OCEAN DRILLING PROGRAM

LEG 147 SCIENTIFIC PROSPECTUS

HESS DEEP RIFT VALLEY

Dr. Kathryn Gillis
Department of Geology & Geophysics
Woods Hole Oceanographic Institution
Woods Hole
Massachusetts 02543
Co-Chief Scientist

Dr. Catherine Mével
Laboratoire de Pétrologie
Université Pierre et Marie Curie
4 place Jussieu T26, E3
75252 Paris cedex 05, France
Co-Chief Scientist

Dr. James Allan
Staff Scientist, Leg 147
Ocean Drilling Program
1000 Discovery Drive
Texas A&M University Research Park
College Station, Texas 77845-9547

Philip D. Rabinowitz
Director
ODP/TAMU

Jack G. Baldauf
Manager of Science Operations
ODP/TAMU

Timothy J.G. Francis
Deputy Director
ODP/TAMU

August 1992

Scientific Prospectus No. 47
First Printing 1992

Copies of this publication may be obtained from the Director, Ocean Drilling Program, Texas A&M University Research Park, 1000 Discovery Drive, College Station, Texas 77845-9547. In some cases, orders for copies may require payment for postage and handling.

DISCLAIMER

This publication was prepared by the Ocean Drilling Program, Texas A&M University, as an account of work performed under the international Ocean Drilling Program, which is managed by Joint Oceanographic Institutions, Inc., under contract with the National Science Foundation. Funding for the program is provided by the following agencies:

Academy of Sciences (Russia)
Canada/Australia Consortium for the Ocean Drilling Program
Deutsche Forschungsgemeinschaft (Federal Republic of Germany)
European Science Foundation Consortium for the Ocean Drilling Program
(Belgium, Denmark, Finland, Greece, Iceland, Italy, The Netherlands, Norway, Spain, Sweden Switzerland, and Turkey)
Institut Français de Recherche pour l'Exploitation de la Mer (France)
National Science Foundation (United States)
Natural Environment Research Council (United Kingdom)
Ocean Research Institute of the University of Tokyo (Japan)

Any opinions, findings and 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, the participating agencies, Joint Oceanographic Institutions, Inc., Texas A&M University, or Texas A&M Research Foundation.

This Scientific Prospectus is based on pre-cruise site-survey information and JOIDES panel discussions. The operational plans within reflect JOIDES Planning Committee and thematic panel priorities. During the course of the cruise, actual site operations may indicate to the Co-Chief Scientists and the Operations Superintendent that it would be scientifically advantageous to amend the plan detailed in this prospectus. It should be understood that any proposed changes to the plan presented here are contingent upon approval of the Director of the Ocean Drilling Program in consultation with the Planning Committee and the Pollution Prevention and Safety Panel.

Abstract

The primary objective of Leg 147 will be to recover a long continuous core of gabbros and, possibly, the shallow mantle generated at the fast-spreading East Pacific Rise (EPR). Hess Deep is the deepest part of a westward-propagating rift valley that is opening up the eastern flank of the equatorial EPR in advance of the propagating Cocos-Nazca spreading center. The exposure in the Hess Deep rift valley floor has provided a unique opportunity to sample a representative section of normal ocean crust formed at the fast-spreading EPR that is far from any fracture zone. The highest priority site is located on the crest of an intra-rift ridge where gabbro outcrops have been identified during a *Nautile* dive program (Francheteau et al., 1990). Recovery of gabbros and peridotites is critical in order to characterize the igneous, metamorphic, and structural evolution of the lower crust and upper mantle generated at a fast-spreading ridge, as well as the vertical variation in its physical and magnetic properties. This leg represents the first of a proposed multi-leg program.

Introduction

Investigation of the global ocean-ridge system during the past decade using remote geophysical techniques has greatly changed our view of the structure of the oceanic crust. To test the models that have emerged from these studies and to better understand the interplay between magmatic, tectonic, and hydrothermal processes at mid-ocean ridges, it is necessary to sample complete sections of the oceanic lithosphere. Current drilling technology, however, precludes recovery of continuous sections through the upper crust down to the mantle. An alternative approach, developed during a JOI/USSAC Workshop on Drilling the Oceanic Lower Crust and Mantle (Workshop Participants, 1989), proposes that tectonic exposures be used as the basis for drilling composite sections of the ocean crust in different tectonic environments with a series of strategically chosen offset drill holes.

The Hess Deep region is an example of such a tectonic window in oceanic lithosphere where dismembered crustal sections created at a fast-spreading center (the East Pacific Rise) are exposed. Submersible observations have shown that the dike/gabbro transition, massive sections of gabbros, and peridotites crop out on the walls and the floor of this rift. A multi-leg drilling program was proposed to reconstruct a composite section of oceanic lithosphere by drilling a combination of holes (Dick et al., 1990; Gillis et al., 1990). Leg 147 is the first drilling program to be devoted to this plan. The primary objective of this leg will be to drill the first long continuous section of gabbros, possibly down to the gabbro/peridotite transition (petrologic Moho), formed in a fast-spreading environment. This long gabbro core will be compared to the section of oceanic gabbro drilled at site 735B, in a slow-spreading environment, to test various models of magmatic, tectonic, and hydrothermal processes at mid-oceanic ridges.

Background and Scientific Objectives

Detailed bathymetric, petrologic, and geophysical surveys conducted during the past decade along the global mid-ocean-ridge system have greatly modified our view of the stratigraphy of the oceanic crust. The simple layer-cake model that requires a continuous, elongate magma chamber has been replaced by a model of segmented volcanism, in which magma chambers are discontinuous features fed intermittently from below at regularly spaced points (e.g., Whitehead et al., 1984; Crane, 1985; MacDonald, 1987). Our current view of how the rate of magma supply and, thus, the spreading rate influence the internal stratigraphy of the oceanic crust has been developed primarily on the basis of remote geophysical techniques and can be tested through petrologic and structural study of drill core.

The deep rift valleys of slow-spreading ridges suggest that there is a low rate of magma supply and that magmatism is ephemeral. Although there is no seismic evidence for the presence of a magma chamber at slow spreading ridges (Detrick and Purdy, 1980), gravity anomalies along the Mid-Atlantic Ridge (MAR) suggest that magmatic accretion is focused and/or that the crust is thicker at discrete centers along the axis (Lin et al., 1990). These zones of mantle upwelling and associated volcanism occur within individual segments bounded by both transform and non-transform off-sets and may explain the chemical discontinuities between segments (Whitehead et al., 1984; Lin et al., 1990; Sempéré et al., 1990). Variation of the ridge morphology within and between individual segments along the MAR reflects the cyclicity of tectonic extension and magmatism (e.g., Karson et al., 1987).

A study of earthquake focal mechanisms at the MAR indicates that brittle failure under extension occurs to depths as great as 7-8 km, presumably where the lithosphere has had a chance to cool between magmatic episodes (Toomey et al., 1985; Huang and Solomon, 1988). If crust created at slow-spreading centers is built by small, short-lived magmatic intrusions, it may be predicted that both brittle and ductile deformation occurs in Layer 3 while the crust is within the vicinity of a ridge. Because deformation would enhance hydrothermal flow, it is possible that the lower crust undergoes significant high-temperature alteration at a ridge. Ductile shear zones within the plutonic sequence recovered at the slow-spreading Southwest Indian Ridge (SWIR) during Leg 118 are interpreted as zones of enhanced permeability that acted as conduits for hydrothermal flow to the lower plutonics (Cannat et al., 1991 ; Dick et al., 1991 ; Stakes et al., 1991). Lower crust seismic reflectors in the old Atlantic crust (McCarthy et al., 1988) may represent zones of deformation and hydrothermal flow similar to those observed in the gabbroic core of SWIR (Cannat et al., 1991; Dick et al., 1991) and in the Bay of Islands ophiolite (Casey et al., 1990).

Until recently, it has been predicted that large, steady-state magma chambers would be maintained at fast-spreading ridges that would produce a thick layered sequence in the lower crust similar to the layered sequences in the Oman Ophiolite and continental layered intrusions (e.g., Pallister and Hopson, 1981). New geophysical data predict a narrow, thin lens of melt that is underlain by an extensive crystal-mush zone that may extend down to the base of the crust (see the review by Detrick, 1991). The igneous stratigraphy of the lower crust at fast-spreading ridges should vary with the relative size and geometry of the chamber and crystal-mush zone and may or may not show evidence for anhydrous ductile deformation. The evolution of cumulates and the mechanism of melt extraction from long-lived crystal-mush zones is not known, but it must differ from crystal-mush zones in small, ephemeral magma chambers as documented at the SWIR (Bloomer et al., 1991 ; Dick et al., 1991). For example, a long-lived crystal-mush zone may explain why magmas erupted at fast-spreading ridges are generally more fractionated than magmas at slow-spreading ridges (Sinton and Detrick, 1992).

The presence of long-lived axial magma chambers at fast-spreading ridges would probably fix the brittle-ductile transition at the top of the thin melt lens, with extension within the magma chamber being taken up by laminar flow of the crystal mush. Because the absence of ductile deformation should preclude the early penetration of seawater into the lower crust, high-temperature hydrothermal alteration may not be a significant process beneath fast-spreading ridges, producing a pattern of hydrothermal alteration in the lower crust that is different from slow-spreading ridges (Mével and Cannat, 1991).

Thus, it is probable that the lower crust in oceanic crust generated at fast-spreading ridges is strikingly different than that formed at slow-spreading ridges. We anticipate that the gabbroic core recovered during Leg 147 will provide important new insights into processes of crustal formation at fast-spreading ridges and will be an important comparison to the gabbroic core recovered at the slow-spreading SWIR during Leg 118.

Geological background

Regional setting

Hess Deep is the deepest part of a westward-propagating oceanic rift valley that is opening up the eastern flank of the equatorial EPR in advance of the westward-propagating Cocos-Nazca spreading center (Lonsdale, 1988) (Fig. 1). The western end of the rift valley is 30 km from the EPR axis, where approximately 0.5-Ma EPR crust is broken by two 5-km-wide east-west grabens, which join a few kilometers farther east (Fig. 2). As the rift valley is traced eastward, it broadens to 20 km and deepens to >5400 m; its uplifted shoulders rise to depths less than 2200 m. Approximately 70 km east of the EPR axis, the Cocos-Nazca spreading center begins to build a volcanic ridge in the rift valley, and the rift escarpments are locally uplifted an additional 500 m at narrow horsts. Farther east, the wedge of newly accreted crust formed by north-south spreading expands to a mature, medium-rate (50 mm/yr total) spreading center, and the rift escarpments become the "rough-smooth boundary" of the Galapagos gore.

The Hess Deep rift valley is propagating into a random part of the EPR at a rate that matches the 65 km/m.y. half rate of EPR spreading (Lonsdale, 1988). A steady-state interpretation of the present topography indicates that growth of the rift escarpments is correspondingly fast, with the 3250 m of total relief of the Hess Deep area being created as a rift propagates about 30 km, i.e., in 0.5 m.y. Because there are no obvious effects of the presence of Hess Deep on the EPR accretion process, the Hess Deep crustal window is very different from a fracture-zone trough. This part of the EPR axis is not exactly typical, however, as it has been the western boundary of a Galapagos Microplate for the past 1 m.y., rather than part of the Pacific-Cocos or Pacific-Nazca boundary. Between 2°20' N and 1°50' N, this microplate is affected by a southward-migrating non-transform offset (Lonsdale, 1989), whose pseudofault "wake" has recently been intersected by the western end of the Hess Deep rift valley.

The fault scarps that bound the rift valley are seismically active (Neprochnov et al., 1980) and are exposing 0.5- to 1.0-Ma EPR crust. Rocks observed on these scarps appear to have been freshly exposed and are not encrusted with manganese oxides. The rift valley is asymmetric, with the Hess Deep ridge axis occurring closer to the southern than the northern wall. The southern wall rises continuously in large steps to a crest of 2200 m depth, approximately 7 km south of the deep. The EPR plateau is fairly flat, and abyssal-hill lineations intersect the scarp. The northern scarp is twice as far from the deep. Abyssal-hill lineations generally extend up to the scarp except in the area of a rift-shoulder horst, where a crustal block has been rotated. Soviet multichannel reflection profiling along the EPR flanks indicates that seismic Layers 2A (lava sequence) and 2B (dike complex) are of normal thickness (about 2 km) and that Layer 3 (gabbroic complex) may be somewhat thinner than usual (3-3.5 km) (Zonenshain et al., 1980). A major intra-rift ridge occurs between the Hess Deep and the northern scarp and extends eastward, overlapping the western end of the Cocos-Nazca ridge (Fig. 2).

Geology of the Hess Deep

The geology of the Hess Deep region was investigated during two submersible cruises: in 1988, the floor and walls of the rift valley were studied with the *Nautile* during a series of 22 dives (Francheteau et al., 1990; Francheteau et al., 1992), and in 1989, the rift valley walls were investigated with the *Alvin* in a series of 11 dives (Lonsdale, unpubl. data). The following is a summary of the results of these field programs.

Volcanics, sheeted dikes, and, locally, gabbros crop out along the scarps that bound the Hess Deep rift valley. A talus ramp intersects the scarps within the sheeted-dike complex that is approximately 1200 m thick. Dikes are generally subvertical and strike north-south, parallel to the EPR fabric. Gabbros underlie the sheeted dikes within a rift shoulder horst along the northern scarp. In this region, the dikes are locally rotated. Typically, a 100-300-m-thick layer of pillow lavas is separated from the sheeted dikes by an intermediate zone of variable thickness (50-500 m), consisting of a mixture of extrusives and intrusives, including thick horizontal layers that may represent sills.

A complete, albeit dismembered, crustal section of the EPR, including volcanics, sheeted dikes, gabbros, and peridotites, is exposed on the floor of the Hess Deep rift valley (Fig. 3;

Francheteau et al., 1990). The slope that rises southward from the axis of Hess Deep averages 45° and is covered with basaltic and diabasic rubble. A gentle, 15°-20° slope, stepped with secondary high-angle faults, extends north of Hess Deep for 5-6 km. Lower crustal rocks with rare peridotites crop out in ledges that dip into the lower slope from 5400 and 4500 m depth. Mineralogical (R. Hekinian et al., unpubl. manuscript) and geochemical (Blum, 1991) data for the plutonic rocks show that the most magnesian gabbros lie at the greatest depths, which may reflect formation within the lower level of a magma chamber (R. Hekinian et al., unpublished manuscript). Semi-horizontal ledges of dolerite occur in a mainly sedimented terrain between 4500 and 4000 m. A change in slope at 4000 m marks the southern edge of the east-west-trending intra-rift ridge, which culminates at 2900 mbsl. At the western end of this ridge, gabbroic rocks crop out with isolated occurrences of volcanics. Further east, pillow lavas and dikes crop out along the crest of the ridge, and low-temperature hydrothermal activity was observed.

Farther east, north of the tip of the Cocos-Nazca ridge, plutonic and ultramafic rocks crop out between 4500 and 3500 m depth along a gentle slope that is locally ≤10°. Cr-spinel-bearing dunites and harzburgites (up to 50% serpentinized) were sampled from subhorizontal ledges that dip to the north. Gabbros have been recovered by well-positioned dredges due west of this area (Fig. 4). The geology and structure between these two areas are not known.

Two alternative rifting models have been proposed for the Hess Deep rift valley (Francheteau et al., 1990). One emphasizes the vertical movement of mantle horsts or serpentine diapirs to expose mantle rocks. The other postulates rupture of the lithosphere by low-angle detachment faults similar to those mapped and imaged at rifting sites in continental lithosphere and recently postulated for the regenerating axial rift valleys of slow-spreading ridges. Both models are compatible with the observed bathymetry and outcrop distribution (Fig. 4). Preliminary interpretation of on-bottom gravity and seismic data recently collected across the intra-rift ridge indicates that the ridge is composed of high-density and -velocity material (L. Dorman and J. Hildebrand, pers. comm.). These new data suggest that the intra-rift rift ridge is a block of unserpentinized lower crustal rocks, supporting the latter model.

In both models, the dolerites and basalts sampled along the western transect between 4500 and 4000 m are interpreted as dismembered fragments of upper EPR crust. These dolerites and basalts are consistently poor in titanium (Blum, 1991), overlapping the field of Cocos-Nazca basalts but not the field of EPR basalts from the area, which are systematically richer in titanium (J. Natland, pers. comm.). They do however, fall within the range of basalts from 13°N EPR (R. Hekinian, pers. comm.). Therefore, it is not possible to determine unequivocally the origin of the basalts exposed on the rift-valley floor. Whatever interpretation is preferred for the formation of the intra-rift ridge, it is probable that the opening of the rift left some imprint of the previously formed EPR crust.

Proposed Drill Sites

The primary scientific objective of Leg 147 is to recover a long, continuous section of gabbros and possibly the transition across the petrologic Moho. HD-3 has been selected as the highest priority site on the basis of technical constraints (shallowest water depth of the proposed sites, flat-lying outcrops). HD-2 and HD-4 are proposed as alternate sites in the event that HD-3 does not fulfill this objective.

Hess Deep 3: Crest of the intra-rift ridge (2°18'N, 101°31.6'W; 3075 m water depth).

The primary objective of Hess Deep 3 is to recover a long continuous core of plutonic rocks and possibly the transition across the petrologic Moho into the shallow mantle. HD-3 is located at the crest of the western end of the intra-rift ridge, in the vicinity of *Nautile* dive 5. Plutonic rocks are exposed as discontinuous, flat-lying outcrops, several meters in size, separated by sediment with sparse rock fragments. It is probable that the sedimented areas are underlain by a thin (1-5 m?) zone of talus. A bare-rock guidebase would be required.

Hess Deep 2: South of the intra-rift ridge and north of the deep, south of Hess Deep 3 (2°15.2'N, 101°33'W; 5000 m water depth).

The objective of Hess Deep 2 is to recover a long, continuous section of plutonics and possibly the transition across the petrologic Moho into the shallow mantle. HD-2 is located in an area where plutonic rocks are exposed as subhorizontal outcrops, along a 15°-20°

slope. These outcrops are separated by sedimented areas and talus piles, some of which appear to be fairly recent. The plutonic rocks look more fragmented than at Site HD-3 and therefore will probably be more difficult to drill. There is evidence of low-temperature hydrothermal alteration. Some mylonites were recovered with the submersible. A bare-rock guidebase would be required.

Hess Deep 4: South of the intra-rift ridge and north of the Cocos-Nazca ridge (2°16.8'N, 101°26.6'W; 4100 m water depth).

The objective of Hess Deep 4 is to recover a continuous section of the shallow mantle. In the area of HD-4, dunites with Cr-spinels and foliated harzburgites (up to 50% serpentinized) are exposed along a gentle slope. Degraded outcrops are separated by 30-50-m-wide ponds of sediment. The presence of dunites in the section, by analogy to similar sections in ophiolites, suggests that this area may expose the transition zone across the lower plutonics into the mantle. A hole at this site will be the first opportunity to recover the transition zone and upper mantle beneath a fast-spreading ridge. The petrofabrics and strain-stress history of the rocks will provide information on the flow and creep processes in the shallow mantle beneath a ridge. A bare-rock guidebase would be required.

Operations

Drilling strategy and time estimates

The ship will depart from San Diego on 26 November 1992 and return to Panama on 21 January 1993. The ship will be on site for 42.6 days, and there will be 8.1- and 5.3-day transits at the beginning and end of the cruise, respectively.

Once in the Hess Deep region, the ship will drop a beacon and proceed to drill site HD-3. The TV camera system will be lowered on the drill string, and an approximately 500 m × 500 m survey will be conducted to determine potential locations for HD-3. Once the best target is determined, a hard-rock guide base will be deployed. The slope of the guide-base will be determined, and the local area will be viewed to ensure that the site offers optimal drilling conditions. If it is satisfactory, the hole will be started with a conventional rotary bit. Once coring commences, drilling will continue at HD-3 until the end of the leg, saving the appropriate time for logging.

In the event that the initial drill site is not satisfactory, or that initiation of the hole fails for technical reasons, the guide-base will be moved to another location within the surveyed area, the new area will be surveyed, and drilling will commence. This procedure will continue until a hole is initiated and core is recovered.

In the event that no suitable location can be found at site HD-3 or that HD-3 does not meet the scientific objectives of the leg, the ship will proceed to HD-2 and the same site survey plan will be followed. Similarly, if drilling problems are encountered at HD-2 or if the scientific objectives of the leg are not met at HD-2, the ship will move to HD-4.

The hard-rock guidebase operations for all proposed sites are summarized in Figure 5.

Downhole measurements

Downhole measurements will be conducted at the end of the leg to determine the structure and seismic stratigraphy within the borehole, to refine the lithostratigraphy and the extent of alteration, and to determine the crustal magnetization. A total of 3.5 days have been scheduled for the logging program, which will include, in order of priority: (1) the standard tools, including FMS (formation microscanner), quad-combo (resistivity, sonic, density), and geochemical tool; (2) digital BHTV (bore-hole televiewer); (3) VSP (vertical seismic profile); and (4) magnetic susceptibility (depending on tool availability). In the event that logging time is lost due to tool failure or other technical problems, the lowest priority logs will not be run. If more than the allotted time is available for logging because of drilling problems late in the cruise, a packer experiment will be run.

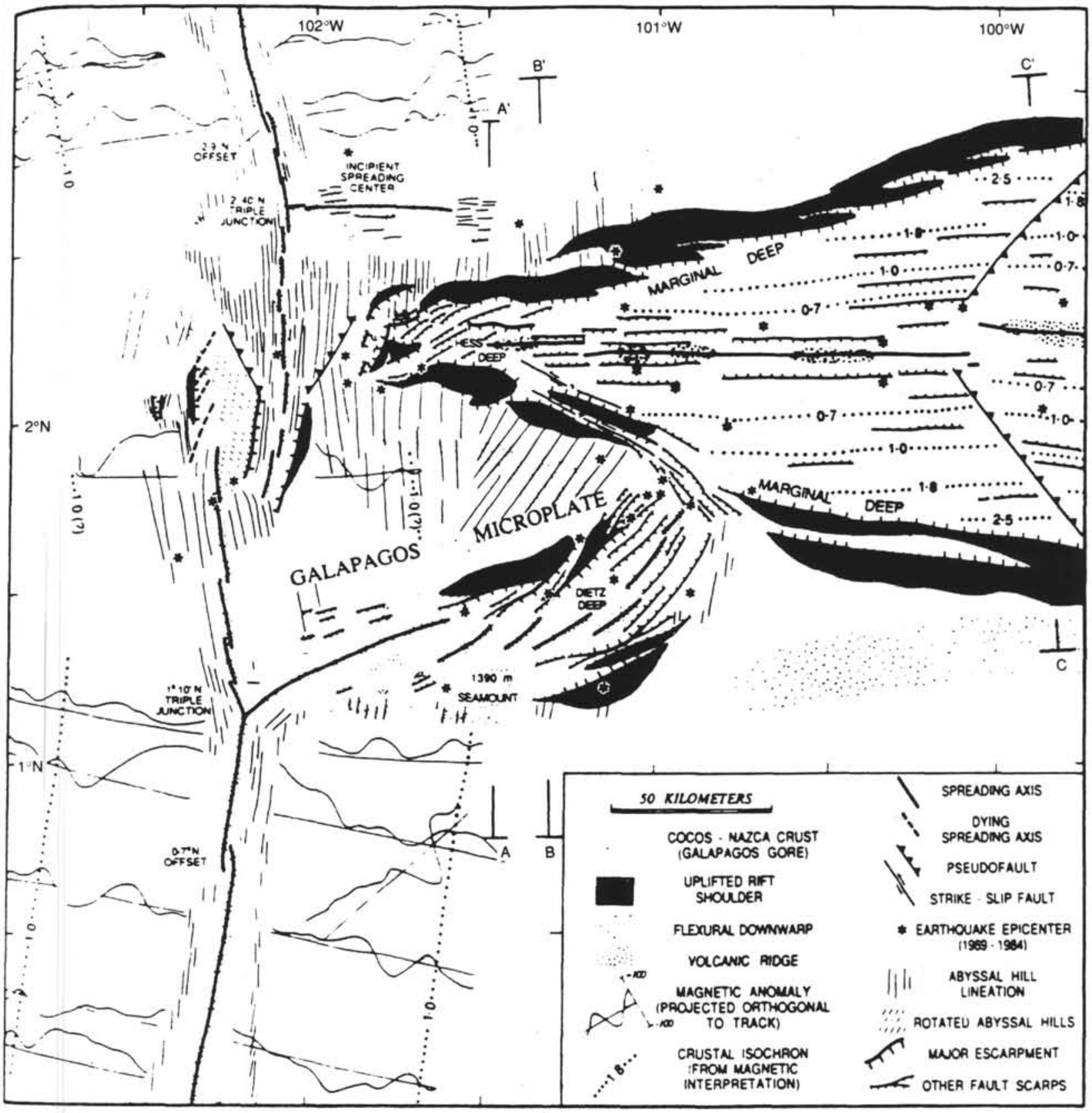

Figure 1. Location of Hess Deep at the western end of the propagating Cocos-Nazca spreading axis (from Lonsdale, 1988, copyright by the American Geophysical Union)

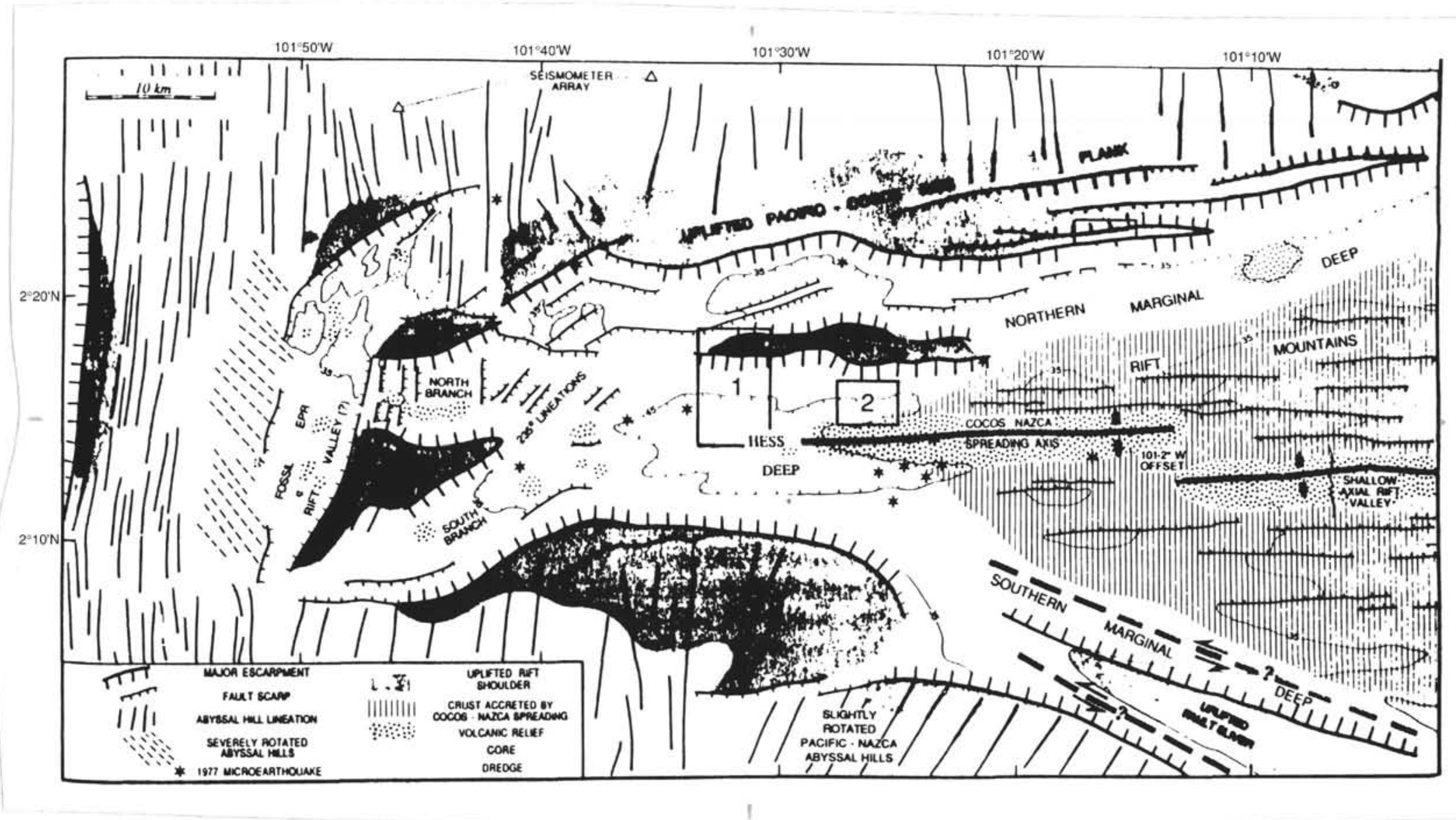

Figure 2. Tectonic sketch map of the Hess Deep rift valley (from Lonsdale, 1988, copyright by the American Geophysical Union) The three areas proposed for drilling are outlined.

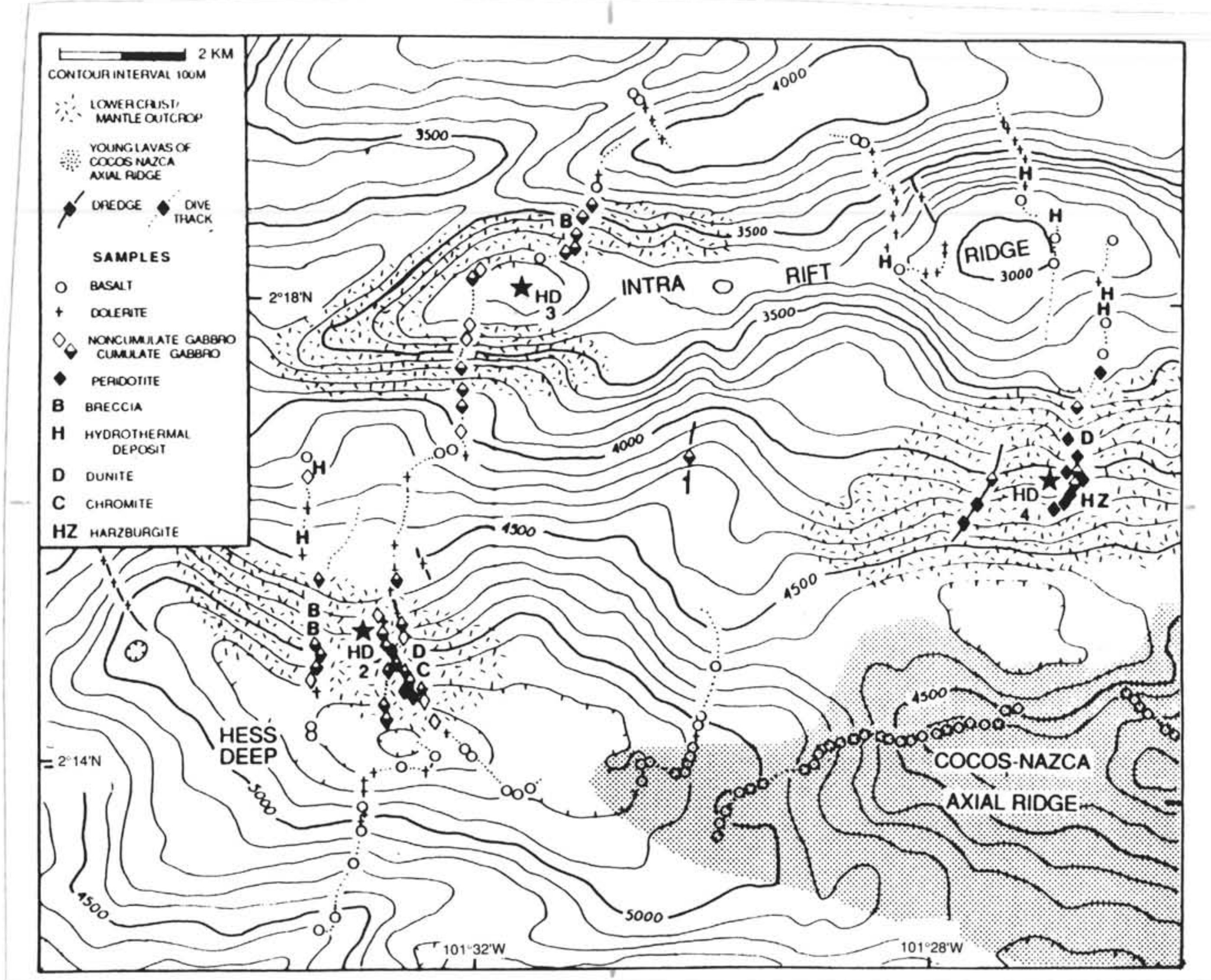

Figure 3. Geologic and bathymetric map of the Hess Deep rift valley. Geology is based upon the *Nautile* dive series and dredge results from the F/S *Sonne* and *Atlantis II* (from Francheteau et al., 1990). Stars indicate the locations of the three proposed drilling sites.

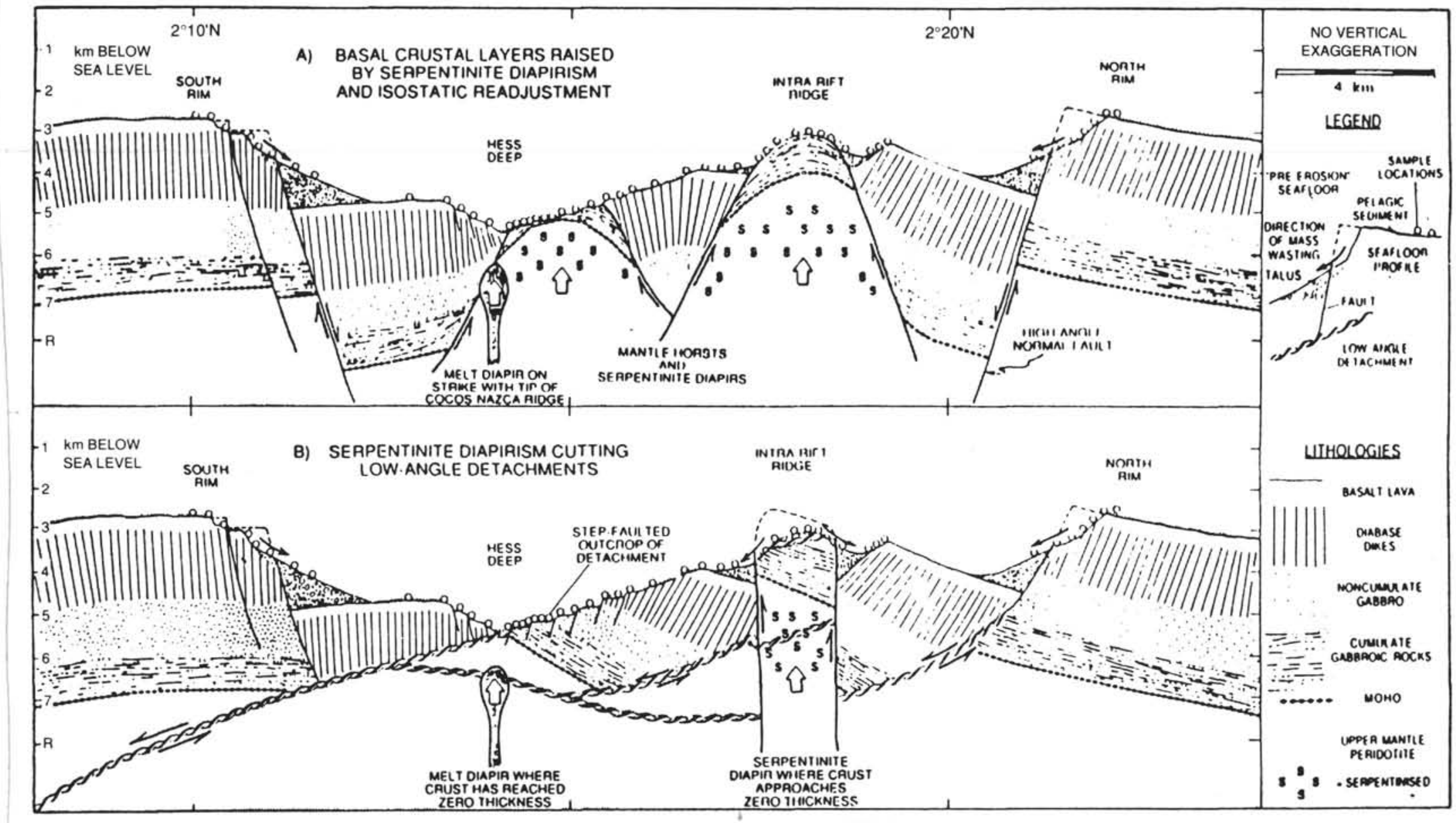

Figure 4. Interpretive cross sections depicting two models for the surficial geology and topography of the Hess Deep rift valley. Model A implies that the basal crustal layers have been raised by serpentine diapirism and isostatic readjustment. Model B invokes low-angle detachments with only restricted diapirism. Small open circles shown on the surface represent places where samples were taken. The models are drawn with no vertical exaggeration (Francheteau et al., 1990).

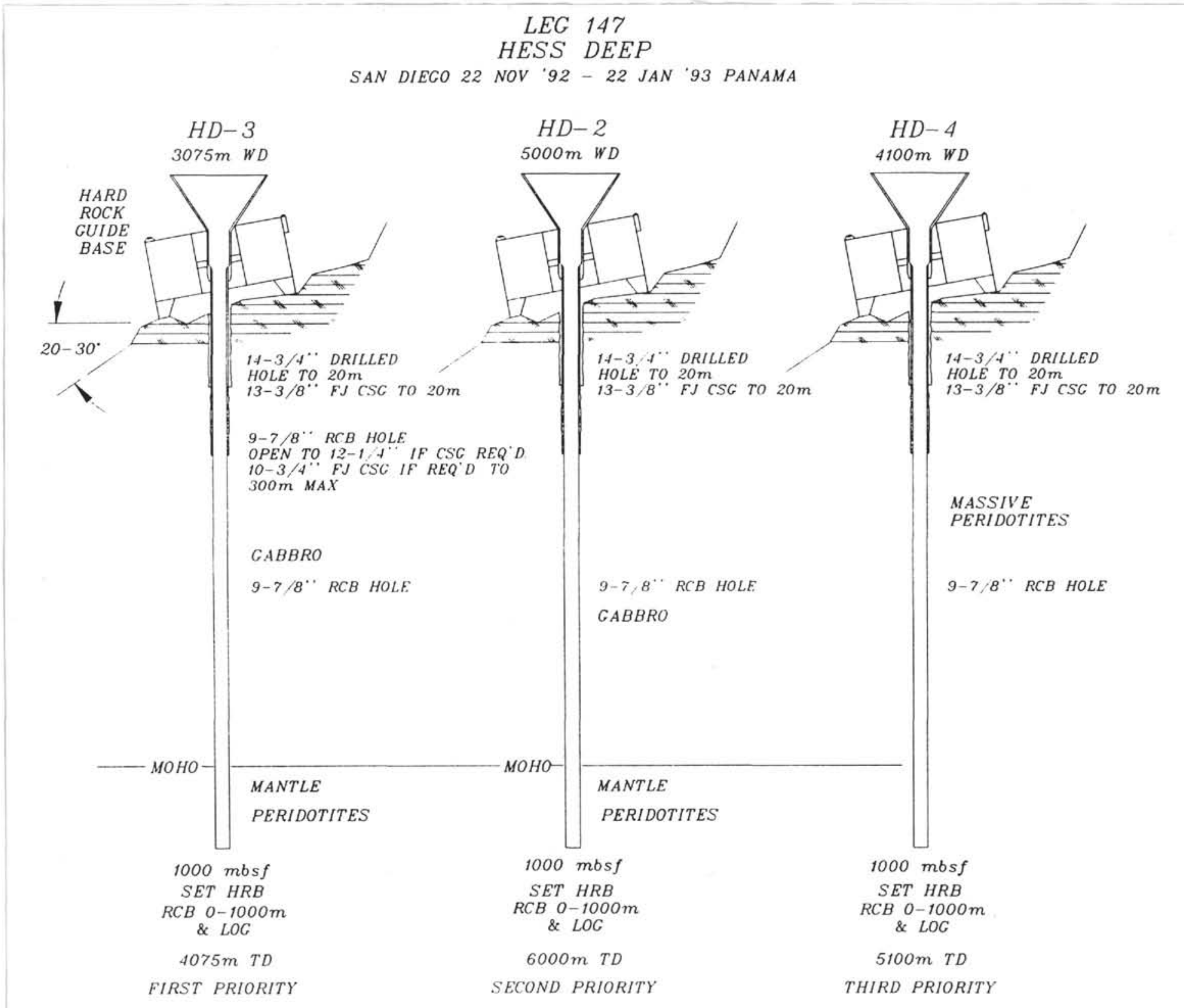

Figure 5. Schematic representation of the hard-rock guidebase operation during Leg 147.

Leg 147 Time Estimates

Primary Site:-

Site	Location Latitude	Location Longitude	Water depth (m)	Penetration (m)	Drill (days)	Log (days)	Total (days)	Transit (days)
San Diego	32°48'N	117°06'W						
								8.1
HD-3*	2°18'N	101°31.6'W	3075	500*	39.1	3.5	42.6	
								5.3
Panama	7°20.3'N	80°02'W						
		Subtotals =		500*	39.1	3.5	42.6	13.4
		Grand total =					**56.0 days at sea**	

Alternate Sites:

Site	Location Latitude	Location Longitude	Water depth (m)	Penetration (m)
HD-2	2°15.2'N	101°33'W	5000	500*
HD-4	2°16.5'N	101°27'W	4100	500*

* If HD-3 is satisfactory, it will be cored as deep as time permits. In the event that HD-3 is not satisfactory geologically or for technical reasons, the guidebase will be moved to another location in the HD-3 survey area, the new area will be surveyed, and drilling will commence. This procedure will continue until a hole is initiated and core is recovered. In the event that no suitable location can be found at the HD-3 site or that HD-3 does not meet the scientific objectives of the leg, the ship will proceed to HD-2, and the same site survey plan will be followed. Similarly, if drilling problems are encountered at HD-2 or if the scientific objectives of the leg cannot be met at HD-2, the ship will move to HD-4.

Note: transit times are calculated for a speed of 10.5 kt.

Site : HD-3
Priority : 1
Position: 2°18.0'N, 101°31.6'W
Water depth : 3075 m
Sediment thickness : none

Background information: Complete SeaBeam coverage (F/S *Sonne* , H. Puchelt, unpubl., data, and *Atlantis II*, P. Lonsdale, unpubl. data). Multichannel seismic profile along rift-valley scarps (Zonenshain et al., 1980). F/S *Sonne* (H. Puchelt, unpubl., data) and *Atlantis II* dredges (P. Lonsdale, unpubl. data). 22 *Nautile* dives along rift-valley floor and walls of valley: 5 dives in vicinity of drill site (Francheteau et al., 1990). On-bottom gravity and seismics (R/V , Dorman and Hildebrand, unpublished data).

Proposed drilling program: After a camera survey of the seafloor to select a target area, deploy the guidebase and drill a hole to 1000 mbsf with a conventional rotary bit.

Logging: (1) Standard logging suite (formation micro scanner, quad-combo, geochemical); (2) digital borehole televiewer (BHTV); (3) vertical seismic profile (VSP); (4) magnetic susceptibility (depending on tool availability).

General objective: Recover a long continuous section of the lower level plutonics and possibly the transition across the petrological Moho into the mantle peridotites. Such a section will allow characterization of the igneous, metamorphic, and structural evolution of the lower crust and upper mantle generated at a fast-spreading ridge, as well as the vertical variations in physical and magnetic properties.

Nature of rock anticipated: Massive plutonics and, possibly, massive, more or less serpentinized peridotites. Possible faulting, particularly at the petrologic Moho transition.

Special Requirement: Bare-rock guidebase.

Site: HD-2
Priority: 2
Position: 2°15.2'N, 101°33'W
Water depth: 5000 m
Sediment thickness: none

Background Information: Complete SeaBeam coverage (F/S *Sonne*, H. Puchelt, unpubl., data and *Atlantis II*, P. Lonsdale, unpubl. data). Multichannel seismic profile along rift-valley scarps (Zonenshain et al., 1980). F/S *Sonne* (H. Puchelt, unpubl., data) and *Atlantis II* dredges (P. Lonsdale, unpubl. data). 22 *Nautile* dives along rift-valley floor and walls of valley: 5 dives in vicinity of drill site (Francheteau et al., 1990). On-bottom gravity and seismics (R/V *Thomas Washington*, Dorman and Hildebrand, unpublished data).

Proposed drilling program: After a camera survey of the seafloor to select a target area, deploy the guidebase and drill a hole to 1000 mbsf with a conventional rotary bit.

Logging: (1) Standard logging suite (formation micro scanner, quad-combo, geochemical); (2) digital borehole televiewer (BHTV); (3) vertical seismic profile (VSP); (4) magnetic susceptibility (depending on tool availability).

General objective: Recover a long continuous section of the lower level plutonics and possibly the transition across the petrological Moho into mantle peridotites. Such a section will allow characterization of the igneous, metamorphic, and structural evolution of the lower crust and upper mantle generated at a fast-spreading ridge, as well as the vertical variations in physical and magnetic properties.

Nature of rock anticipated: Massive plutonics and, possibly, massive, more or less serpentinized peridotites. Possible faulting, particularly at the petrologic Moho transition.

Special Requirement: Bare-rock guidebase.

Site: HD-4
Priority: 3
Position: 2°16.5'N, 101°27.0'W
Water depth : 4100 m
Sediment thickness: none

Background information: Complete SeaBeam coverage (F/S *Sonne*, H. Puchelt, unpubl., data and *Atlantis II*, P. Lonsdale, unpubl. data). Multichannel seismic profile along rift-valley scarps (Zonenshain et al., 1980). F/S *Sonne* (H. Puchelt, unpubl., data) and *Atlantis II* dredges (P. Lonsdale, unpubl. data). 22 *Nautile* dives along rift valley floor and walls of valley: 5 dives in vicinity of drill site (Francheteau et al., 1990). On-bottom gravity and seismics (R/V *Thomas Washington*, Dorman and Hildebrand, unpublished data).

Proposed drilling program: After a camera survey of the seafloor to select a target area, deploy the guidebase and drill a hole to 1000 mbsf with a conventional rotary bit.

Logging: (1) Standard logging suite (formation micro scanner, quad-combo, geochemical) ; (2) digital borehole televiewer (BHTV) ; (3) vertical seismic profile (VSP); (4) magnetic susceptibility (depending on tool availability).

General objective: Recover a section of the transition zone across the petrological Moho into the mantle peridotites to characterize the petrology and deformation of the transition zone and upper mantle generated at a fast-spreading ridge, as well as their physical and magnetic properties.

Nature of rocks anticipated: Massive plutonics and massive, more or less serpentinized peridotites.

Special requirements: Bare-rock guidebase.

References

Bloomer, S.H., Meyer, P.S., Dick, H.B.J., Ozawa, K., and Natland, J.H., 1991. Textural and mineralogic variations in gabbroic rocks from Hole 735B. *In* Robinson, P.T., Von Herzen, R.P., et al., *Proc. ODP*, *Sci. Results*, 118: College Station TX (Ocean Drilling Program), 21-40.

Blum, N., 1991. Structure and composition of oceanic crust and upper mantle exposed in Hess Deep of the Galapagos microplate. PhD thesis, Universität Karslruhe, Germany, 218 pp.

Cannat, M., Mével, C., and Stakes, D., 1991. Normal ductile shear zones at an oceanic spreading ridge: tectonic evolution of the Site 735 gabbros (southwest Indian Ridge). *In* Robinson, P.T., and Von Herzen, R.P., et al., *Proc. ODP, Sci. Results*, 118: College Station TX (Ocean Drilling Program), 415-430.

Casey, J.F., Rowley, M., Xia, C., and Kurz, M., 1990. Lower crustal rheology, strain localization, low-angle seismic reflectors and deep hydrothermal penetration in near-ridge environments. *Eos,* 71:629.

Crane, K., 1985. The spacing of rift axis highs: dependence upon diapiric processes in the underlying asthenosphere. *Earth Planet. Sci. Lett.,* 72:405-414.

Detrick, R.S., 1991. Ridge crest magma chambers : A review of results from marine seismic experiment at the East Pacific Rise. *In* Peters, Tj., Nicolas, A., and Coleman, R.G. (Eds.), *Ophiolite Genesis and Evolution of the Oceanic Lithosphere*: Kluwer Academic Publishers, 7-20.

Detrick, R.S. and Purdy, G.M., 1980. The crustal structure of the Kane Fracture Zone from seismic refraction studies. *J. Geophys. Res.*, 85:3759-3777.

Dick, H.J.B., Gillis, K., and Lonsdale, P., 1990. Deep crustal drilling in fast-spreading crust at the Hess Deep. *JOIDES Drilling Proposal*, 375/D: Austin, TX (JOIDES Office).

Dick, H.J.B., Meyer, P.S., Bloomer, S., Kirby, S., Stakes, D., and Mawer, C., 1991. Lithostratigraphic evolution of an *in-situ* section of oceanic layer 3. *In* Robinson, P.T., and Von Herzen, R.P., et al., *Proc. ODP, Sci. Results*, 118: College Station TX (Ocean Drilling Program), 439-496.

Francheteau, J., Armijo, R., Cheminee, J.L., Hekinian, R., Lonsdale, P., and Blum, N., 1990. 1 Ma East Pacific Rise oceanic crust and uppermost mantle exposed by rifting in Hess Deep (equatorial Pacific Ocean). *Earth Planet. Sci. Lett.*, 101:281-295.

Francheteau, J. Armijo, R., Cheminée, J.L., Hekinian, R., Lonsdale, P., and Blum, N., 1992. Dyke complex of the East Pacific Rise exposed in the walls of Hess Deep and the structure of the upper oceanic crust. *Earth Planet. Sci. Lett.*, 111:109-121.

Gillis, K.M., Dick, H.B.J., Lonsdale, P., and Natland, J., 1990. Deep crustal drilling in fast-spreading crust at the Hess Deep. *JOIDES Drilling Proposal*, 387/E revised: Austin, TX (JOIDES Office).

Huang, P.Y., and Solomon, S.C., 1988. Centroid depths of mid-ocean ridge earthquakes: Dependence on spreading rate. *J. Geophys. Res.,* 93:13,445-13,477.

Karson, J., Thompson, G., Humphris, S.E., Edmond, J., Bryan, W.B., Brown, J.R., Winters, A.T., Pockalny, R.A., Casey, J., Campbell, A.C., Klinkhammer, G.P., Palmer, M.R., Kinzler, R.J., and Sulanowska, M.M., 1987. Along-axis variations in seafloor spreading in the MARK area. *Nature,* 328:681-685.

Lin, J., Purdy, G.M., Schouten, H., Sempéré, J.-C., and Zervas, C., 1990. Evidence from gravity data for focussed magmatic accretion along the Mid-Atlantic Ridge. *Nature,* 344:627-632.

Lonsdale, P., 1988. Structural pattern of the Galapagos microplate and evolution of the Galapagos triple junction. *J. Geophys. Res.*, 93:13,551-13,574.

Lonsdale, P., 1989. The rise-flank trails of migrating offsets of the equatorial East Pacific Rise, *J. Geophys. Res.*, 94:251-293.

McCarthy, J., Mutter, J.C., Morton, J.L., Sleep, N.H., and Thompson, G.A., 1988. Relic magma chamber structures preserved within the Mesozoic North Atlantic crust? *Geol. Soc. Am. Bull.*, 100:1423-1436.

MacDonald, K., 1987. Tectonic evolution of ridge-axis discontinuities by the meeting, linking or self-decapitation of neighboring ridge sediments. *Geology*, 15:993-997.

Mével, C., and Cannat, M., 1991. Lithospheric stretching and hydrothermal processes in oceanic gabbros from slow-spreading ridges. *In* Peters, Tj., Nicolas, A., and Coleman, R.G. (Eds.), *Ophiolite Genesis and Evolution of the Oceanic Lithosphere*:: Kluwer Academic Publishers, 293-312.

Neprochnov, Y.P., Sedov, V.V., Semenov, G.A., Yelnikov, I.N., and Filaktov, V.D., 1980. The crustal structure and seismicity of the Hess Basin area in the Pacific Ocean. *Oceanology*, 20:317-322.

Pallister, J.S., and Hopson, C.A., 1981. Samail ophiolite plutonic sequence: Field relations, phase variation, cryptic variation and layering, and a model of a spreading ridge magma chamber. *J. Geophys. Res.*, 86:2593-2644.

Sempéré, J.-C., Purdy, G.M., and Schouten, H., 1990. Segmentation of the Mid-Atlantic Ridge between 24° N and 30°40' N. *Nature*, 344:427-431.

Sinton, J., and Detrick, R., 1992. Mid-Ocean ridge Magma chambers. *J. Geophys. Res.*, 97:197-216.

Stakes, D., Mével, C., Cannat, M., and Vanko, D., 1991. Metamorphic stratigraphy of Hole 735B. *In* Robinson, P.T. and Von Herzen, R.P., et al., *Proc. ODP, Sci. Results*, 118: College Station TX (Ocean Drilling Program), 153-180.

Toomey, D.R., Solomon, S.C., Purdy, G.M., and Murray, M.H., 1985. Microearthquakes beneath the median valley of the Mid-Atlantic ridge near 23° N: Hypocenters and focal mechanisms. *J. Geophys. Res.*, 90:5443-5458.

Whitehead, J.A., Dick, H.J.B., and Shouten, H., 1984. A mechanism for magmatic accretion under spreading centers. *Nature*, 312:146-148.

Workshop Participants, 1989. Drilling the Oceanic Lower Crust and Mantle: A Global Strategy for Exploring the Deep Oceanic Crust and Mantle in the 1990's. *JOI/USSAC Workshop Report, Woods Hole Oceanographic Institution Technical Report*: WHOI-89-39.

Zonenshain, L.P., Kogan, L.I., Savostin, L.A., Golmstock, A.J., and Gorodnitskii. A.M., 1980. Tectonics, crustal structure and evolution of the Galapagos Triple Junction. *Mar. Geol.*, 37:209-230.

Leg 147 Participants

Co-Chief Scientist:	Kathryn Gillis Department of Geology and Geophysics Woods Hole Oceanographic Institution Woods Hole, Massachusetts 02543
Co-Chief Scientist:	Catherine Mével Laboratoire de Petrologie C.N.R.S. URA 736 Université Pierre et Marie Curie 4 place Jussieu T26, E3 75252 Paris cedex 05 France
Staff Scientist:	Jamie Allan Ocean Drilling Program 1000 Discovery Drive Texas A&M University Research Park College Station, Texas 77845-9547
Physical Properties Specialist:	Gerardo J. Iturrino Rosenstiel School of Marine and Atmospheric Science Division of Marine Geology and Geophysics 4600 Rickenbacker Causeway Miami, Florida 33149-1098
Geochemist/Petrologist:	Norbert Blum University of Karlsruhe Institut für Petrographie und Geochemie Kaiserstr. 12 D-7500 Karlsruhe Federal Republic of Germany
Inorganic Geochemist:	Trevor J. Falloon Geology Department University of Tasmania GPO Box 252C Hobart, Tasmania 7001 Australia
Petrologist:	Shoji Arai Department of Earth Sciences Kanazawa University Kakuma, Kanazawa 920-11 Japan

Petrologist:	Hazel M. Prichard The Open University Department of Earth Science Walton Hall Milton Keynes, MK7 6AA United Kingdom
Igneous Petrologist:	Henry Dick Department of Geology and Geophysics Woods Hole Oceanographic Institution Woods Hole, Massachusetts 02543
Igneous Petrologist:	Jim Natland Rosenstiel School of Marine and Atmospheric Science Division of Marine Geology and Geophysics 4600 Rickenbacker Causeway Miami, Florida 33149-1098
Igneous Petrologist:	John Malpas Department of Earth Sciences Memorial University St. John's, Newfoundland A1B 3X5 Canada
Igneous Petrologist:	Rolf-Birger Pedersen Geological Institute University of Bergen Alleg. 41 N-5007 Norway
Igneous Petrologist:	TO BE NAMED
Metamorphic Petrologist:	Gretchen Früh-Green Inst. for Mineralogy and Petrology ETH-Z, CH-8092 Zürich Switzerland
Metamorphic Petrologist:	Deborah S. Kelley Department of Geology and Geophysics Woods Hole Oceanographic Institution Woods Hole, Massachusetts 02543

Metamorphic Petrologist:	Craig Edward Manning Department of Earth and Space Sciences University of California, Los Angeles 405 Hilgard Avenue Los Angeles, California 90024-1567
Structural Geologist:	Françoise Boudier Université Montpellier 2 Laboratoire de Tectonophysique Place E. Bataillon 34095 Montpellier cedex 05 France
Structural Geologist:	Lori Anne Kennedy Center for Tectonophysics Texas A&M University College Station, Texas 77843-3113
Paleomagnetist:	Janet E. Pariso School of Oceanography University of Washington Seattle, Washington 98195
Paleomagnetist:	Eiichi Kikawa Department of Geophysics Texas A&M University College Station, Texas 77843-3114
Paleomagnetist:	TO BE NAMED
Physical Properties/ Geophysics VSP Specialist:	Mark A. McDonald Scripps Institution of Oceanography University of California, San Diego, 0205 La Jolla, California 92093
Physical Properties/ Magnetics Specialist:	Carl Richter Department of Geological Sciences University of Michigan 1006 C.C. Little Building Ann Arbor, Michigan 48109
JOIDES Logging Scientist:	Christopher J. MacLeod Institute of Oceanographic Sciences Brook Road, Wormley Godalming Surrey GU8 5UB United Kingdom

LDGO Logging Scientist:	Bernard Célérier Lamont-Doherty Geological Observatory Columbia University Palisades, New York 10964
Schlumberger Engineer:	David Ritz Schlumberger Offshore Services 369 Tri-Star Drive Webster, Texas 77598
Operations Superintendent:	Eugene Pollard Ocean Drilling Program 1000 Discovery Drive Texas A&M University Research Park College Station, Texas 77845-9547
Development Engineer:	Michael Storms Ocean Drilling Program 1000 Discovery Drive Texas A&M University Research Park College Station, Texas 77845-9547
Laboratory Officer:	Burney Hamlin Ocean Drilling Program 1000 Discovery Drive Texas A&M University Research Park College Station, Texas 77845-9547
Curatorial Representative:	Lorraine Southey Ocean Drilling Program 1000 Discovery Drive Texas A&M University Research Park College Station, Texas 77845-9547
Marine Computer Specialist/System Manager:	Matt Mefferd Ocean Drilling Program 1000 Discovery Drive Texas A&M University Research Park College Station, Texas 77845-9547
Marine Computer Specialist/System Manager:	TO BE NAMED Ocean Drilling Program 1000 Discovery Drive Texas A&M University Research Park College Station, Texas 77845-9547

Marine Laboratory Specialist/Yeoperson:	Michiko Hitchcox Ocean Drilling Program 1000 Discovery Drive Texas A&M University Research Park College Station, Texas 77845-9547
Marine Laboratory Specialist/Photography:	Barry Cochran Ocean Drilling Program 1000 Discovery Drive Texas A&M University Research Park College Station, Texas 77845-9547
Marine Laboratory Specialist/Chemistry:	Chieh Peng Ocean Drilling Program 1000 Discovery Drive Texas A&M University Research Park College Station, Texas 77845-9547
Marine Laboratory Specialist/Chemistry :	Philip Rumford Ocean Drilling Program 1000 Discovery Drive Texas A&M University Research Park College Station, Texas 77845-9547
Marine Electronics Specialist:	Roger Ball Ocean Drilling Program 1000 Discovery Drive Texas A&M University Research Park College Station, Texas 77845-9547
Marine Electronics Specialist:	Eric Meissner Ocean Drilling Program 1000 Discovery Drive Texas A&M University Research Park College Station, Texas 77845-9547
Marine Laboratory Specialist/XRF-XRD:	Mary Ann Cusimano Ocean Drilling Program 1000 Discovery Drive Texas A&M University Research Park College Station, Texas 77845-9547
Marine Laboratory Specialist:	"Gus" Gustafson Ocean Drilling Program 1000 Discovery Drive Texas A&M University Research Park College Station, Texas 77845-9547

Marine Laboratory Specialist/UWG-FMS:	Robert Kemp Ocean Drilling Program 1000 Discovery Drive Texas A&M University Research Park College Station, Texas 77845-9547
Marine Laboratory Specialist/Phys. Props.:	Jean Mahoney Ocean Drilling Program 1000 Discovery Drive Texas A&M University Research Park College Station, Texas 77845-9547
Marine Laboratory Specialist/Storekeeper:	Jeff Millard Ocean Drilling Program 1000 Discovery Drive Texas A&M University Research Park College Station, Texas 77845-9547
Marine Laboratory Specialist/FMS-SMT:	Don Sims Ocean Drilling Program 1000 Discovery Drive Texas A&M University Research Park College Station, Texas 77845-9547
Marine Laboratory Specialist/Magnetics:	Monica Sweitzer Ocean Drilling Program 1000 Discovery Drive Texas A&M University Research Park College Station, Texas 77845-9547
Marine Laboratory Specialist:	Claudia Muller Ocean Drilling Program 1000 Discovery Drive Texas A&M University Research Park College Station, Texas 77845-9547
Marine Laboratory Specialist:	Steve Maury Ocean Drilling Program 1000 Discovery Drive Texas A&M University Research Park College Station, Texas 77845-9547