fig. 2).

Site 976 ranges from uppermost middle Miocene to uppermost Pleistocene/Holocene. Three major hiatuses were recorded: between the late and early Pliocene, early Pliocene and latest Miocene, and within the late Miocene (Tortonian). Sedimentation rates were calculated as 205 m/m.y for the Pleistocene/ Holocene, 341 m/m.y. for the late Pliocene, 167 m/m.y. for the early Pliocene, and 33 m/m.y. for the late Miocene.

Sediments at Site 976 were subdivided into four lithostratigraphic units.

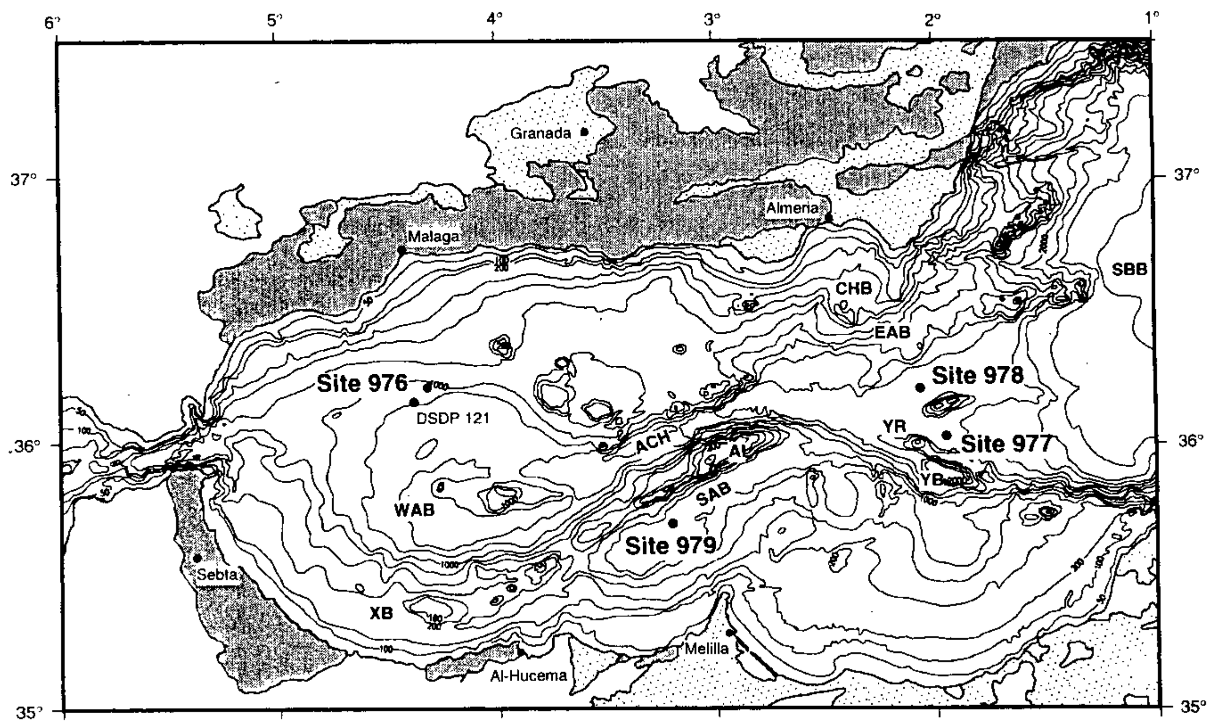

Figure 2. Bathymetric map of the Alboran Sea showing position of Leg 161 sites and DSDP Site 121. Contours in meters. Map onshore. Stippled: Miocene marine sediments; Shaded: Alboran Crustal Domain (Metamorphic Complexes in Betics and Rif). ACH: Alboran Channel; AI: Alboran Island in the Alboran Ridge; CHB: Chella Bank; EAB: Eastern Alboran Basin; SAB: South Alboran Basin; SBB: South Balearic Basin; WAB: West Alboran Basin; XB: Xauen Bank; YB: Yusuf Basin; YR: Yusuf Ridge.

Unit I contains a Holocene-Pleistocene, open-marine, hemipelagic facies of nannofossil-rich clay, nannofossil clay, and nannofossil silty clay. Continuous and discontinuous, clayey, silt laminae occur irregularly throughout the unit.

Twenty eight ORL's occur in five discrete intervals within Unit I, consisting mainly of nannofossil clay to nannofossil-rich clay and generally contain 0.9 to 1.3% TOC (background is 0.5% TOC), and range in thickness from <20 cm to >2 m.

Unit II consists of Pliocene sand, silt, calcareous silty clay, and nannofossil clay.

Unit III is Miocene/Pliocene in age and consists of nannofossil and nannofossil-rich clay and claystone. Hiatuses/unconformities occur between the early and late Pliocene, at the Miocene/Pliocene boundary, and within the Tortonian.

Unit IV immediately overlies basement in both holes, and consists of coarse-grained, poorly sorted, coarse pebbly sand, and a 15 cm-thick interval of glauconite-rich, sandy-silty claystone of marine facies.

The contact between basement and the middle Miocene sediments is sharp and has an irregular topography, possibly produced by faulting. Faulting of the basement is indicated by breccia throughout the basement in Holes 976B and 976E. In the upper 40 m of basement, some fault breccias are formed by highly angular metamorphic clasts in a matrix with a Miocene sedimentary component.

The high-grade metamorphic basement rocks of the Alboran Basin at Site 976 are formed of the following lithotypes.

(1) High-gradegraphitic schist with biotite, sillimanite aggregates and with andalusite and garnet porphyroblasts in some places.

(2) Felsic gneiss, commonly with biotite, feldspar, plagioclase, sillimanite, andalusite porphyroblasts up to 1 cm, cordierite porphyroblasts up to 1 cm, and locally some muscovite. In places, the gneiss grades into high-grade schist, and into migmatitic gneiss.

(3) Felsic biotite-cordierite-sillimanite-andalusite gneiss with irregular veins and patches of weakly foliated or unfoliated granite, with biotite and tourmaline. The granitic material forms veins parallel to, or cutting across, the foliation. Associated coarse-grained quartz veins with tourmaline are abundant. In places, the granitic material contains cordierite.

(4) Dolomite marble and calcite marble with minor amounts of phlogopite and chlorite. The calcite marble near the top of the basement in Hole 976E is interlayered, on a small scale, with calc-silicate rock and biotite-sillimanite schist.

(5) Banded rocks with thin layers of calcite or dolomite, garnet, plagioclase, calc-silicate minerals, including diopside and calcic amphibole, and serpentine(?) after forsterite(?). These minerals commonly occur as reaction zones between marble and schist.

(6) Fine-grained, hypidiomorphic, granular leucogranite occurs throughout the sequence, probably in the form of dikes. The granite has small amounts of biotite and tourmaline.

With the exception of the leucogranite dikes and the granitic leucosomes, all basement rock types show a well-developed foliation., and evidence of penetrative ductile deformation, followed by extensive brittle fracturing. At least three sets of ductile fabrics and structures can be distinguished. The metamorphic sequence is also cut by numerous zones of fault breccia and fault gouge, the dolomitic marble, in particular, is commonly associated with zones of brecciation and faulting.

The metamorphic history of basement rocks at Site 976 is most easily explained by tectonic exhumation of middle crustal rocks accompanied by substantial heating.

Interstitial-water profiles suggest the presence of a deep-seated brine, which is preliminarily interpreted to be either a Messinian-age paleofluid, or a brine originating from dissolution of salts in a deeper part of the basin.

One of the most exciting results of Site 976 is the discovery that basement beneath the Alboran Basin is formed by rocks of continental origin that have undergone high-temperature meta-morphism during exhumation and isothermal decompression.

Site 977

Site 977 is located south of Cabo de Gata in the eastern Alboran Basin, halfway between the Spanish and Algerian coasts, at a water depth of 1984 m. The site is situated south of the Al-Mansour Seamount in a 36 km-wide graben, which is bounded by the Yusuf Ridge to the south and the Maimonides Ridge to the north (Fig. 2).

Site 977 penetrated 598.5 m of Miocene(?)/Pliocene-to-Holocene sediments. The Pliocene/ Pleistocene boundary is at 266.95 mbsf. The biostratigraphic data are not conclusive as to whether the Miocene/ Pliocene boundary was reached at this site. A hiatus was noted in the lower Pliocene between 490.59 and 490.63 mbsf. Average sedimentation rates at Site 977 are 148 m/m.y for the Pleistocene-Holocene, 98 m/m.y. for the upper to uppermost lower Pliocene, and 91 m/m.y. for the lower Pliocene.

The sedimentary sequence recovered at Site 977 was subdivided into two lithostratigraphic units, based on downhole changes in sedimentary structure and grain size.

Unit I contains Pliocene-Pleistocene sediments of an open-marine, hemipelagic facies, consisting predominantly of nannofossil clay to nannofossil-rich, silty clay, slightly to moderately bioturbated throughout the unit.

Thirty-nine ORL's occur in Unit I, some of which resemble sapropels recovered at previous Sites 974 and 975. The appearance of ORL's at Site 977 is important, as it suggests that organic-rich sedimentation occurred basinwide in the western Mediterranean; organic carbon concentrations in some ORL's reach levels that are similar to those found in the eastern Mediterranean sapropels.

Unit II (532.9-598.5 mbsf) is composed of partly cemented, sandy gravel, which is
early Pliocene to Miocene(?) in age. Recovery was less than 1% with only 2 cm of
granule-rich sand and 40 cm of gravel being recovered from a cored interval of 57.8 m.
The gravel consists predominantly of volcanic clasts and few sedimentary clasts. A coating of calcareous cement, suggests that the gravel has been derived from the partly cemented sandy gravel.

Interstitial-water profiles are dominated by organic-matter degradation and carbonate diagenesis. The strong seismic reflector recognized in the area likely corresponds to the gravel-bearing interval that has been sampled to 598.5 mbsf. This seismic reflector correlates with the "M-reflector", the top of Messinian evaporites at our previous Sites 974 and 975. Drilling results at Site 977 suggest that, in the eastern Alboran Basin, the M-reflector corresponds to a strong erosional event.

The recovery of ORL's at Site 977 is an intriguing discovery that documents intervals with organic carbon concentrations (which in some cases reach levels found in sapropels from the eastern Mediterranean) across the western Mediterranean Sea.

Site 978

Site 978 is located in the eastern Alboran Basin, south of Cabo de Gata and 24 km north of Site 977. The site lies in a small, east-west-trending basin within the same 35 km-wide graben as Site 977, but north of the Al-Mansour Seamount (Fig. 2).

A continuous sequence of 485 m of upper Miocene to Pleistocene sediments was recovered at Site 978. The Pliocene/Pleistocene boundary is between 222.77 and 223.35 mbsf; the Miocene/Pliocene boundary occurs between 607.51 and 611.39 mbsf. In the Pliocene interval, foraminifers are abundant and preservation is generally good. Miocene foraminifers are moderately to poorly preserved. Sedimentation rates were 127 m/m.y. for the Pleistocene, 110 m/m.y for the late Pliocene, 122 m/m.y. for the early Pliocene, and 100 m/m.y. for the late Miocene.

The sedimentary sequence sampled at Site 978 was divided into three lithologic units.

Unit I consists of early Pleistocene-to-Pliocene nannofossil clay to claystone, which is variably bioturbated.

Unit II consists of an upper Miocene, gravel-bearing interval, containing pebbles of volcanic and sedimentary rocks. The contact between Units I and II was not recovered. Some pebbles have smooth, rounded, weathered(?) surfaces and some are partly covered by a thin coating of microcrystalline calcareous material, zeolites, and smectite. The pebbles are formed of andesitic basalt to andesite, chert, limestone, quartzite, and metamorphic rocks.

Unit III consists of Miocene sandy and silty layers, which exhibit parallel and cross lamination and inverse to normal grading. Sparse bioturbation, in-situ brecciation, and clastic dikes are observed throughout this unit.

Sediment bedding is mostly horizontal, and sporadic slump folding and small, syn-sedimentary faults occur. Slump folds are well preserved near the base of the Pliocene. Late Miocene sediments are significantly more consolidated than the overlying Pliocene sequence. Bedding in the Miocene section is also mostly horizontal, but some units are cut by numerous dilational fractures with irregular orientations.

Interstitial water salinity, chloride, sodium, and calcium increase downhole, with a steepening of the concentration gradients below 450 mbsf. Sulfate concentrations are close to zero to 450 mbsf and increase steeply below 500 mbsf. No halite salts are known at depth in this area, and the high concentrations of these elements are likely due to trapped Messinian-age paleo-seawater or lateral migration of saline fluids produced by dissolution from Messinian halite deposits present in the South Balearic Basin, about 30 km east of Site 978.

11 magnetic polarity zones were identified between 390 and 610 mbsf at Site 978, and correlation with biostratigraphic data suggests that these represent polarity subchron C2An.2n through subchron C3n.4n (3.22 to 4.98 Ma).

The uppermost Miocene, gravel-bearing interval, containing pebbles of volcanic rocks in Unit II and encountered at 620.9 mbsf at Site 978, can be seismically correlated with the gravel interval sampled at 598.5 mbsf at Site 977. This correlation confirms the correspondence between this gravel-bearing sedimentary interval and the M-reflector, and the fact that this reflector represents a strong erosional event in the eastern Alboran Basin.

Drilling at Site 978 was successful in sampling the post-rift and the upper part of the syn-rift sequence of the eastern Alboran Basin and in determining that late, syn-rift sediments correspond to the upper Miocene (Tortonian).

Site 979

Site 979 is located in the southern Alboran Basin, a narrow depression between Alboran Island and the Moroccan coast, about 45 km north of Cabo Tres Forcas, Morocco. The site is situated south of the northeast-southwest-trending Alboran Ridge. The ridge(>30 km wide and ~150 km long) rises ~1000 m above the surrounding basin floor and above sea level at Alboran Island. Deformation is expressed as a series of folds and faults that extend from the southern flank of the Alboran Ridge to the adjacent basin floor (Fig. 2).

The recovered stratigraphic interval ranges from upper Pliocene to uppermost Pleistocene/ Holocene. The Pliocene/ Pleistocene boundary is between 340.77 and 345.33 mbsf. Calcareous nannofossils and planktonic foraminifers are abundant and well preserved in most of the sequence. Benthic foraminifers suggest lower epibathyal (500-1300 m) to upper mesobathyal (1000-1800 m) depths for these sediments. Average sedimentation rates at Site 979 were calculated at 196 m/m.y. for the Pleistocene and 176 m/m.y. for the late Pliocene. A short hiatus within the upper Pliocene was recognized, below which the biostratigraphic age data suggest an increase in sedimentation rate to 696 m/m.y.

The sediments recovered at Site 979 were quite uniform. Only one lithological unit was recognized.

Unit I is composed of Pleistocene-to-Pliocene, open-marine hemipelagic deposits with minor siliciclastic detrital layers. The dominant lithology is nannofossil clay, which accounts for about 40% of the stratigraphic section. A typical composition of these hemipelagic facies is about 53% clay, 40% calcareous nannofossils, 6% micrite, 1% foraminifers, and trace amounts of detrital mica, opaque minerals, sponge spicules, and fecal pellets.

The Pliocene-to-Pleistocene sediments recovered at Site 979 are for the most part horizontal, but there are local intervals of dipping beds.

The interstitial water profiles at Site 979 appear to be influenced by two main processes, early diagenesis of organic matter and the presence of a saline brine at depth.

At Site 979 a comparison between seismic data and drilling results suggests that tectonic activity, including uplifting by folding and/or faulting of the Alboran Ridge, occurred from the late Pliocene to the Holocene. The high sedimentation rates suggest that active subsidence and sedimentation were coeval with the recent contractive reorganization of the Alboran Basin.

Drilling multiple holes at each site, with coring intervals offset in depth, helped to ensure that intervals missing within a single hole were recovered in adjacent holes. During Leg 161, the continuity of the recovered sedimentary sequence was confirmed by development of composite depth sections at the multiple-cored sites (Fig. 3).

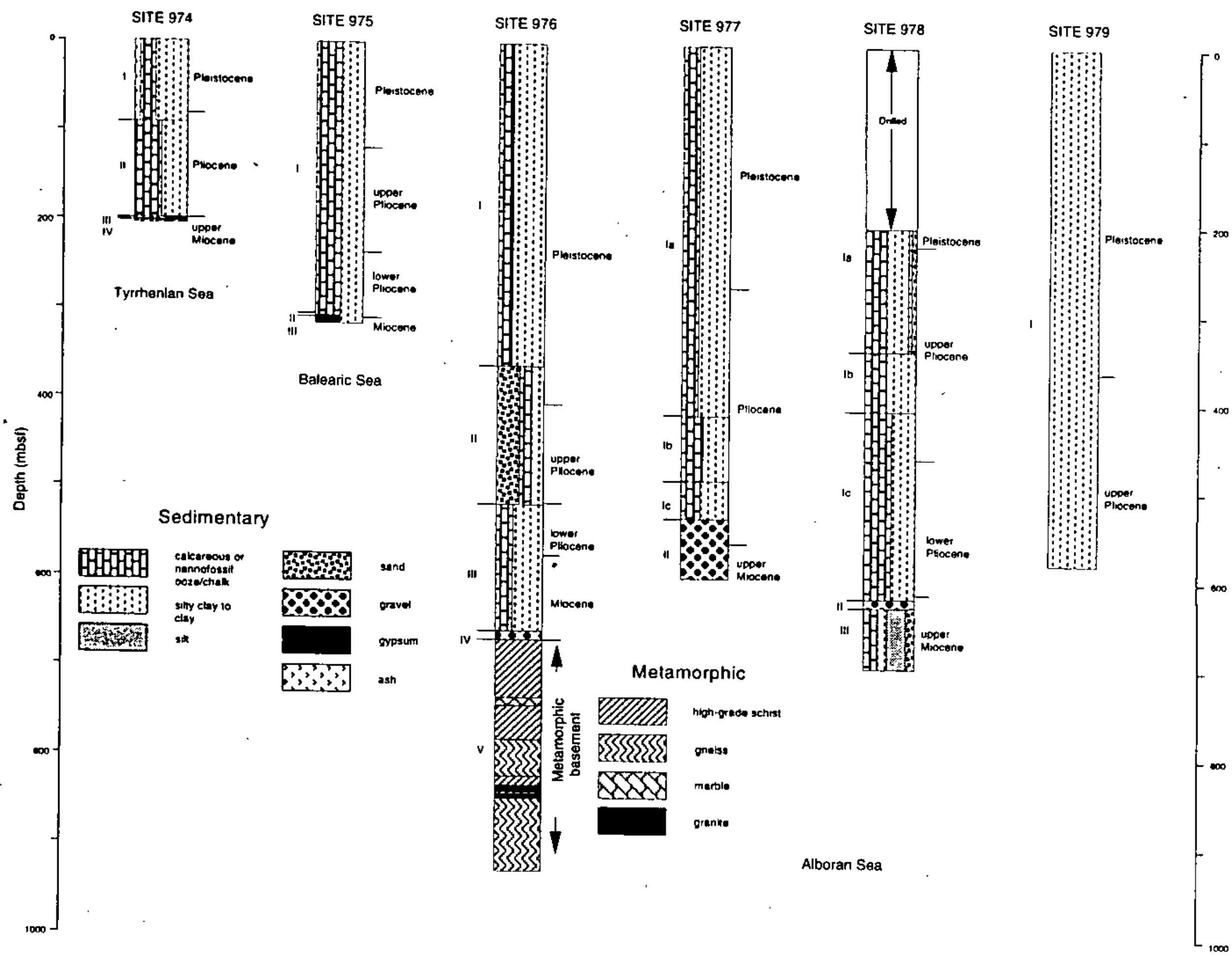

Figure 3. Lithostratigraphic summary of Leg 161 drill sites in the western Mediterranean.

Science Operator Prospectus Leg 165

Caribbean Ocean History and the Cretaceous/Tertiary Boundary Event

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ABSTRACT

Leg 165 drilling will address two major themes: the nature of the Cretaceous/Tertiary boundary and the influence of tropical seas on global ocean history and climate evolution. Drilling at five primary sites will provide a unique opportunity to examine nearly 90 m.y. of Earth history, including (1) the K/T boundary impact event, mechanisms of ejecta dispersal, and environmental consequences from

aerosols and fallout of ejecta; (2) catastrophic extinction events and biotic recovery; (3) the nature of climate forcing in the pre-Neogene world and tests of climate models with boundary conditions very different from those of today; (4) several episodes of moderate to extreme climatic warmth (early Late Cretaceous, early Eocene, early to mid Pliocene); (5) the evolution of tropical sea surface temperatures and changes in meridional temperature gradients; (6) changes in oceanic circulation and in sources of deep and intermediate water masses through Late Cretaceous and Cenozoic time; (7) the closing of low latitude oceanic gateways, the opening of a major gateway within the Caribbean, and the oceanic and climatic consequences of low latitude tectonics during the late Neogene; (8) tropical climate variability during the late Quaternary; and (9) nature and origin of Caribbean crust.

INTRODUCTION

The principal hypothesis put forward to account for the worldwide Cretaceous/Tertiary boundary mass extinctions is the impact of a large bolide on the Earth. The discovery of fresh impact glasses at the K/T boundary in the Beloc Formation of Haiti, in the Mimbral sequence of northeastern Mexico, and at DSDP Sites 536 and 540 in the Gulf of Mexico provides evidence for a major impact event in the Caribbean region. Geochemical evidence from these glasses also yields constraints for an impact site on continental crust overlain by evaporite-rich sediments, which is consistent with the stratigraphy near the 180 km to 300 km Chicxulub impact crater on the Yucatan Peninsula of Mexico. The discovery of impact glass-bearing deposits in the circum-Caribbean region indicates that sediments within the Caribbean Sea have an excellent potential for yielding K/T boundary layers similar to the rare sections exposed on land. Leg 165 will drill a series of sites in the Caribbean Sea and on the margin of the Yucatan Basin for the purpose of penetrating and recovering the K/T interval (Fig. 1).

In addition to K/T boundary objectives, the Leg 165 drilling program will address diverse aspects of tectonics, paleoceanography, climatology, and evolution in the tropics, thereby providing new information on the role of the tropics in the ocean-climate system through geologic time. The recovery of relatively complete Upper Cretaceous, Tertiary, and Quaternary sedimentary sequences in the Caribbean will greatly advance our knowledge of a wide range of major paleoceanographic and paleoclimatic problems. Chief among these are:

- the nature of climate forcing in the pre-Neogene world in order to test climate models under different boundary conditions:
  a) low latitude sea surface temperatures and changes in equator-to-pole temperature gradients through the late Mesozoic and Cenozoic,
  b) the linkage between greenhouse gases and warm global climates of the past, and
  c) the role of oceanic heat transport during times of moderate to extreme warmth (e.g., Late Cretaceous, early Eocene, and early Pliocene), including a test of the hypothesis of warm saline deep and intermediate water formation in the pre-Neogene record;

- the tropical record of abrupt ocean and climate change (e.g., Paleocene/Eocene boundary, Eocene/Oligocene boundary, Younger Dryas event), including the impact on and response of benthic and planktonic microbiota;

- improving resolution and correlations between calcareous and siliceous plankton biostratigraphy and paleomagnetic stratigraphy, and refining low latitude Upper Cretaceous and Paleogene chronostratigraphy;

- the role of Caribbean tectonics in the evolution of North Atlantic paleoceanography and Northern Hemisphere glaciation during the

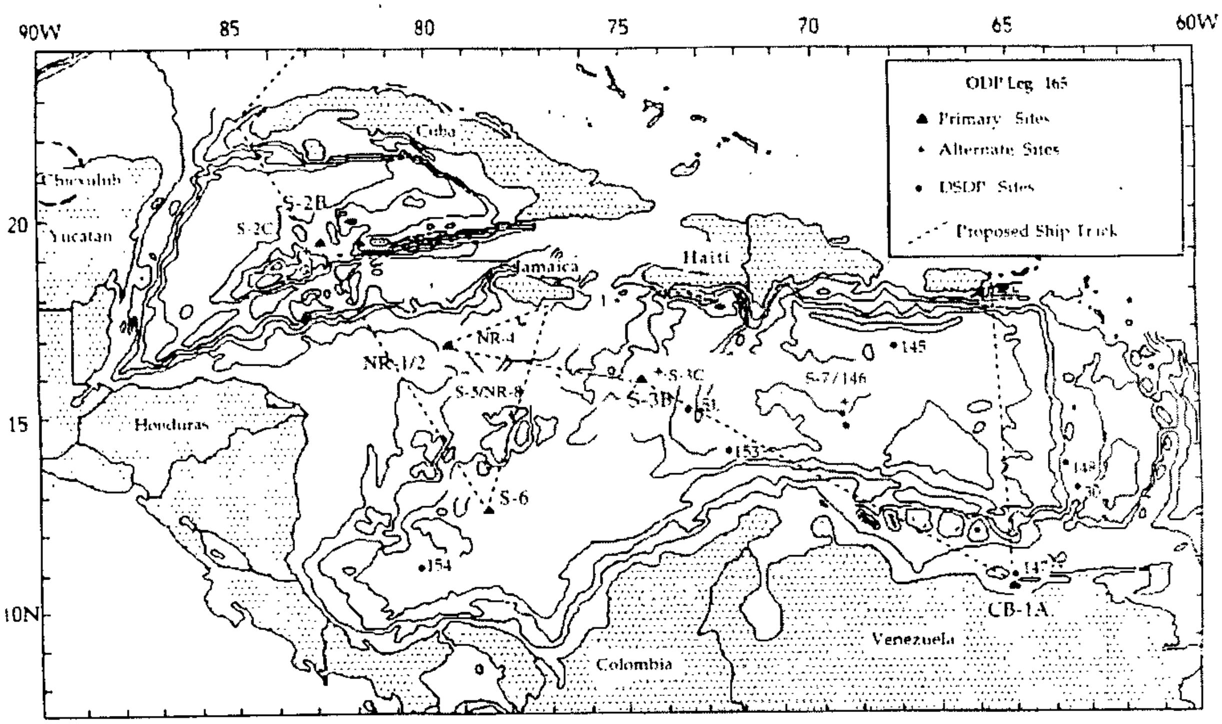


Figure 1: Location of primary and alternate sites in the Caribbean, to be drilled during ODP Leg 165.

late Neogene, especially the opening of a major intra-Caribbean gateway during the middle to late Miocene, and the closing of the Central American Seaway during the late Miocene and Pliocene;

• the history of variations in intermediate and deep water masses in the Caribbean during the late Neogene and Quaternary and implications for global circulation;

• the potential linkages between sub-millennial climatic events of the northern latitudes (e.g., Heinrich events), modes of deep water formation, and variability of tropical climate in the late Quaternary;

• the environmental conditions of anoxic basin development.

The drilling during Leg 165 will also address important problems related to the age and origin of the Caribbean oceanic crust as a large igneous province (LIP) and the nature and origin of the Cayman Ridge.

SCIENTIFIC OBJECTIVES AND METHODOLOGY

The Cretaceous/Tertiary Boundary

The major outstanding issue regarding the K/T boundary event is the exact relationship between the bolide impact and the associated extinctions. This issue relates to bolide size, impact angle, ejecta dispersal, and, perhaps most important, the geochemistry of the impact terrain. It turns out that the Yucatan terrain has geologic features that are likely to have brought about uniquely severe environmental effects from the impact. Evidence from the geochemistry of impact glasses or tektites indicates that two dominant geologic formations were melted: (1) Paleozoic continental crust (producing black, high-silica tektite glasses), and (2) Cretaceous evaporites and carbonates. Drilling in the Caribbean region will have a bearing on a number of problems associated with the K/T boundary event, as discussed below.

Total Ejecta Mass

Ejecta from the bolide impact consists of three principal components: (1) melt ejecta, in the form of impact glass spherules or tektites; (2) gases from vaporized target material, dominantly water, CO_2, and SO_2, which have converted to a stratospheric aerosol; and (3) crustal rock ejecta or "dust," consisting of proximal breccia and distal crystal fallout (shocked quartz, etc.). Previous estimates of a high atmospheric mass loading at the K/T boundary due to large amounts of rock "dust" may be high by a factor of 4, and that rock "dust" was therefore probably not a major climate-forcing factor in the wake of the impact.

The proposed Leg 165 drilling will provide much-needed constraints on the solid ejecta mass distribution, as the proposed sites form a transect that crosses the hypothesized transition between the thick proximal ejecta (within 1400 km) from source, and the thin distal ejecta. Most models assume an axisymmetric distribution of the ejecta blanket deposit, but a recent proposal, that the Chicxulub structure represents an oblique impact, implies that the ejecta distribution would be asymmetric (Fig. 2).

Ejecta Dispersal Mechanisms

Studies of the well-preserved and thick (0.5-1 m) Haiti K/T boundary sections indicate that the ejecta deposit consists of three principal units that reflect different depositional processes. The basal unit is normally graded, and the grain size of glass spherules (up to 8 mm diameter) indicates that they are ballistic fallout. The center unit is interpreted as a density current deposit or turbidite, possibly related to an impact-generated tsunami or seiche event, such as has been proposed for similar debris flow deposits at the K/T boundary in northern Mexico. The uppermost unit most likely represents late-stage fallout of aerosols and atmospherically suspended impact "dust". The proposed drilling will provide additional information on the units grain size, depositional mechanisms, and possible facies variations in the ejecta layer as a function of distance from source.

Volatile Components and Extinction Mechanisms

The geochemical evidence from the Haiti impact glasses or tektites, high sulfur content (up to 1 wt%),
high oxygen fugacity, and sulfur isotopic composition of the high-Ca yellow impact glasses are conclusive evidence of their formation by fusion of evaporite and carbonate in the presence of a silicate melt. The geologic constraints indicate that the impact produced a large stratospheric vapor plume consisting of the potent brew of CO_2, SO_2, and H_2O in about equal proportions. These inferences are fully supported by the geologic evidence of the Cretaceous stratigraphy of the Yucatan Peninsula.

Coring through complete K/T boundary sections is likely to yield glass spherules for further quantitative evaluation of the possible role of evaporites and carbonate sediments in the formation of the impact melt. The recovered boundary deposit may also contain fragmentary ejecta from the impacted terrain, such as carbonates and evaporites, and information on the thickness distribution of the im-

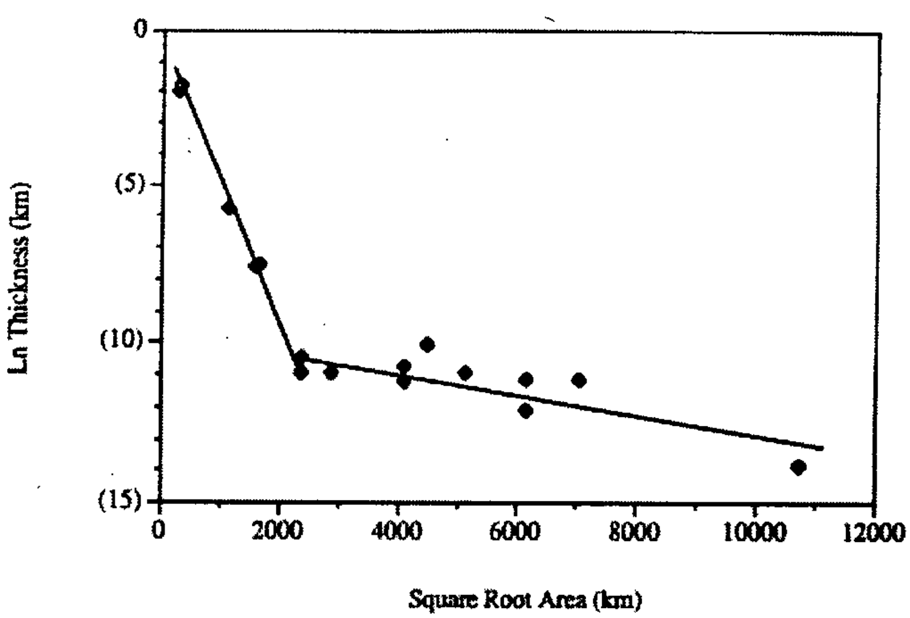


Figure 2. The global thickness distribution of the K/T boundary ejecta deposi. The thickness distribution can best be represented as a two-segment plot, in the form of ln (-thickness) vs. Square root of isopach area. An assumption is made that the thickness isopachs are circular in shape. The intersection of the two segments is at a distance of 1400 km from the Chicxulub impact crater.

pact ejecta deposit will help constrain impact angle and the direction and magnitude of the blast zone. Analyses of microbiota and stable isotopes will shed light on the environmental changes accompanying the bolide impact.

Cretaceous and Paleogene Ocean and Climate History

The tropics hold an important key to understanding how the ocean-climate system operated through time, in defining climate parameters such as deep and surface water temperatures and chemistry, in understanding how the tropical biota responded to changes, in helping to identify causes, rates, and magnitudes of climate change, and in defining the role the ocean plays in mitigating these changes.

Climate Forcing in the Late Cretaceous and Paleogene

The late Aptian-earliest Turonian, are believed to have been the warmest of the Cretaceous, attributed to heightened plate tectonic activity and elevated levels of CO_2 in the atmosphere, and ocean circulation was dominated by the circum-tropical Tethys Ocean. Bottom, deep, and/or intermediate water masses may have formed in Tethys, on its adjacent broad shelves or in epicontinental seas, by the sinking of warm saline tropical waters. This mode of deep water formation is widely suspected to have been an important if not the dominant mode during the mid to Late Cretaceous and during part of the Paleogene. Warm saline deep water formation is consistent with global circulation modeling of Cretaceous oceans and climate, which suggests strong precession-scale variation in evaporation-precipitation balances over low- and mid-latitude epicontinental seas. Recovery of Cretaceous and Paleogene sequences from the Caribbean will greatly aid in isotopic testing of the hypothesis of warm saline deep and intermediate waters, since this region is likely to have been close to potential sources.

Recent work suggests that very warm surface water temperatures persisted in the southern high latitudes from Turonian through early Campanian time. Possible causes of the relatively high temperature of polar waters include elevated concentrations of greenhouse gases and increased ocean heat transport from low to high latitudes. The relative importance of these factors can be assessed by isotopic documentation of tropical sea surface temperatures (SSTs). The Caribbean seafloor contains Upper Cretaceous sequences that are highly suitable for such documentation.

Analysis of sedimentologic and faunal data from the ancient sequences in the Caribbean will document the sensitivity of the low latitude ocean to Milankovitch-band forcing and may document the presence of threshold events in Late Cretaceous paleoceanographic and paleoclimatic history. Caribbean drill sites may also provide suitable sequences for analysis of chronostratigraphically well-constrained stable isotopic trends in the Late Cretaceous ocean, allowing testing for the global or regional extent of large climate steps in the Late Cretaceous "greenhouse".

The determination of tropical Sea Surface Temperatures (SSTs) will help to test the validity of greenhouse forcing models for times of global warmth. In addition, recovery of relatively complete Cretaceous and Paleogene sequences from the Caribbean would closely constrain the regional presence and timing of gradual and abrupt changes in surface and deep $d^{18}O$ and $d^{13}C$ trends, and elucidate relationships between tropical climate change and plankton evolution.

Abrupt Climate and Ocean Change in the Pre-Neogene Record

Two episodes of abrupt climate change are prominent features of the Paleogene record: the extreme warming event that occurred near the time of the Paleocene/Eocene boundary, and the abrupt cooling event recorded near the Eocene/Oligocene boundary. Superposed on the warming trend that began in the late Paleocene and culminated in the early Eocene was an abrupt warming in the southern high latitudes during latest Paleocene time. Both surface and deep water temperatures increased rapidly, perhaps within 10 k.y., coincident with a major extinction event in deep-sea benthic foraminifers, an event that has been attributed to a rapid change in the mode of deep ocean circulation. Warm saline deep waters originating in the tropics, much like the circulation pattern suspected for part of the mid- and Late Cretaceous interval, may have caused the warming event and extinctions. The abrupt cooling of deep waters in the earliest Oligocene represents one of the largest cooling steps of the Cenozoic is attributed to the establishment of a large icesheet on Antarctica.

Both of these episodes of rapid climate change in the Paleogene represent transient climatic states, sustained briefly by positive feedbacks associated with the abrupt reorganization of ocean and/or atmospheric circulation. Another possible example of abrupt ocean and climate change in the pre-Neogene record are the black shale events ("Oceanic Anoxic Events") of the mid Cretaceous. Excellent recovery of continuous Paleogene and Upper Cretaceous sequences in the Caribbean, at sites with minimal Neogene overburden, is vital to address these types of questions.

Late Cretaceous and Paleogene Chronostratigraphy

The Cretaceous and Paleogene tropical deep-sea record still lacks the spatial and temporal coverage, core recovery, and paleomagnetic control to correlate low latitude sequences at sub-million-year time scales to the Tethyan Gubbio sequence and high-latitude sequences (e.g., ODP Sites 689 and 690). Successful recovery of Upper Cretaceous sequences from this region will provide valuable paleomagnetic and biostratigraphic records for refinement of tropical chronostratigraphy.

Development of relatively high-resolution low-latitude chronostratigraphies may be aided by the presence of Milankovitch-scale sedimentary variations in Upper Cretaceous and Paleogene Caribbean sequences. Similar Milankovitch-scale variation has been successfully used for high resolution K/T stratigraphy.

Neogene and Quaternary Ocean and Climate History

Recovery of cores in the Caribbean basins north and south of the Nicaragua Rise and in present-day channels of the NNR will test Neogene models for surface and deep circulation related to the opening and closure of gateways and shed some light on mixing of the world ocean and regulation of high-latitude climate.

Drilling in the Caribbean Sea between roughly 900 and 3300 m water depth will provide new data in the global array of equatorial monitors of surface and deep-water circulation. Such drilling will address questions of both regional and global paleoceanographic, paleoclimatic, and paleobiological significance, including, the history of the Caribbean Currentis its strength of flow related to tectonic events within the region, how has Neogene variation in the Caribbean Current influenced the evolution of North Atlantic circulation, and climate, what has been the evolutionary and ecological response of planktonic biota to the partial demise of the carbonate megabank along the Nicaragua Rise and closure of the Central American Seaway?

Initiation and Evolution of the Caribbean Current

The Caribbean oceanic surface circulation has been significantly modified by two major Neogene tectonic events: 1) foundering of the NNR and the opening of a major intra-Caribbean gateway; and 2) closure of the Central American Seaway and the cutoff of the Atlantic-Pacific gateway. The first event, possibly related to a reorganization of the spreading within the Cayman Trough, was responsible for the opening of a new gateway for the North Atlantic Western Boundary Current in the middle Miocene through the partial demise of a carbonate megabank that covered the full length of the NNR (Fig. 3). The seaway's opening during the middle Miocene along the NNR is hypothesized to have had a direct impact on the initiation of the "modern" western boundary current with some potential link to the onset of the NADW formation in the late middle Miocene.

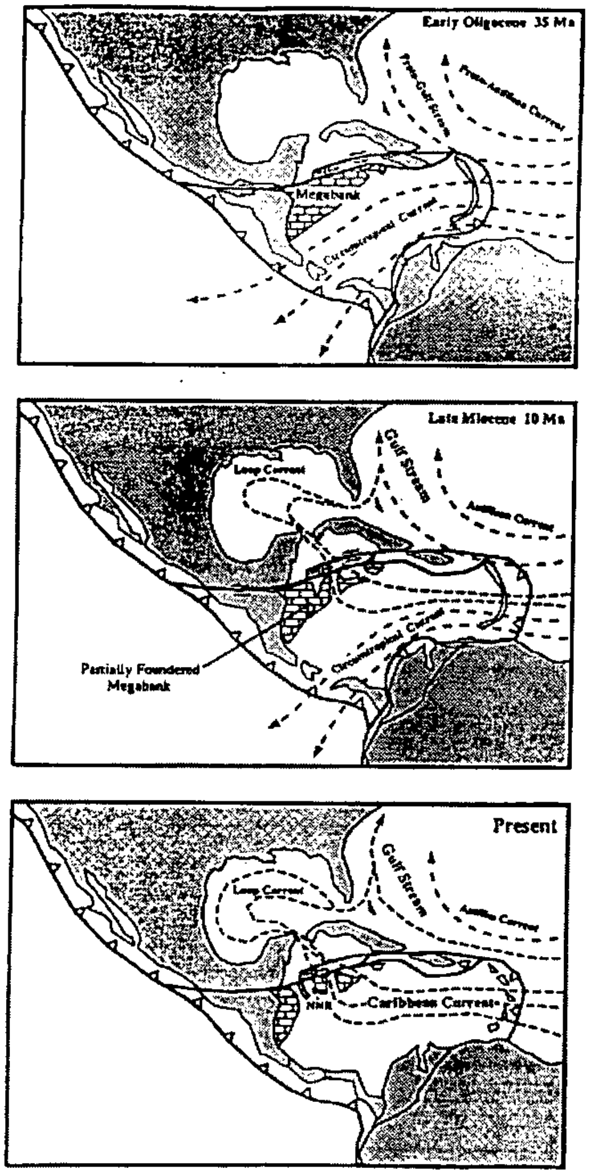


Figure 3. Simplified paleoreconstructions of the Caribbean, showing the timing of proposed megabank foundering and the resultant current regimes from Oligocene to the present.

The development of a strong North Atlantic Western Boundary Current in the Caribbean sometime in the middle Miocene is clearly documented in the Gulf of Mexico and in the Straits of Florida. Intensification of the Loop Current/Gulf Stream circulation during the middle Miocene is supported by numerous observations downcurrent of the Nicaragua Rise and Yucatan Strait. Drilling downstream of the Nicaragua Rise and on the NNR itself will provide new data on the foundering of the rise, timing of the initiation of the Caribbean Current (and intensification of the Loop Current/Gulf Stream), changes in the strength of the Caribbean Current during the late Neogene, and relationship to changes in conveyor circulation and North Atlantic climate.

Closure of the Central American Seaway

Closure of the Central American Seaway was accompanied by changes in coiling directions in planktonic foraminifers, temporary disappearance of certain foraminifers from the Atlantic Ocean, and initial appearance of several new species, which are largely restricted to the Atlantic Basin. Neogene sequences to be collected on Leg 165 will help to further document changes in planktonic assemblages that accompanied the formation of distinct Caribbean water masses and to test relationships between oceanographic history and the disappearance and repopulation of plankton in the Atlantic during glacial and interglacial stages.

History of Deep and Intermediate Waters in the Caribbean

The presence of relatively shallow sills separating the major basins in the Caribbean makes each basin a sensitive monitor for the history of intermediate waters in the open Atlantic Ocean. Because different parts of the Caribbean Sea are silled at depths that presently range from 1400 to 1800 m, sediments are thought to record variations in the flux and mixture of both Antarctic Intermediate Water (AAIW) and Upper North Atlantic Deep Water (UNADW). The relative proportions of these source waters in the low latitudes of the western North Atlantic can be monitored by studying carbonate preservation and other geochemical proxies of deep water character (e.g., d^{13}C, Cd/Ca) in the Caribbean basins.

Analyses of late Neogene Caribbean records across the 900-3300 m water depth range represented by the primary drill sites should document paleoceanographic linkages between Caribbean surface water flow and rates of NADW formation, and intermediate water mass history. In turn, this will shed important light on our understanding of how Caribbean tectonics has influenced the global "conveyer belt" of surface and deep ocean flow, and hence the evolution of Neogene climate.

Late Quaternary Tropical Climate Variability

Information on rates and magnitudes of tropical climate change is greatly lacking on interannual to millennial time scales. Annually laminated, high deposition rate sediments of the anoxic Cariaco Basin will provide an important late Quaternary record of tropical ocean and climate variability on these sub-Milankovitch time scales. The Cariaco Basin is well situated to record in its sediments a detailed history of trade wind-induced coastal upwelling and fluvial discharge from northern South America, phenomena both related to past changes in the strength and position of the Intertropical Convergence Zone (ITCZ). The basin's location also makes it highly suitable for recording surface ocean changes that result from changes in the Atlantic's thermocline conveyor circulation. By their varved nature, the sediments of the Cariaco Basin offer the prospect of examining how short-term climate sensitivity responds to past changes in large-scale global boundary conditions. The record to be obtained will also provide a well-constrained basis for theoretical and temporal linkage of tropical paleoclimate events and processes of other regions (e.g., Laurentide meltwater events and the Younger Dryas cold event in the North Atlantic Basin).

Relationships between Environmental Change and Sedimentary and Geochemical Properties in Modern and Cretaceous Anoxic Basins

Drilling of annually laminated Cariaco Basin sediments will also allow documentation of relationships between environmental change and sedimentary and geochemical properties in modern large anoxic basins. This basin may provide an analogue for the older anoxic basins of the Caribbean Plate. Late Cretaceous black shales are known from the Venezuela Basin (DSDP Site 146) and from marine sequences of northern South America (Colombia and Venezuela). Deposition of these black shales is likely to have been largely controlled by Caribbean tectonics. During the Cretaceous and Paleogene, this region was marked by a large "Cretaceous basalt province" and island arc complexes that were at least locally subaerially exposed. As likely barriers to regional deep-water flow and possible causes of extensive Cretaceous upwelling in this region, they undoubtedly affected regional paleoceanographic conditions. The causes of black shale deposition in the Caribbean during Late Cretaceous time remain enigmatic due to the complex regional tectonic history, post-depositional diagenesis of land-based outcrops, and our incomplete understanding of relationships between oceanographic conditions and the sedimentary geochemistry of Holocene analogs, like the Cariaco Basin. Additional offshore records in the Caribbean can be used to test possible relationships between regional Cretaceous paleogeography, black shale deposition, and paleoceanographic conditions (including water mass characteristics and productivity).

Caribbean Tectonics and the Nature of Crust in the Region

The Caribbean Crust as a Large Igneous Province (LIP)

Large oceanic plateaus have long remained curious enigmas within the general understanding of ocean crust formation. Recent ODP drilling in the Indian and Pacific oceans has documented the volcanic origin of the Kerguelen (Legs 119 and 120) and Ontong Java (Leg 130) plateaus. These huge provinces (10 million km^3) appear to be formed over brief periods of intense volcanism and are likely to be the oceanic equivalents of continental flood basalt provinces. Development of these provinces may be caused by the massive, initial eruptive phase of plumes rising from the deep mantle. A better understanding of large igneous provinces (LIPs) carries implications for crustal accretion, global elemental fluxes, and mantle composition and circulation.

A conspicuous feature of the Caribbean crust is the existence of laterally extensive acoustic reflectors which show up on seismic profiles in the Colombia and Venezuela basins. Two prominent horizons, A" and B", have been mapped out by numerous workers and sampled during early DSDP drilling. On DSDP Leg 15, horizon B" was sampled, and found to consist of basalt and diabase whose mineralogy and geochemical characteristics are distinct from those of MORB. This discovery led to the recognition of a Coniacian to early Campanian flood basalt event within the Caribbean, of great extent (600,000 km^2) and exceptional thickness (up to 20 km), and showed that the top of the plateau is the widespread smooth B" seismic reflector.

Plate reconstructions indicate that original Caribbean crust was formed along one of the spreading centers in the Pacific (Fig. 4) and it is speculated that the volcanism that built the Caribbean oceanic plateau is associated with the onset of the Galapagos hot spot. Additional evidence for the LIP character of the Caribbean can be found in the geochemistry of the basaltic rocks from the interior and margins of the province, similar to other oceanic plateau basalts such as the Ontong Java Plateau and the Nauru Basin. The isotopic signature of basalts from the Dumisseau Formation in Haiti and from Gorgona are similar to the plume-related basalts of the Galapagos, providing additional support for the origin of the Caribbean LIP in the Galapagos area with subsequent eastward migration and insertion in its present position between North and South America. The high-MgO rocks from the circum-Caribbean are particularly interesting in that they indicate eruption temperatures of up to 1500°C and could be associated with as much as 50% partial melting of the mantle. Such large degrees of melting, once thought to be restricted to Precambrian times, may be indicative of the early stages of flood basalt events.

There is now considerable evidence in support of the hypothesis that large areas of the Caribbean, as delineated by the presence of layer B", represent a LIP, and drilling during Leg 165 at proposed sites S-6 and S-3B will help to elucidate the nature of this important province. It is hoped that this drilling will indicate the age and basalt compositional patterns of the province and help provide a link to tectonized crustal sections of the plateau exposed subaerially along its margins. At this time, nothing is known about the plateau basalts in the large western region (Colombia Basin), where proposed site S-6 is located.

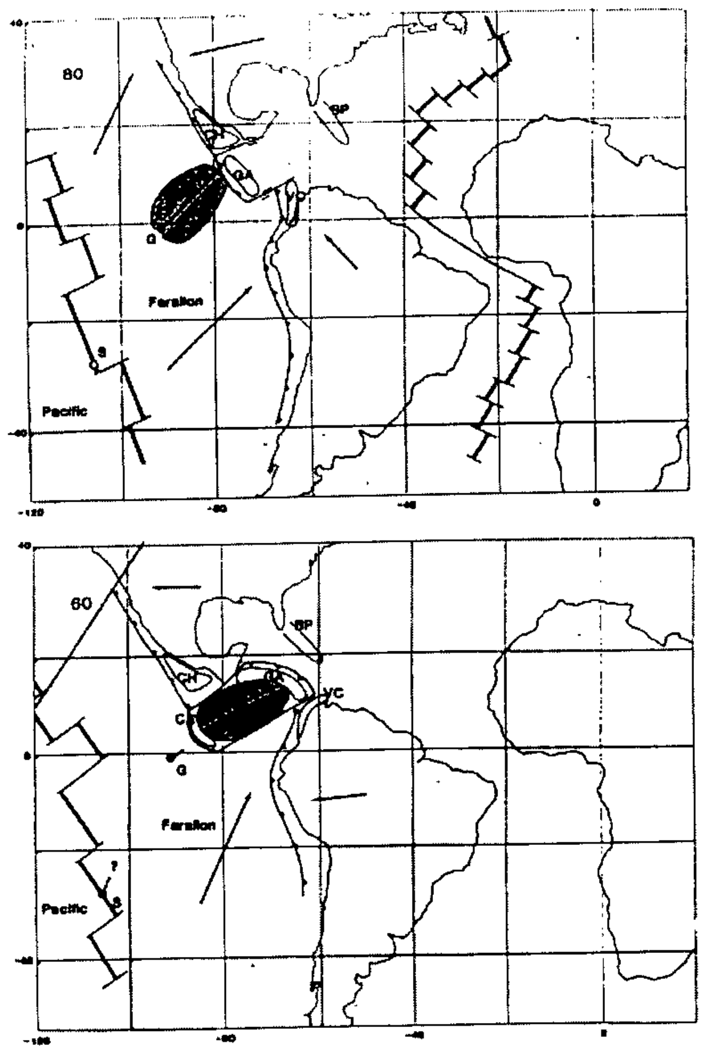


Figure 4. Plate tectonic evolution of the Caribbean region, assuming a Galapagos hot-spot source for the Caribbean large igneous province. Upper figure shows the configuration of the region at 80 Ma, with the oceanic plateau formed at the Galapagos hot spot (solid circle) shown in stippled pattern. Arrows indicate plate motion vectors. The lower figure shows the configuration at 60 Ma, where CA is the Central America arc, G is the Galapagos hot spot, and S is the Sala y Gomez hot spot.

Nature of the Cayman Ridge

The Cayman Ridge forms a major structural feature that separates the Cayman Trough from the Yucatan Basin. While the Yucatan Basin is quite likely to be floored by oceanic crust, judging from magnetic anomalies and other geophysical data, the origin and age of the crustal basement forming the Cayman or Camaguey Ridge are important and unsolved problems. The Cayman Ridge has become an isolated structural high due to the opening of the Yucatan Basin and movement along the Cayman Trough transform fault. The complement of the Cayman Ridge is therefore in the Greater Antilles to the east. The relatively shallow depth (3 km) and thick crust of the Cayman Ridge are consistent with the idea that it may represent a Late Cretaceous island arc complex, as supported by radiometric ages of granodiorites and amphibolites dredged from the north wall of the Cayman Trench. Proposed site S-2B on Leg 165 is the first attempt at deep-sea drilling in the region of the Cayman Ridge and Yucatan Basin. Results from this site not only will address the age and nature of the ridge basement but will also have a bearing on the age and opening of the Yucatan Basin to the west.

DRILLING STRATEGY

Leg 165 will follow a drilling strategy that will provide a transect of APC, XCB, and rotary cores of Cretaceous to Cenozoic sedimentary deposits across the northern and western Caribbean, and the Cariaco Basin of offshore Venezuela. All sites will be single APC cored to refusal (approximately 150-200 mbsf). The Cariaco Basin proposed site CB-1A will be triple APC/XCB cored to 180 mbsf.

For the Cretaceous/Tertiary objectives, the distribution of sites will provide information on variation of the thickness, grain size, and lithology of the impact ejecta deposit from proximal (~400 km paleodistance from Chicxulub) to distal areas, with distal sites fanning out from southwest to southeast of the crater. During rotary drilling of the relatively thin K/T boundary deposit, we propose to enhance core recovery by drilling only half a core barrel before core recovery in this drilling interval, in order to prevent core loss.

Rotary coring into the igneous basement at several of the primary sites will provide important information about the composition, age, and character of the basaltic rocks that underlie the sediments of the Caribbean and contribute to its anomalous crustal thickness. These samples are critical for an evaluation of the Caribbean basement as a large igneous province (LIP) that was transported from the Pacific.

The primary site on the northern Nicaragua Rise will be drilled to the level of an inferred drowned megabank to reconstruct the history of subsidence. The overlying sediments will provide a record of the development of the Caribbean current and its intensification as the Isthmus of Panama formed and the Central American Seaway closed.

In the shallow drilling (~180 m) proposed in the Cariaco Basin, a continuous, high-resolution record of sedimentation during the late Quaternary is sought. The most complete core recovery will be obtained here by triple, overlapping APC coring.

Logging Plan

Downhole measurements will comprise an important component of the proposed science because core recovery in the deepest sediments, those representing the late Mesozoic-early Cenozoic transition, is likely to be low. Standard logs are to be run in high-resolution mode (1-in. sampling) and some intervals could be logged several times. Log measurements will not be required at the Site in the Cariaco Basin because of shallow penetration depth.

The K/T boundary is expressed as a well-defined lithologic change over 1 to 2 m (normally graded ejecta overlain by clay layer), which can be resolved by both standard and higher-resolution log measurements. A special strategy will be applied in the logging of the K/T boundary section, to get a very high resolution of a relatively thin deposit (1 to 2 m) of distinct lithology, compared to other sediments. Because the K/T boundary deposit will be geochemically distinct from the surrounding sediments, we propose to use the geochemical log to define the boundary better, in case of poor core recovery. We also anticipate that the boundary deposit has a characteristic high magnetic susceptibility, and thus will show up as a distinct peak on the GHMT log. If the K/T boundary ejecta deposit has physical properties that are sufficiently different from the background sediments, the FMS will give a resistivity image of the formation. It will also allow us to look at the orientation of the formation contacts and any fabric that might exist in the formation.

This leg may provide an excellent opportunity to use core and log data integration as a means to reconstruct continuous, detailed records of regional lithologic variability and paleomagnetic stratigraphy since the late Mesozoic.

SAMPLING OF CRITICAL INTERVALS

In view of its scientific importance, the K/T boundary must be regarded as a critical interval in the sediments cored during this leg, and sampled accordingly. This critical interval is the boundary deposit itself, which may be up to 1 or 2 m thick, and the sediments 3 m above and below the boundary deposit. In addition to its biostratigraphic identification, the boundary can be defined by geochemical means. Identification of the boundary will be done on board the vessel by analysis of a suite of trace elements that are diagnostic of the boundary impact ejecta (altered impact glass and aerosol fallout). Samples for onboard XRF analysis of trace elements will be routinely taken at close spacing from the sediment throughout this critical interval, as well as in the K/T boundary deposit itself.

SITE SUMMARIES

PROPOSED PRIMARY SITES

Site: S-2B (Cayman Ridge)
Priority: 1 Position: 19°29.1'N, 82°55.6'W
Water Depth: 3177 m
Sediment Thickness: 845 m (approved to a depth of 855 mbsf)
Seismic Coverage: SCS lines E9417-13 and E9417-16; SP 320 on SCS Line E9417-13

Objectives:
(1) Determining processes of impact deposition at a K/T boundary sequence relatively proximal to the Yucatan Peninsula.
(2) Late Cretaceous(?) and Paleogene tropical ocean and climate history.
(3) Isotopic and microfaunal/floral documentation of regional paleoceanographic conditions before and after middle Miocene(?) subsidence of the northern Nicaragua Rise (i.e., the Neogene initiation and evolution of the Caribbean Current downstream of the Nicaragua Rise).
(4) Assessing the history of Atlantic intermediate waters in the Yucatan Basin.
(5) Age and nature of the Cayman Ridge basement.

Drilling Program: Hole A: APC to refusal, XCB to total depth (basement). Hole B (if necessary): wash-down, RCB to basement; 10 m penetration of basement.

Logging and Downhole Operations: Four runs with the quad-combo tool string, geochemical tool string, GHMT magnetic logging tool, and multiple passes of FMS through K/T boundary interval. Core orientation on Hole A.

Site: S-6 (unnamed rise, Colombia Basin)
Priority: 1 Position: 12°43.2'N, 78°46.2'W
Water Depth: 2811 m
Sediment Thickness: 1313 m (approved to a depth of 1335 mbsf)
Seismic Coverage: UTIG MCS line CT1-12A; SCS RC-1201; SP 4780 on UTIG MCS Line CT1-12A

Objectives:
(1) Recovery of a K/T sequence distal from the Chicxulub crater and on a different tangent to the crater than other K/T sequences (for testing the direction of the K/T impact and types of emplacement processes associated with the impact).
(2) Late Cretaceous and Paleogene tropical ocean and climate history.
(3) Recovery of an extended sequence for high-resolution chronostratigraphy of the low latitude Late Cretaceous.
(4) Recovery of Paleogene and Neogene sediments that, at shallower sub-bottom depths, will be appropriate for stable isotopic reconstruction of low latitude paleoceanographic conditions and events, including the Miocene and Pliocene transition from seawater flow westward through the Central American Seaway to the present post-closure situation of northward flow through the Yucatan channel.
(5) To determine impact of the carbonate megabank partial drowning and Caribbean Current initiation, possibly during middle to late Miocene, on the sedimentation in upcurrent adjacent basins still open to the low latitude eastern Pacific Ocean.
(6) To determine the impact of closure of the Central American Seaway on the pelagic sedimentation especially due to the isolation of the Colombia basin from the low latitude eastern Pacific Ocean and the general strengthening of the Caribbean current.
(7) Relatively high-resolution analysis of tropical climate variability and Late Quaternary NAIW history.
(8) Documentation of Atlantic intermediate water history in the Colombia Basin.

Drilling Program: Hole A: APC to refusal, XCB to refusal. Hole B: drill ahead to approximately 600 m, set reentry cone and case hole, RCB to basement; 10 m basement penetration.

Logging and Downhole Operations: Four runs with the quad-combo tool string, geochemical tool string, GHMT magnetic logging tool, and multiple passes of FMS through K/T boundary interval. Core orientation on Hole A.

Site: NR-1/2 (Pedro Channel, northern Nicaragua Rise)
Priority: 1 Position: 16°33.2'N, 79°52.0'W
Water Depth: 910 m
Sediment Thickness: 600 m (approved to a depth of 650 mbsf)
Seismic Coverage: SCS lines CH9204-30 and CH9204-05; SP 1495 on SCS line CH9204-30

Objectives:
1) Estimate the timing (possibly middle Miocene?) for the formation of Pedro Channel by drilling in the transition from periplatform sediments to the underlying shallow water limestones (i.e., the upper part of the drowned megabank). Seaways formed by the partial drowning of the carbonate megabank covering the northern Nicaragua Rise during the Oligocene and early Miocene (Pedro Channel and Walton Basin; NR-1/2 and alternate site NR-4), are part of a major gateway opening along the Nicaragua Rise for the Caribbean Current. The formation of these seaways has therefore played a significant role in the establishment of the modern Western Boundary Current in the North Atlantic Ocean.

2) Unravel the history of the Caribbean Current across the northern Nicaragua Rise by drilling the sedimentary periplatform sequence overlying the drowned parts of the megabank. In addition to the widening and deepening of the newly formed northern Nicaragua Rise seaways, variations of the Caribbean Current strength since the late Miocene would also be related to the gradual shoaling and ultimate closure of the Central American Seaway in the mid Pliocene. The drilling strategy is to penetrate the most continuous periplatform section, first to develop late Neogene litho- and chronostratigraphies, and then to analyze the direct influence of the Caribbean Current on the sediment deposition. By drilling this sedimentary sequence, features in the high- resolution seismic lines away from NR-1/2 (e.g., as major erosion, tectonic displacement) could be placed within a chrono- and lithostratigraphic framework.

Drilling Program: Hole A: APC to refusal, XCB to total depth (carbonate platform). Hole B (if required): wash-down, RCB to total depth. Time permitting, a second APC-only hole will be drilled.

Logging and Downhole Operations: Four runs with the quad combo-tool string, geochemical tool string, GHMT magnetic logging tool, and FMS. Core orientation on Hole A.

Site: S-3B (lower Nicaragua Rise, near DSDP Site 152)
Priority: 1 Position: 15°45.4'N, 74°54.6'W
Water Depth: 3322 m
Sediment Thickness: 460 m (approved to a depth of 470 mbsf)
Seismic Coverage: SCS lines E9417-10 and E9417-5A; SP 1500 on SCS Line E9417-10

Objectives:
(1) Recovery of a relatively undisturbed high-resolution, deep-water K/T sequence.
(2) Cretaceous and Paleogene sediments suitable for isotopic reconstruction of low latitude surface water temperatures (e.g., for determining latitudinal gradients in Late Cretaceous and assessing the relative importance of greenhouse gas concentrations (i.e., atmospheric CO_2) and latitudinal heat transport to Late Cretaceous climate).
(3) Development of high-resolution low latitude Late Cretaceous and Paleogene chronostratigraphy.
(4) Assessment of low latitude paleoceanographic changes that have taken place from Late Cretaceous to Holocene times.

Drilling Program: Hole A: APC to refusal, XCB/MDCB to basement; 10 m basement penetration.

Logging and Downhole Operations: Four runs with the quad-combo tool string, geochemical tool string, GHMT magnetic logging tool, and multiple passes of FMS in K/T boundary interval.

Site: CB-1A (Cariaco Basin, DSDP Site 147)
Priority: 1 Position: 10°42.5'N, 65°10.5'W
Water Depth: 892 m
Sediment Thickness: 1500 m (approved to a depth of 180 mbsf)
Seismic Coverage: SCS survey from PLUME Leg 07, lines K1-J1 and W1-X1

Objectives: Extremely high-resolution records for studying
(1) Rates and magnitudes of tropical Atlantic climate change at interannual to millennial time scales over the late Quaternary (including late Quaternary variability in tradewind intensity and position of the intertropical convergence zone).
(2) Relationships between Cariaco Basin ventilation and paleoclimatic and paleoceanographic change in the late Quaternary.
(3) Relationships between environmental change and sedimentary and geochemical properties in modern large anoxic basins.
(4) A downstream link to paleoceanographic objectives of Amazon Fan drilling (Leg 155). Re-drilling of DSDP Site 147 (Leg 15).

Drilling Program: Triple APC/XCB to 180 mbsf.

Logging and Downhole Operations: Core orientation on Hole A and Hole B.

Logging Operator Report Leg 159

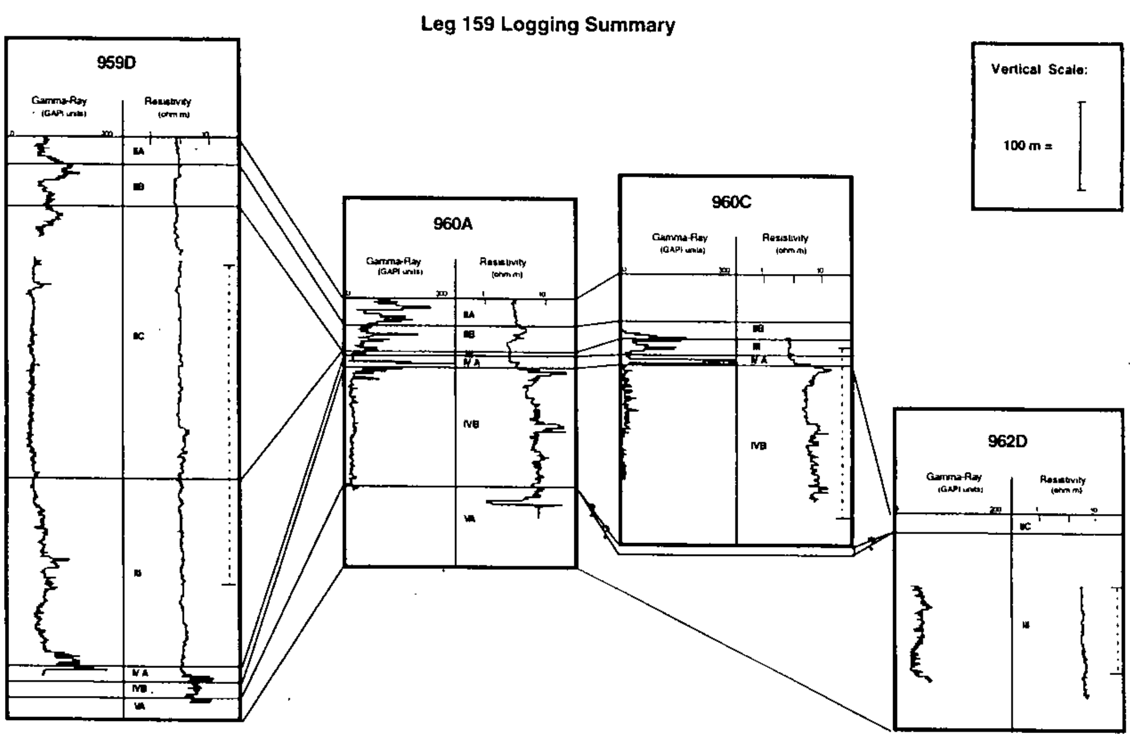
THE CÔTE D'IVOIRE - GHANA TRANSFORM MARGIN EASTERN EQUATORIAL ATLANTIC

Leg 159 addressed the evolution of the Cote d'Ivoire/ Ghana transform margin, one of the best-known examples of a former transform boundary between continental and oceanic crust. Transform faults are not as thoroughly understood as divergent and convergent margins; transform continental margins such as those in the Eastern Equatorial Atlantic have not previously been investigated by drilling. The specific objectives of this project were to investigate the deformation and sedimentation associated with the Cote d'Ivoire/ Ghana transform margin and its development, to quantify its nature, structure and deformational history, and to place constraints on the opening of the oceanic gateway between the central and south Atlantic during the Cretaceous era.

Logging data (summarized in Figure 1) were collected in four holes at three sites (Holes 959D, 960A, 960C and 962D), all located on continental crust on a ridge adjacent to the continent/ocean transition. The logs obtained correlate well with core measurements where core recovery was good. At Site 960, where two holes were logged, the logs provide measurements over sections of the holes where core recovery was particularly poor and core measurements rare.

Bridging and poor hole conditions prevented logging in the upper segment of Hole 959D but downhole measurements were successfully obtained over the

Figure 1.



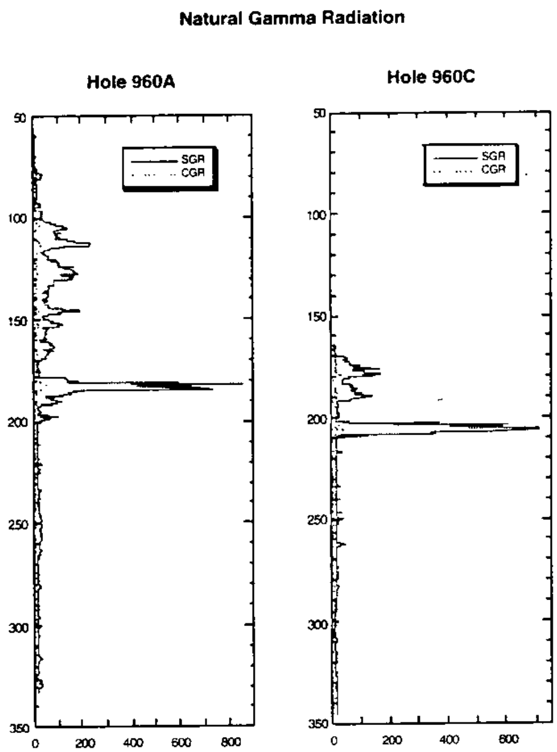


Figure 2.

lower part of the hole (395-1077 mbsf). The Schlumberger Quad,-Formation MicroScanner (FMS), and Geochemical (GLT) toolstrings were run and the logs were of generally excellent quality apart from limited deterioration due to borehole wash-out near the top (405-424 mbsf) and bottom (1025-1045 mbsf) of the logged interval. The sonic and density logs were used to create a synthetic seismogram, which allowed increased precision of time/depth conversions of the seismic data. The boundaries separating the lithological units defined from core measurements are confirmed by changes in the logs at depths coinciding with these boundaries. An increase in micritization and a decrease in porcellanite, coinciding with a short term drop in clay content, is well-defined by a sharp rise in velocity and resistivity and an accompanying drop in porosity at approximately 750 mbsf (within Subunit IIC). The transition from the black claystone of Unit III to the sandstones at the top of Unit IV is also well delineated by most of the logs. Preliminary interpretation of the FMS data shows bedding planes dipping consistently towards NNW with dips increasing downhole from 5 to 14 degrees. Postcruise processing should improve the data and provide core orientation information which will allow the structural geologists and paleomagnetists to orient their measurements. The geochemical log data obtained at this site show good characterization of variable clay and carbonate compositional changes.

Following the end of logging operations, a short transit was made to Site 960, on the crest of the Marginal Ridge, three miles south of Site 959. Logging in Holes 960A and 960C was severely hampered by a combination of bridges and extreme borehole washout but provided valuable information over intervals where core measurements in both holes are infrequent due to poor core recovery. Bridging prevented the Quad toolstring from reaching the bottom of Hole 960A; the main log covered the interval 361.3-73.3 mbsf. Only one third of the logged interval was of a diameter less than 16 inches and these conditions seriously affected the quality of the sonic, density, and porosity data collected. Resistivity and gamma ray data may also have been affected, but to a lesser degree. The gamma ray log (Figure 2) shows an anomalously high reading, indicating high levels of uranium at approximately 185 mbsf, caused by phosphate nodules at that depth. Neither the FMS nor GLT toolstrings were run at Hole 960A. At Hole 960C, a reduced Quad string measuring only natural gamma ray, resistivity, and sonic came within 5 m of total depth (logging 121.2-92.4 mbsf and 374.6-159.7 mbsf). Unfortunately, the borehole again was shown by the caliper curve to be washed out for well over half of the logged interval, resulting in poor quality sonic data. The gamma ray anomaly seen in Hole 960A was again well-defined in this hole at approximately 205 mbsf. Because of the importance of collecting structural data from the hole, the FMS was run in Hole 960C over the interval 354.5-173.7 mbsf despite the poor borehole conditions. Preliminary results indicate that the bedding is dipping NE with no evidence for increasing dip with depth. Although data quality was understandably poor, it may improve when processed onshore.

Bridging in Hole 962D prevented the reduced Quad toolstring from reaching the bottom 65 meters of the hole. The log covered 328-162 mbsf and a repeat log covered 306.5-173 mbsf. Approximately 50% of the logged interval was of a diameter greater than 14 inches, which seriously degraded the quality of the sonic data collected. The logged interval falls entirely within the deepest unit, which is of particular importance in ascertaining the deformational history of the margin. The FMS toolstring was unable to get past a bridge at 293 mbsf but approximately 100 meters (293-192 mbsf) was logged with two passes. The data was all collected within the oldest strata drilled and will provide essential structural information in the sandstones, siltstones, claystones and limestones which make up this unit, thought to be synchronous with the transform faulting episode.

International News, Meetings and Announcements

INTERNATIONAL NEWS

AUSTRALIA

Rowena Duckworth, Science Co-ordinator of the Ocean Drilling Program, Australian Secretariat, writes from DOWN UNDER to say that there will be a special day-long ODP session at the annual ***Australian Geoscience Convention (AGC)in Canberra (Feb. 18-25)1996***, at which all the Australian panel members, shipboard scientists and proposal proponents will make presentations. Rowena, who received her Ph.D. from the University of Wales, Cardiff, admits that the concept is imported from Cardiff and modelled on the very successful annual ***UK ODP Forum***.

Tremendous excitement is building in the South Pacific in anticipation of the JOIDES Resolution arrival in the area in 1998. Consequently, at the recent annual SOPAC meeting, an ODP working group was formed to coordinate planning efforts.

The Australian Secretariat now produces a bimonthly national ODP newsletter, copies of which are available on request from Rowena (ausodp@jcu.edu.au).

ESF

21st ESCO Meeting
Reykjavik, Iceland (2-5 September, 1995)

Contributed by ESF PCOM member Judy McKenzie

The JOIDES Resolution was in Reykjavik, Iceland from September 3-6, 1995 prior to departing for Leg 163 (South East Greenland VRM). The European Science Foundation Consortium for the Ocean Drilling (ESCO) used this occasion to hold its 21st meeting in Reykjavik on September 3rd. The meeting was kindly hosted by the Icelandic ESCO Delegate Arny Sveinbjorndottir (Science Institute, University of Iceland). The 21st ESCO Meeting was the first to be organised by the ESCO Secretariat from its new headquarters in Zurich, Switzerland. Since July 1995, the ESCO Secretariat has been under the direction of Judith McKenzie, ESCO Chair and ESF Member of PCOM, and Silvia Spezzaferri, ESCO Science Co-ordinator. During the meeting, the delegates discussed the strategies to be adopted for the renewal of the drilling program in each of the ECOD countries. Jeff Fox, the new Director of Science Operation at ODP/TAMU, attended the afternoon session and reported on the reorganisation of ODP for the future.

Other ODP related activities were attached to the ESCO meeting. On the evening prior to the meeting, a typical Icelandic dinner was offered to the ESCO Delegates by the European Science Foundation. Sigmundur Gudbjarnarson, Chair of the Icelandic Research Council, welcomed the delegates to Iceland. Prior to meeting on September 3rd, the ESCO Delegates made an early morning, unscheduled visit to the JOIDES Resolution, 2 hours after the ship had docked at the end on the successful, high recovery Leg 162 (North Arctic Atlantic Gateways II). The ESCO delegates could experience first-hand the feeling of jubilation felt by all the Leg 162 participants at the end of a highly successful cruise.

On September 4th, the two ESF Co-chiefs of the high latitude Legs 162 and 163, Eystein Jansen and Hans Christian Larsen, were invited to speak at a meeting organised by Omar Gudmundur Fridleiffson at the Nordic House in Reykjavik. Jansen presented the main preliminary results of Leg 162, which focused on an investigation of Northern Hemishpere glaciation records in the North Atlantic. He stressed the importance of the Ocean Drilling Program and the drilling ship JOIDES Resolution to accomplish this type of research. Larsen presented the results of Leg 152 and focused on the investigation of the volcanic rifted margins and glaciations on the East Greenland Margin, which were the objectives of the up-coming Leg 163.

The ESCO Delegates, as well as many of the shipboard scientists from Legs 162 and 163, took advantage of the opportunity of being in Iceland to make short excursions into the surrounding countryside. They enjoyed the beautiful scenery and the extraordinary geology of this country, which is uniquely situated in the high northern latitudes on top of the North Atlantic mid-ocean spreading ridge.

UNITED KINGDOM

A two-day meeting entitled***The Geological Evolution of Ocean Basins: Results for the Ocean Drilling Program*** was hosted by the Geological Society at Burlington House in London October 18-19, 1995. Highlights of the UK's involvement and contributions to the Ocean Drilling Program were presented in more than 28 talks and poster displays. The meeting was a timely opportunity for the UK ODP community to tout their successes as a NERC review of the UK's participation in ODP is currently underway. Keynote speakers included John Mutter (LDEO) and Nick Shackleton (Cambridge University). Among the highlights of the meeting were the talks given by Phil Weaver (Southampton Oceanographic Centre), Sherm Bloomer (Oregon State University), Alan Kemp (Southampton Oceanographic Centre) and John Parkes (Bristol University).

Phil Weaver presented results from ODP leg 157 in the ***Development of the Madeira Abyssal Plain and the Evolution of the Canary Basin***. The results of Leg 157 have shown that increased erosion within the Canary Basin began at about 13.5 million years, as shown by turbidite deposition on the Madeira Abyssal Plain, and has continued to the present day with major flows involving tens to hundreds of km^3 occurring ever few tens of thousands of years.

In a talk entitled, ***Magmatism and tectonics at convergent margins: recent advance from ocean drilling***, Sherm Bloomer summarised ODP drilling at convergent margins. One of the most exciting elements of this talk was a discussion of the important advances made possible by the introduction of the Formation Micro Scanner (FMS) logging tool. In Sherm's words, "the FMS allows us to do FIELD GEOLOGY in ocean sediments!"

In his talk, ***Ultra-high resolution climate signals from laminated sediments***, Alan Kemp summarised results from Site 893 (Santa Barbara Basin), Leg 112 (Peru), Leg 138 (Eastern Equatorial Pacific) and Legs 160 and 161 (Mediterranean). Kemp emphasised that the delicate sediment fabrics preserved in piston coring, together with the unique depth of penetration of the ***JOIDES Resolution*** coring system have made such high resolution past ocean/climate variability on the time scales equivalent to modern observations and historical records possible.

John Parkes presented a summary of results from bacteriological investigation of sediments from nine ODP Legs in the Pacific and Atlantic Oceans in his talk, ***Bacteria, Carbon and Biomass.*** The work of Parkes and others has unequivocally established the presence of deep bacterial biosphere in marine sediments to at least a depth exceeding 600 meters which, in terms of carbon, has increased the global biosphere by approximately 10%. In light of the special attention accorded the deep biosphere in the new ODP Long Range Plan, Parkes' talk stimulated lively discussion.

A Proceedings volume will be published by the Geological Society. Requests should be addressed to Adrian Cramp or Chris MacLeod in the Department of Earth Sciences, University of Wales, Cardiff CF1 3YE, UK.

USA

Roger Larson (URI) replaced Audrey Meyer (SEA) as USSAC Chair from October 1, 1995. One of his first tasks is to preside over the newly established USSAC subcommittee on ***Post 2003 Drilling Platforms.*** The subcommittee, which consists of Roger Larson, Audrey Meyer, Jamie Austin, Earl Shanks, and Jim Natland, will investigate possible drilling platforms for post 2003 scientific ocean drilling.

The ODP CD ***From Mountains to Monsoons*** was displayed at the NSF Science Diversity Conference in Washington, DC on September 21-23, 1995 at the request of NSF. The CD was used as part of an effort to show educators the variety of geoscience-related materials that are currently available. The final version of the ODP ***From Mountains to Monsoons*** CD will be available for duplication and distribution in November.

Recently funded JOI/USSAC Site Augmentation and Workshop Proposals include:

- Carolyn Mutter (LDEO): West Woodlark Basin Site Augmentation Proposal.
- Sherwood Wise, Tom Davies, and Peter Clift (Florida State U., UTIG, and WHOI): Funds to Attend the Workshop "Objectives and Implementation of an Ocean Drilling Stratigraphic Network (ODSN)" to be held December 18-20, 1995 in Bremen.

ODP - InterRidge - IAVCEI Workshop

The Ocean Lithosphere & Scientific Drilling into the 21st Century

26-28 May, 1996
Woods Hole Oceanographic Institution
Woods Hole Massachusetts, USA

Convenors:

H.J.B. Dick (USA)
C. Mével (France)

Steering Committee

M. Cannat (France)
M.F. Coffin (United States)
J.R. Delaney (United States)
R.S. Detrick (United States)
R.A. Duncan (United States)
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J.A. Karson (United States)
J.L. Karsten (United States)
C.J. MacLeod (Great Britain)
J.H. Natland (United States)
P. Pezard (France)
R. Searle (Great Britain)
D. Stakes (United States)
K. Tamaki (Japan)

This symposium and workshop is jointly sponsored by the JOIDES Planning Committee of the Ocean Drilling Program, the InterRidge Steering Committee for an internationally coordinated study of ocean ridges, and the Commission on Large-Volume Basaltic Provinces of the International Association of Volcanology and Chemistry of the Earth's Interior. Its purpose is 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. A program which must include drilling in crust formed at fast and slow ridges, near and far from mantle hot spots, and at large oceanic igneous provinces (LIPs) formed outside the framework of the global ridge system.

In 1998 the Ocean Drilling Program begins Phase III of scientific drilling in the oceans, concluding the current program at the end of 2002. A new phase (IV) of ocean drilling, however, is being planned for beyond 2003. It will likely involve multiple platforms and riser drilling, bringing the ability to drill in-situ through the entire ocean crust.

The symposium will review the current state of knowledge of the ocean lithosphere, summarize the capabilities of present drilling technology and review new technologies planned for Phase IV. Some contributed talks, and a poster session on the composition and structure of the ocean lithosphere, are solicited from participants. The workshop will seek to establish community goals and priorities for ocean lithosphere drilling for 1998 to 2003, and begin the formal planning and proposal process for multi-leg deep drilling during Phase IV.

Deadline for applications 1 Feb. 1996. Late applicants will be accepted on a space available basis only.

For Information or to Apply Contact:

Ocean Lithosphere & Scientific Drilling Conference, InterRidge Office, Dept. of Geological Sci., Univ. of Durham, South Road, Durham, DH1 3LE, UK, email: intridge@durham.ac.uk.

For funding, participants must separately contact their national RIDGE or ODP program, or other national source. US participants should contact Dr. Henry Dick, C/O Ms. May Reed, McLean Laboratory, Woods Hole Oceanographic Institution, Woods Hole, MA 02543, email: mreed@whoi.edu.

InterRidge

LIPs

ODP INTERNATIONALIZATION

The ODP Program Director at JOI, Dave Falvey, continues his global travels in his quest for potential partners in the ODP. Recent trips have included visits to Brazil, Korea, Taiwan, and China to discuss ODP "associate member status." Falvey has also been invited to attend a special workshop at the Russian Academy of Sciences on November 26, 1995 to discuss the potential future involvement of Russia with the ODP.

If you have any News or meeting announcements that you would like included in the JOIDES Journal, please e-mail them to;

joides@cardiff.ac.uk

If you wish to use figures, can you please send them as binhexed .pict files.

ODP INTERNATIONAL REVIEW

The first meeting of the ODP Council International Review Committee, chaired by Gordon Greve, took place at LDEO on September 6-8, 1995. Presentations were made by selected scientists on the accomplishments of the past decade of the ODP and on the four new initiatives outlined in the new Long Range Plan. Modifications to the ODP Long Range Plan were discussed and drafting changes recommended by the Review Committee. In addition, Ellen Kappel of JOI undertook preparation of a summary of accomplishments for the period 1991-1995.

The ODP Council International Review Committee held its second meeting in Frankfurt, Germany on October 31 - November 1, 1995. Don Heinrichs of NSF provided an overview of feedback from NSF regarding the ODP. The program is generally regarded as a success, as evidenced by the fact that the overwhelming majority of cruises tend to accomplish the scientific goals. Heinrichs outlined some of the scientific accomplishments of the program: the scientific problems that can only be addressed through the ODP, non-scientific benefits, and the evolving LRP. Issues considered contentious by the ODP community in the area of publications, management and planning and technology development were also reviewed.

Rob Kidd (PCOM Chair) recounted the evolution of the Long Range Plan from the inception of the revision process involving PCOM, EXCOM and finally JOI. The development of the science themes, sub-themes, and new initiatives were explained and the linkages of these to the overall science objectives clarified. Ellen Kappel (JOI) and Rob Kidd were receptive to suggestions made by the Committee regarding further refinement of the LRP and met subsequently to jointly address the committee's comments and recommendations. JOI, with input from Kidd, will produce the pre-publication version of the LRP by the end of November.

Rob Kidd also discussed the science planning intended to accompany the revised LRP. The program is envisioned by PCOM to remain a primarily proposal driven program with the call for post 1998 proposals based on the 1995-96 LRP, Expertise on the JOIDES Thematic Panels will change as necessary to meet the scientific objectives of the LRP. As ODP strives to forge links with other global geoscience programs, mechanisms for interaction, possibly including joint ODP/global program workshops or detailed planning groups, will be developed accordingly. In some cases, more formal ties will be initiated with programs that desire a stronger association with ODP, such as the Nansen Arctic Drilling program (NAD).

The committee also received presentations from Jeff Fox and Dave Falvey on the implementation and funding of the science set forth in LRP, respectively. In addition, Rob Kidd and Dave Falvey reported on the technology development and other platforms required for the implementation of the LRP. Charles Sparks, former JOIDES TEDCOM Chair, delivered a special report on the details of a proposed slim line riser system.

The third and final meeting of the ODP Council International Review Committee will take place during the week of AGU at Stanford University. The Committee's report will be submitted to NSF by January 12, 1996.

MEETING ANNOUNCEMENTS

The ***XXV General Assembly of the European Seismological Commission (ESC)*** will be held on September 9 - 14, 1996 in Reykjavik, Iceland. Several sessions of special interest to the ODP research community are anticipated. In addition, field trips to the plate boundary areas (rift zones and transform zone of South Iceland) will be arranged. For further information write to Mr. Bardi Thorkelsson, LOC XXV General Assembly ESC, The Icelandic Meteorological Office, Bustadavegur 9, 150 Reykjavik, Iceland (Fax: +354 552 8121 and Email: esc96@vedur.is)

Over the last five years, a substantial research effort has focused on the mid-oceanic ridge in the central North Atlantic, including the France-US FARA Project and various investigations under the ***Ocean Drilling Program***, the British Bridge program, the European Marflux project, and by Russian, Japanese and Portuguese scientists. The results of this extensive work will be summarized and future research objectives formulated at an international ***Mid-Atlantic Ridge Symposium*** to be held in Iceland during the week of June 17 - 21, 1996. The meeting, sponsored by French and US science agencies to mark the end of the program, is being convened under the auspices of ***InterRidge***.

The meeting, which will be held in the University of Iceland, is supported as a Ewing symposium by Lamont-Doherty Earth Observatory with associated publication of papers in a Ewing Symposium volume. Other research reports will be published in a volume of abstracts. The symposium will include a field trip to the Reykjanes Peninsula and be preceded or followed by a field trip to the Eastern Volcanic Zone.

Those interested in being on the mailing list for future information, including a preliminary outline of scientific sessions and of field trips, are requested to send their names and full addresses at their earliest convenience to: The InterRidge Office (address over page). All e-mail responses should state FARA-IR Symposium as Subject.

GLOBAL GEOSCIENCE PROGRAM NEWS

INTER-RIDGE

During the last six months, significant progress has been made in both the ***Quantification of Fluxes*** and ***Southwest Indian Ridge (SWIR)*** Projects. In addition, the international ridge crest biologist community within InterRidge has been actively organising a number of important initiatives. Looking into the future, InterRidge is moving progressively towards a coordinating role for it's integrated Phase 2 projects. The provisional InterRidge calendar of upcoming events reflects the program's continuing interaction with a broad range of international organisations in working towards common aims and objectives.

In August 1995, an actual/virtual meeting of the ***SWIR Working Group*** was held at Woods Hole Oceanographic Institution and on the Internet to draft a Project Plan. The result is an integrated 3-5 year science plan involving six to eight legs of ship time aimed at multi-disciplinary investigation of the super-slow spreading Southwest Indian Ridge. The ***SWIR Project Plan*** is currently undergoing a last round of revision and will soon be available on the World Wide Web and for distribution in hard copy.

An InterRidge Workshop,***"Quantification of Fluxes at Mid-Ocean Ridges: Experiment Design"***, was held on 26-27 June 1995, in Cambridge UK. The principal objective of the workshop was to design a 'box' experiment to quantify mass, energy and chemical fluxes occurring at mid-ocean ridges at the segment length scale and extending from the mantle up into the water column. Site selection and integration with other InterRidge projects were discussed. The workshop report will soon be available from the InterRidge Office.

The ***Biological Studies Ad Hoc Committee*** of InterRidge met April 24 and 25 at Rutgers University, USA, to discuss integration of biological studies in the three principal InterRidge themes, draft an international agreement for sample exchange, and maximise the effectiveness of biological sampling during 'geological' cruises. In addition to accomplishing these objectives, a number of other initiatives were recommended and undertaken by the ridge crest biologists. These include a ***Ridge Crest Biologist Directory*** on the WWW, an on-line sample database, and compilation and publication of a Faunal Identification Manual.

For further information about InterRidge please contact: Heather Sloan, InterRidge Office, Department of Geological Sciences, University of Durham, South Road, Durham, DH1 3LE, UK
Tel: 44-191-374-2532. Fax: 44-191-374-2510, e-mail: intridge@durham.ac.uk

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INTERNATIONAL LITHOSPHERE PROGRAM

University of Texas PCOM member Tom Shipley attended an ***International Lithosphere Program*** meeting in Japan in September, 1995. The purpose of the meeting was to develop new initiatives, including ocean drilling, for convergent margins studies. This meeting was led by Kinoshita, Talwani, C. Moore and Kastner.

In Memorium - MEL PETERSON

We are sad to report that Dr. Mel Peterson, 66, former director of the international Deep Sea Drilling Project at Scripps, died of a heart attack on Sept. 20, while on a fishing trip in Mexico.

Mel joined Scripps Institution in 1960 following completion of his doctoral dissertation in the Dept. of Geology at Harvard University. Within a period of seven years he had achieved international prominence as a sedimentologist. Mel was appointed chief scientist of DSDP in 1967 and its director in 1971. His insights into what constituted the solvable and first-order problems of the oceans' role in earth history allowed him to guide DSDP into remarkable successes. He managed the entire project for Scripps, shaping the general scientific plans formulated by the scientific advisory panels of the JOIDES international consortium of oceanographic and earth science institutions into operational reality. He recruited and directed the large staff of scientists, engineers, and technicians that sailed for Scripps on the Glomar Challenger, and oversaw the publication of the 96-volume set of scientific reports on its 15 years of drilling in the world ocean.

Colleagues remember Mel as a hands-on experimental and observational scientist, always bursting with ideas for new experiments, and always ready to share his insights with anyone seeking his advice. Those of us fortunate to have sailed with him remember his love for the sea, and his personal qualities of generosity and good humor that made him such a fine shipmate.

Mel is survived by his wife Margaret; two sons, John and Bruce; and two daughters, Katrina and Valerie. A memorial service was held at Village Community Church in Rancho Santa Fe.

(Ed Goldberg, Jerry Winterer)

ODP Site Summary Form 6/93 Fill out one form for each proposed site and attach to proposal

Title of Proposal:	
Site-specific Objective(s) (List of general objectives must be inc. in proposal)	

	Proposed Site	Alternate Site
Site Name:		
Area:		
Lat./Long.:		
Water Depth:		
Sed. Thickness:		
Total penetration:		

	Sediments	Basement
Penetration:		
Lithology(ies):		

Coring (check): 1-2-3-APC VPC* XCB MDCB* PCS RCB DCS* Re-entry

Downhole measurements:

*Systems currently under development

Target(s) :(see Appendix of Proposal Submission Guidelines6/93) A B C D E F G (check)ß

Site Survey Information (see Appendix of Proposal Submission Guidelines6/93 for details and requirements):

		Check	Details of data available and data still to be collected
01	SCS deep penetration		
02	SCS High Resolution		
03	MCS and velocity		
04	Seismic grid		
05	Refraction		
06	3.5 or 12 kHz		
07	Swath bathymetry		
08	H.-res side-looking sonar		
09	Photography/video		
10	Heat flow		
11	Magnetics/gravity		
12	Coring		
13	Rock sampling		
14	Current meter		
15	Other		

Weather, Ice, Surface Currents:

Territorial Jurisdiction:

Other Remarks:

	Name/Address	Phone/FAX/Email
Contact Proponent:		

ODP Proposal News

The way to get your ideas into the JOIDES/ODP system is by submitting either a Letter of Intent or a full drilling proposal. 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 response, the preparation of a formal proposal may be recommended.

A full drilling proposal must include an outline of thematic objectives and how drilling strategies will be integrated with other investigations in the proposed area, information on site survey data, and strategies for drilling, sampling, and downhole measurements. The scientific objectives of drilling proposals should be linked to COSOD, ODP Long Range Plan (LRP), or thematic panel White Paper themes (these documents are available from the JOIDES Office).

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. Proposals received by the JOIDES Office are forwarded to the four thematic panels for review and appropriate service panels and the sub-contractors (ODP-TAMU, ODP-LDEO and the Site Surevy Data Bank).

Remember: Proposals must be updated every three years to remain on the active list.

JOIDES PROPOSAL REVIEW DEADLINES

While drilling proposals can be submitted at any time of year to the JOIDES Office, Thematic Panels review proposals twice a year, in Spring and Fall, following the JANUARY 1 and JULY 1 deadlines for submission. The JOIDES Office returns comments, recommendations, and data package requirements to proponents in April and October. Proposals submitted directly to thematic panels are not reviewed.

PROPOSAL PREPARATION AND FORMAT GUIDELINES

TARGET LENGTH: The main body of text of an ODP drilling proposal should be about 25 pages in length, and an ODP drilling proposal must contain an ABSTRACT (400 words or less).

All relevant FIGURES should be in the main body of the proposal or placed after the references. Proponents may submit additional foldouts, large maps, and full seismic sections with a master copy of a proposal to be retained on file in the JOIDES Office. Proponents should not expect these to be reduced by the JOIDES Office or Panel Chairs, and therefore they may not be distributed with proposals to the thematic panels for review (the panels conduct science reviews, not technical evaluations). Foldouts, large maps, and full seismic sections should be sent to the Site Survey Data Bank at LDEO as part of the Site Survey Data Package at such time as proponents are instructed by the JOIDES Office.

COLOUR FIGURES should be avoided as they often jam copy machines. They are not essential unless conveying the most complex information.

Do not attach REPRINTS to proposals. Proponents may submit these with the proposal to be kept on file in the JOIDES Office, but they will not be sent out with proposals to the panels for review.

All pages should be NUMBERED sequentially.

Use only staples for BINDING, please. Proposals are torn apart to facilitate copying.

MARGINS should be at least one inch all the way around regardless of paper size.

Completed ODP Site Summary Forms containing information on DRILLING SITES that are tied to the stated scientific objectives and justified by appropriate site survey data are required. Blank site summary forms are available from the JOIDES Office on disk or hard copy or can be downloaded from the anonymous ftp server (see pages 28 and 62).

CARDIFF is on the Web

The JOIDES Office in Cardiff invites you to browse their World Wide Web home page

It is still under development, but can already be used to download Panel Minutes (as rtf files) and to view the JOIDES Journal Volume 21, No.1 (Feb 1995), and has links to ODP-TAMU. Future plans are to link to all the main sub-contractors and to include all the JOIDES Directory information, the JOIDES Calendar, and active ODP proposal information. Please visit our home page and send any comments to me by clicking on my name at the bottom right of the home page.

The home page of the JOIDES Office is available through the Department of Earth Sciences at the University of Wales server on:

http://servant.geol.cf.ac.uk

For more information, please contact: *Dr. Kathy Ellins*
JOIDES OFFICE, Department of Earth Sciences, University of Wales,
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Tel: +44 1222 874541, Fax: +44 1222 874943, Internet: joides@cardiff.ac.uk

PROPOSALS (Reviewed in the Fall of 1995)

Proposal No	Date Received	Abbreviated Title	Contact
300-Add2	3 July 1995	Return to 735B	Dick, H. J. B.
334-Add	30 June 1995	Galicia Margin S' Reflector	Boillot, G.
334-Add2	Sept. 5 1995	Galicia Margin S' Reflector	Boillot, G.
348-Rev	30 June 1995	New Jersey TIE: U.S. Mid-Atlantic Transect	Miller, K
355-Add	3 July 1995	Peruvian Margin Gas Hydrates	Von Huene, R
404-Add2	3 July 1995	Western North Atlantic sediment Drifts	Keigwin, L.
426-Rev	30 June 1995	Australia-Antarctic Dis ordance	Christie, D
431-Rev	3 July 1995	Western Pacific Geophysical Network	Suyehiro, K
445-Add	3 July 1995	Nankai Trough 'Accretionary prism	Moore., G.F.
448-Add2	30 June 1995	Ontong Java Plateau	Kroenke, L.W.
450-Add	3 July 1995	Taiwan Arc Continent Collision	Lundberg, N.
455-Rev	30 June 1995	N.W.A.M.P.	Piper, D.J.W.
457-Rev2	30 June 1995	Kerguelen Plateau	Frey, F.A.
461-Rev	3 July 1995	Ocean-Continent Transition west of Iberia	Whitmarsh, R.B.
462-Rev	3 July 1995	Blake Plateau and Blake Nose	Norris, R.D.
464-Add	3 July 1995	Southern Paleoceanography Transect	Gersonde, R
468-Rev	30 July 1995	Carbonate Platforms/Romanche Fracture Zone	Bonatti, E.
473-Add	30 May 1995	Saanich Inlet	Nagihara, S.
473-Add	30 June 1995	Saanich Inlet	Bornhold, B.D.
474—	30 April 1995	Offset Engineering Leg	Pettigrew, T.L.
475—	30 June 1995	Physical Properties in Accretionary Prisms	Moore, J.C.
476—	4 July 1995	Hudson Apron Submarine Slope Stability Transect	Pratson, L.
477—	4 July 1995	Sea of Okhotsk and Bering Sea	Takahashi, K.
478—	3 July 1995	Eastern Nankai Multiple Shortening	Tokuyama, H.
479—	3 July 1995	Felsic Volcanic, East Manus Back-Arc Basin	Binns, R.A.
480—	3 July 1995	Caribbean Cretaceous Basalt Province	Driscoll, N.
481—	3 July 1995	Red Sea Deeps	Ludden, J.

LOIs (Reviewed in the Fall of 1995)

LOI No	Date Received	Abbreviated Title	Contact
54	July 3, 1995	Water Circulation and Sediment History: Indian Ocean	Davies, T.A.
55	July 3, 1995	Drilling in a non-accretionary convergent plate margin	Fryer, P
56	July 3, 1995	APaleogene Equatorial Pacific APC Transect	Lyle, M
57	July 3, 1995	Abyssal Anoxic basins, Southwest Pacific	Kroenke, L.W.
58	July 3, 1995	Slow-Spreading Lithosphere: Mid-Atlantic Ridge/Kane Fracture Zone	Cannat, M
59	July 3, 1995	Monsoon History in the South China Sea	Wang Pinxian
60	July 3, 1995	Return to Tag Hydrothermal Field	Rona, P.A.
61	July 3, 1995	Seychelles Microcontinent	Plummer, P.S.

Propsals in the ODP System that will become Inactive in 1996, if not updated during that year

Proposal No	Date Received	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.
086——	12/10/84	Red Sea	Bonatti, E.
086-Rev	25/09/85	Red Sea	Bonatti, E.
086-Rev2	27/07/92	Drilling in the Red Sea	Bonatti, E.
253——	28/08/86	Black shales in ancestral Pacific, Shatsky Rise	Sliter, W.V.
253-Add	28/12/92	Deposition of organic carbon-rich strata, ancestral Pacific	Sliter, W.V.
253-Rev	19/06/91	Deposition of organic carbon-rich strata, ancestral Pacific	Sliter, W.V.
332——		Ghost of 204——	
332-Rev		Florida Escarpment Drilling transect (Ghost is 204-Rev)	
332-Rev2	25/07/89	Drilling transect, Florida Escarpment	Paull, C.K.
332-Rev3	04/02/92	Florida Escarpment drilling transect	Paull, C.K.
333——	27/07/89	Evolution of pull-apart basin, Cayman Trough	Mann, P.
333-Add	04/02/92	Update to Cayman Trough transect	Mann, P.
337——	31/07/89	Tests of Exxon sea-level curve, New Zealand	Carter, R.M.
337-Add	21/12/92	Tests of Exxon sea-level curve, New Zealand	Carter, R.M.
338——	03/08/89	Sea-level fluct., Marion carbonate plateau, NE Australia	Pigram, C.J.
338-Add	13/07/92	Sea-level fluct., Marion carbonate plateau, NE Australia	Pigram, C.J.
340——	07/08/89	Tectonic, climatic, oceano. change, N Australian margin	Symonds, P.
340-Rev	31/12/92	Tectonic, climatic, oceano. change, N Australian margin	Symonds, P.
347——	15/08/89	L. Cenozoic paleoceanography, South-equatorial Atlantic	Wefer, G.
347-Add	30/07/92	L. Cenozoic paleoceanography, South-equatorial Atlantic	Wefer, G.
347-Rev	24/12/92	Late Cenozoic Paleoceanography, South-equatorial Atlantic	Wefer, G.
372——	26/02/90	Cenozoic circulation and chem. gradients, N Atlantic	Zahn, R.
372-Add	15/12/92	Cenozoic circulation and chem. gradients, N Atlantic	Zahn, R.
372-Add2	01/07/93	Cenozoic circulation and chem. gradients, N Atlantic	Zahn, R.
406——	16/09/91	North Atlantic climatic variability	Oppo, D.
406-Add	24/05/93	North Atlantic climatic variability	Oppo, D.
413——	03/02/92	Magmatic/tectonic evol. of oceanic crust: Reykjanes Ridge	Murton, B.J.
417——	30/06/92	Gas hydrate in vicinity of gas plume, Okhotsk Sea	Soloviev, V.
418——	27/07/92	Miocene biomagnetostrat. reference section, Menorca Rise	Cita-Sironi, M.B.
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.
424——	31/07/92	To "Cork" Hole 395A	Becker, K.
424-Rev	31/12/92	To "Cork" Hole 395A	Becker, K.
425——	31/07/92	MAR at 15°37'N: crust generation at magma-poor MOR	Cannat, M.
425-Rev	01/07/93	Mid-Antlantic Ridge Offset Drilling	Casey, J.F.
427——	31/12/92	South Florida Margin SeaLevel	Hine, A.C.
427-Add	01/07/93	South Florida Margin SeaLevel	Locker, S.D.
428——	28/12/92	Tyrrhenian Seafloor and Hydrothermal Sulfide Deposits	Savelli, C.
429——	31/12/92	Atlantic-Mediterranean Gateway	Nelson, C.H.
432——	28/06/93	Galicia deep hole S-reflector	Reston, T.J.
433——	30/06/93	East Med. Orogeny	Hsü, K.J.

ODP Contractors

Prime Contractor
ODP Publications and JOIDES Journal Distribution

Joint Oceanographic Institutions Inc.,
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Internet: joi@brook.edu

ODP-TAMU

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Texas 77845-9547, U.S.A.
Tel: 409-845-2673
Fax: 409-845-4857
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Science Operations: Cooley@cook.tamu.edu
and Leg Staffing
Sample Requests: Chris@cook.tamu.edu
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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Ocean Drilling Program
Bremen Core Repository
Konsul-Smidt Str. 30
Schuppen 3
28217 Bremen
Germany
Tel: 49 421 396 6336
Fax: 49 421 396 6684
Internet: walter_hale@odp.tamu.edu
* to be completed and sent to ODP-TAMU

JOIDES Office

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Proposal Submissions
JOIDES Journal Articles

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ODP-LDEO

Wireline Logging Services
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Logging Schools
Log - Data Requests

Borehole Research Group
Lamont-Doherty Earth Observatory
Palisades,
New York, 10964, U.S.A.
Tel: 914/ 365-8672
Fax: 914/ 365-3182
Internet: borehole @ldeo.columbia.edu

International Wireline Logging Servce Partners
(Note all requests for data should go to ODP-LDEO)

Laboratoire de Mesures en Forage
Institut Méditerranéen de Technologie
Technopôle de Château-Gombert
F-13451 Marseille Cedex 20
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Tel : 33 91 05 44 99
Fax : 33 91 05 45 01
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Borehole Research
Department of Geology
University of Leicester
Leicester, LE1 7RH
United Kingdom
Tel: 44 116 2523 796
Fax: 44 116 2523 918
Internet: lubr@le.ac.uk

ODP Site Survey Data Bank

Submission of Site Survey Data
Site Survey Data Requests

ODP Site Survey Data Bank
Lamont-Doherty Earth Observatory
P.O. Box 1000, Rt. 9W
Palisades, NY 10964, U.S.A.
Phone: 914/365-8542
Fax: 914/365-8159
email: odp@ldeo.columbia.edu

JOIDES / ODP Panel Directory

Committees

Executive Committee (EXCOM)

Member	Alternate	Liaison to
Beiersdorf, H.		
Briden, J.C.	Summerhayes, C.P.	
Dalrymple, G.B.		
Detrick, R.S.		
Duce, R.A.		
Eldholm, O.	Comas, C.	
Harrison, C.G.A.	Becker, K.	
Lancelot, Y.		
Leinen, M.	Schilling, J.G.	
Mayer, L.A.	Loutit, T.S.	
Mutter, J.	Langseth, M.	
Nowell, A.	Heath, G.R.	
Orcutt, J.		
Raleigh, C.B.		
Stoffa, P.L.		
Taira, A.		

Planning Committee (PCOM)

Berger, W.H.	Kastner, M.	SGPP
Carter, R.M.	Scott, S.	OHP
Dick, H.J.B.	Curry, W.B.	LITHP
Johnson, H.P.		
Kidd, R.B.	Pearce, J.A.	EXCOM, BCOM, PPSP
Kudrass, H.	Beiersdorf, H.	SSP
Larson, R.	King, J.	
McKenzie, J.		SGPP
Mével, C.		LITHP
Mix, A.C.	Levi, S.	OHP
Moore, G.F.		DMP
Mountain, G.		SSP
Natland, J.H.	Swart, P.K.	TEDCOM
Sager, W.W.		IHP
Shipley, T.H.	Coffin, M.F.	PPSP, TECP
Suyehiro, K.	Tamaki, K.	TECP

Technology and Engineering Development Committee (TEDCOM)

Luy, R.		Eickelberg, D.
Maidla, E.	Robertson, P.	
Marsh, G.L. US		
Pheasant, J.	Skinner, A.	
Rasmussen, B.		
Schuh, F.J. US	Vallini, A.	
Shanks, F.E. US		
Shatto, H.L. US		
Sparks, C.		
Summerour, A. US		
Svendsen, W.W. US		
Takagawa, S.		

Thematic Panels

Lithosphere Panel (LITHP)

Member	Alternate	Liaison to
Arai, S.		
Bloomer, S.H.		
Caress, D.		
Castillo, P.R.		
Coffin, M.F.		
Fisher, A.T.		TEDCOM
Fitton, G.	Murton, B.J.	SMP
Gee, J.		OHP/DMP
Gillis, K.M.	O'Reilly, S.	TECP
Girardeau, J.	Ludden, J.	TECP
Koski, R.		SGPP
Rihm, R.		OHP
Sheehan, A.F.		
Weis, D.	Torssander, P.	SGPP
Wilson, D.S.		
Zierenberg, R.A.		

Ocean History Panel (OHP)

Blake, G.H.		SGPP
Clement, B.M.		
Crowley, T.J.		
Erba, E.	Kuijpers, A.	
Gersonde, R.	Zahn, R.	
Hodell, D.A.		
Karpoff, A-M		
Kemp, A.E.S.	Kroon, D.	
Leckie, R.M.		
Loutit, T.S.	Eyles, C.	
Moore, T.C.		
Oppo, D.		
Popp, B.N.		
Prell, W.L.		
Ravelo, A.C.		
Takahashi, K.		

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Produced and distributed by Natural Environment Research Council. For copies, or to be placed on the distribution list contact:

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Publication Statement

The *JOIDES Journal* is edited at the JOIDES Office by Colin Jacobs; Kathy Ellins is the ODP International News, Liaison Group News, and ODP Proposal News reporter, Julie Harris produces the ODP Directory. The JOIDES Office is located at the Department of Earth Sciences, University of Wales, Cardiff, CF1 3YE, United Kingdom.
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The *JOIDES Journal* is published and distributed by the Joint Oceanographic Institutions (JOI) Inc., Washington D.C., for the Ocean Drilling Program under the sponsorship of the National Science Foundation and participating countries. The material is based upon research supported by the National Science Foundation under prime contract OCE-9308410.

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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Publication History

The *JOIDES Journal* is published in yearly volumes which normally consist of three issues published in February (No. 1), June (No. 2), and October (No. 3). Publication commenced in 1975 with volume 1 and has continued since then.

In addition, there are occasional special issues of *JOIDES Journal* which are listed below:

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
EXCOM	29 January - 1 February '96	Washington, DC
* TECP	4 - 6 March '96	California (site to be named)
* OHP	4 - 6 March '96	Kauai, Hawaii
* LITHP	6 - 8 March '96	Corvallis, Oregon
* SGPP	7 - 9 March '96	La Jolla, California
* DMP	early March '96	Japan
* SMP	early March '96	
* IHP	25 - 29 March '96	College Station, Texas
* PPSP		
* TEDCOM		
* SSP	27 - 29 March '96	Edinburgh, United Kingdom
PCOM	22 - 25 April '96	Aix-en-Provence, France
EXCOM	25 - 28 June '96	Oslo, Norway
* SSP	29 July - 1 August '96	Palisades, NY
PCOM	post - 15 August '96	Townsville, Australia
* LITHP	September '96	Kanazawa, Japan
* OHP	2 - 4 October '96	Strasbourg, France
* DMP	19 - 23 October (3 days)	San Diego, California
* SSP	11-13 November '96	Palisades, New York
PCOM	early December '96	Palisades, New York
* OHP	Spring '97	Santa Cruz, California
PCOM	April '97	? Woods Hole, Massachusetts

** meeting not yet formally requested or approved*

JOIDES Resolution Operations Schedule

Leg	Destination	Cruise Dates	Port of Origin †	Total Days	Transit	On Site
164	Gas Hydrates	1 Nov - 19 Dec '95	Halifax, 28 - 31 Oct '95	48	6	42
165	Carib. Ocean History	24 Dec '95 - 18 Feb '96	Miami, 19 - 23 Dec '95	56	11	45
166	Bahamas	23 Feb '96 - 11 Apr '96	San Juan, 18 - 22 Feb '96	48	8	40
166T	Transit	14 - 20 Apr '96	Panama *, 11 - 13 Apr '96	6	6	-
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 Δ	17 - 18 Aug '96	Victoria, 16 Aug '96	2	-	2
169	Sedimented Ridges II	23 Aug - 18 Oct '96	Victoria, 18 - 22 Aug '96	56	6	50
170	Costa Rica Margin	23 Oct - 18 Dec '96	San Diego, 18 - 22 Oct '96	56	11	45
			Panama, 19 - 23 Dec '96			

† Although five day port calls are generally scheduled, the ship sails when ready.
* Leg 166 Scientists disembark in Panama.
Δ Subject to environmental and safety reviews.