OCEAN DRILLING PROGRAM

LEG 140 SCIENTIFIC PROSPECTUS

DEEPENING HOLE 504B

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This Scientific Prospectus is based on pre-cruise JOIDES panel discussions. The scientific and 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 or operationally 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 purpose of Leg 140 is to deepen Hole 504B, the deepest hole ever drilled into oceanic crust, through the dike/gabbro and/or layer 2/3 transition. Located in 5.9-m.y.-old crust, Hole 504B is perhaps the most important reference hole for the composition and structure of "normal" oceanic crust. It represents the best opportunity for sampling the transition between the sheeted dike complex and the underlying gabbros in the context of a complete crustal section.

Leg 140 is scheduled for 16 September to 12 November 1991. About 38 days on site will be devoted to downhole measurements, fishing operations, and coring. Logging (formation microscanner and temperature) will be completed before fishing for a core barrel dropped during Leg 137. Fishing operations should be straightforward and completed within 7 days. The remainder of the leg will be devoted to deepening Hole 504B. Within the last 3-4 days more downhole measurements, including gamma-ray, velocity, resistivity, density, borehole televiewer, geochemical, and permeability tests, will be made.

If unforeseen circumstances should require abandoning work at Hole 504B, the leg will pursue a backup program of drilling in Hess Deep.

INTRODUCTION

During Ocean Drilling Program Leg 140 (16 September to 12 November 1991), *JOIDES Resolution* will return to deepen Hole 504B in the eastern equatorial Pacific (Fig. 1), the deepest hole ever drilled into oceanic crust. The primary purpose of this leg is to core through the dike/gabbro and/or layer 2/3 transition.

Located in 5.9-m.y.-old crust formed at the Costa Rica Rift, Hole 504B presently extends over twice as deep into oceanic crust as any other hole and is the only DSDP/ODP borehole that unequivocally penetrates through the extrusive lavas into the sheeted dikes (Fig. 2). It therefore is perhaps our most important reference hole for the structure and composition of "normal" oceanic crust, and represents our best opportunity for sampling the transition between the sheeted dike complex and underlying gabbros in the context of a complete crustal section.

Leg 140 will be the seventh DSDP/ODP expedition to occupy Hole 504B. The hole was originally spudded during Leg 69 in 274.5 m of sediments overlying basaltic basement, and was then deepened and/or logged during parts of five other DSDP/ODP legs: 70, 83, 92, 111, and 137. These legs provided a wealth of scientific results, much of which is summarized by CRRUST (1982); Cann, Langseth, Honnorez, Von Herzen, White, et al. (1983); Anderson, Honnorez, et al. (1982, 1985); Leinen, Rea, et al. (1986); Becker, Sakai, et al. (1988, 1989a, 1989b); and Becker, Foss, et al. (in press).

Although previous coring, logging, and geophysical programs at Hole 504B achieved unprecedented scientific success, the operational history of the hole was marred by downhole hardware losses and disappointing rates of core recovery. As with all other deep drilling programs, these tendencies have increased with the depth of the hole. They were a particular problem during Leg 111, which experienced several premature bit failures, an overall core recovery rate of less than 13%, and the loss of a large-diameter diamond coring assembly at the end of the leg. Lack of time and proper equipment forced the temporary abandonment of the hole before the lost junk could be removed.

Recently Leg 137 achieved its primary objective, cleaning Hole 504B of the serious junk lost at the end of Leg 111. Operations throughout the leg showed no indication of the supposed problems with the casing, although a borehole televiewer inspection during the last day on site showed flaws with the lower 30-40 m of casing. Leg 137 clearly succeeded in demonstrating that Hole 504B can be advanced to the layer 2/3 transition.

This important success was tarnished by a frustrating inability to retrieve a much less serious piece of junk lost at the end of coring tests. This disappointment can be attributed to a defective fishing tool and a lack of time to procure and deploy any further appropriate tools, not to any difficult presentation of the junk itself. In fact, such tool losses and fishing jobs are not at all unusual in drilling any deep hole, and in this case it is virtually certain that the lost outer core barrel can readily be fished with the proper tool.

SUMMARY OF DSDP/ODP RESULTS FROM HOLE 504B[1]

Hole 504B is located about 200 km south of the Costa Rica Rift (Fig. 1) and presently extends through 274.5 m of sediment and 1347 m of basement, for a total penetration of 1621.5 m. The basement penetration is more than twice that of the second-best 583 m in Hole 332B in the Atlantic. Hole 504B is the only basement hole to have clearly penetrated through the extrusive pillow lavas and into the underlying sheeted dikes predicted from studies of ophiolites. The 1347 m of basement cored in Hole 504B consisted of 571.5 m of pillow lavas and minor flows, underlain by a 209-m zone of transition into 566.5 m of sheeted dikes and massive units (Fig. 2). The lithostratigraphy was determined from a core recovery averaging only about 20% (25% in the pillows, 10-15% in the dikes); it was generally corroborated by an extensive suite of geophysical logs, except that the logs suggested a sharper transition between the pillows and dikes. To date, the lithostratigraphy sampled in Hole 504B is the best direct verification of the ophiolite model of the oceanic crust. However, this verification is only partial, as the lowermost 3-4 km of oceanic crust has never been sampled *in situ*.

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[1]This summary is based upon literature listed in an appended bibliography.

Site survey seismics, heat-flow measurements, downhole temperature (Fig. 3), porosity, and permeability data indicate that the crust at Site 504 is at a particularly interesting stage in its evolution: At a relatively young crustal age, the thick, even sediment cover has mostly sealed the basement against pervasive hydrothermal circulation, and crustal temperatures vary closely about values consistent with predicted, conductive plate heat transfer. Recent detailed heat flow work and numerical simulations indicate that convection still occurs in the permeable, uppermost 500 m of basement beneath the impermeable sediment cover, partly controlled by the presence of isolated basement faults and topographic highs.

The basement rocks recovered from Hole 504B are fine- to medium-grained, plagioclase-olivine $\pm$ clinopyroxene $\pm$ chrome spinel, phyric basalts, with aphyric types more abundant with depth. All of the recovered basalts are mineralogically and chemically altered to some extent. Detailed studies of the downhole variation of secondary minerals and mineral assemblages document the existence of three major alteration zones (Fig. 4):

1. An upper alteration zone in the pillows (274.5-584.5 mbsf) displaying typical effects of oxidative alteration commonly observed in DSDP holes.
2. A lower alteration zone in the pillows (584.5-836 mbsf) that was presumably produced by reactions with low-temperature suboxic to anoxic solutions at low water/rock ratios. This zone is characterized by smectite and pyrite.
3. A high-temperature alteration zone (898-1621.5 mbsf) that produced the first *in-situ* samples of ocean floor basalt containing greenschist-facies alteration minerals.

The pronounced changes in alteration mineralogy observed from 836 to 898 mbsf are interpreted to have resulted from a steep temperature gradient between low-temperature (<100°C) alteration solutions circulating in the pillow lavas and very high-temperature fluids (>300°C) that affected the lower part of basement at the site. The transition between pillow lavas and underlying dikes corresponds closely to the transition from low- to high-temperature alteration, because the bulk permeability and porosity of the dikes are orders of magnitude lower than in the pillows.

In the deepest 200 m of dikes the recovered core is only slightly altered, and actinolite and magnetite become relatively more abundant. Plagioclase is less altered than pyroxene, which is commonly recrystallized to actinolite, in contrast to the dikes above, where plagioclase is more extensively recrystallized than clinopyroxene. These observations suggest that the temperature of alteration may have been higher in the deepest 200 m, where conditions may have approached the "lower actinolite facies."

Despite the effects of alteration, the primary composition and variation of the recovered basalts can be reliably established. The lavas and dikes recovered from Hole 504B are remarkably uniform in composition. Their high MgO contents (up to 9.8 wt%)

and very low abundances of K (0.02%) classify these basalts as olivine tholeiites. Judging from their high Mg values (0.60 to 0.75), the basalts appear to have undergone only limited high-level crystal fractionation.

Hole 504B has been surveyed with the most extensive suite of *in-situ* geochemical and geophysical experiments in any submarine borehole. The geophysical data indicate that the *in-situ* physical properties of the crust change dramatically across the transition from pillow lavas to sheeted dikes: *in-situ* sonic and seismic velocities and electrical resistivity increase sharply, while bulk porosity and permeability drop by orders of magnitude. These measurements demonstrate that the velocity structure of layer 2 at the site is controlled by variations in porosity with depth. The sonic and seismic data are generally consistent with a sharp layer 2B/2C boundary at the top of the sheeted dikes. The sonic data, but not the much longer-wavelength seismic data, indicate a thin layer 2A, consisting of the uppermost 100-200 m of highly porous pillow lavas. This layer corresponds to a highly permeable, underpressured zone into which ocean bottom water has been drawn since the hole was drilled (Fig. 3). Layer 2B comprises the lowermost 500 m of pillows, in which the original porosity has been partially sealed by alteration products.

A vertical seismic profile conducted during Leg 111 indicates that the next major transition lies 100-300 m deeper than present total depth. This is the transition between the sheeted dikes of seismic layer 2C and the gabbros of seismic layer 3, which has never been sampled *in-situ*. Drilling this boundary may be within reach of Leg 140 operations and is its primary purpose.

OPERATIONS PLAN

Leg 140 is scheduled to leave Victoria, B.C., on 16 September 1991 and return to Panama City on 12 November 1991. The schedule includes a 17-day transit to Hole 504B, ~1 week to clean out the fish, 3-4 weeks to core ahead 300-400 m, 4 days of logging, and 2 days' transit to Panama. In the event that Hole 504B cannot be cleaned out, the alternate program is to go to the Hess Deep site (4.5 days transit), install a guide base, core as time permits, and transit to Panama (6.0 days).

The primary objective of Leg 137 was to prepare Hole 504B for coring during Leg 140 by cleaning out fill and junk left in the hole during Leg 111. After milling, the hole was reamed and drilled 9 m to 1570 mbsf using a tricone drill bit. Coring with both rotary (RCB) and Christensen (large-diameter diamond bit) systems further deepened the hole to 1621.5 mbsf. Unfortunately, when the last Christensen core barrel was pulled from the hole, the outer barrel and attached diamond bit were left in the hole. In an attempt to retrieve this fish, part of the overshot grapple broke off and was left like a collar around the outer core barrel (Fig. 5). Attempts to retrieve this compound fish were unsuccessful because of time limitations and the absence of necessary fishing equipment.

The part of the overshot grapple that was retrieved indicates that the top of the outer core barrel is smooth and flat and should therefore be recoverable within 5 days of fishing. If the core barrel, overshot grapple, and diamond bit cannot be fished, they can be milled within 6 days.

Leg 137 demonstrated that Hole 504B can be cored using RCB bits at a penetration rate of 1.0-1.5 m/hr, and with recovery in the range of 10-15%. Although recovery was better (50%) using the Christensen core barrel and diamond bits, it would take an unacceptably long time to deepen the hole. During Leg 137, penetration with the Christensen core barrel was limited to 2 m per round trip of the drill string. This is because cores cut using Christensen core barrels are retrieved by pulling the entire drill string back on board--the cores are not retrieved by wireline. The diamond bits used with the Christensen core barrel were made of the hardest matrix material available, but were worn smooth after only 2 hr of rotation.

For Leg 140, the RCB system will be used exclusively. Operations on Leg 140 will employ RCB bits specially hardened to increase rotating time from 15 to 20-30 hr per bit. In this way, we plan to continuously core 300-400 m deeper in Hole 504B in the time available, with acceptable levels of core recovery inferred from past experience.

CONTINGENCY PLAN

If unforeseen circumstances should require us to abandon work at Hole 504B, Leg 140 will pursue a program of drilling deep oceanic crust exposed at the Hess Deep, as outlined in the appended contingency drilling plan. Should a decision have to be made to move to Hess Deep, it will be made jointly by the Co-Chief Scientists and Operations Superintendent on board together with the Science Operator at ODP/TAMU and the JOIDES Office.

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Table 1. Proposed schedule for Leg 140.

		(days)
1.	Transit Victoria to Hole 504B	17.0
2.	Position ship, run in hole with reentry/cleanout bit, reenter	0.5
3.	Run FMS and temperature logs	0.5
4.	Run in hole, clean out to top of fish, pull out of hole	0.5
5.	Run in hole with lead impresion block, spear or taper tap. Attempt to engage fish, pull out of hole	1.0
6.	Additional fishing if required to recover fish	3.5
7.	Decision to continue fishing or milling at 504B or go to Hess Deep (step 15)	
8.	Milling fish at 504B if required	6.0
9.	Move to Hess Deep if not coring 504B (step 15)	
10.	Coring 504B	21.0

Meters/RCB Bit == 20 rotating hours x 1.3 m/hr avg == 26 m/bit
Cores/RCB Bit == 26 m/bit / 9.5 M/core = 3 cores/bit
Hours/RCB Bit == 10 hr RIH + 20 hr core + [3 cores x 1.5 hr/core wireline] + 7.5 POOH == 42 hr/bit
To core 300 m == (300 m / 26 m/core) x 42 hr/bit == 21 days

11.	Run in hole with reentry bit and dual packer for logs/test	0.5
12.	Log w/ quad combo, BHTV, DLL, FMS and geochem	2.0
13.	Packer flow test, NaBr pill, pull out of hole	1.0
14.	Transit to Panama	2.0
	Hole 504B, total days at sea	57.0

Contingency program for Hess Deep:

15.	Transit from Hole 504B to Hess Deep	4.5
16.	Run drill pipe and TV, check bottom for location	0.5
17.	Pull drill pipe, run hard-rock guide base + 10 m of 16-inch casing	1.0
18.	Core and log Hess Deep with 9-7/8-inch RCB	as time permits
19.	Transit to Panama	6.0

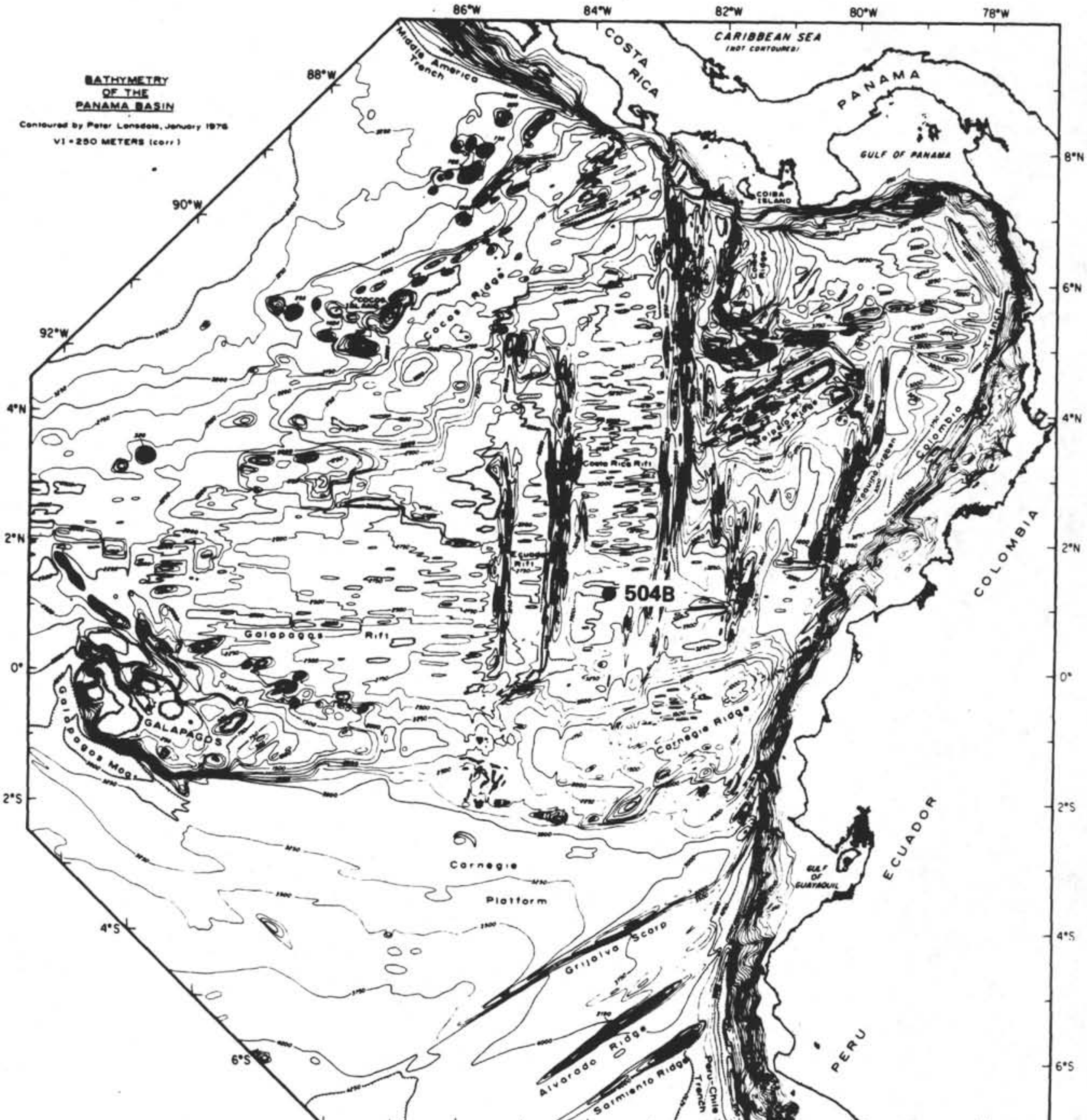

Figure 1. Location of Hole 504B south of the Costa Rica Rift in the eastern equatorial Pacific Ocean. From Lonsdale and Klitgord (1978).

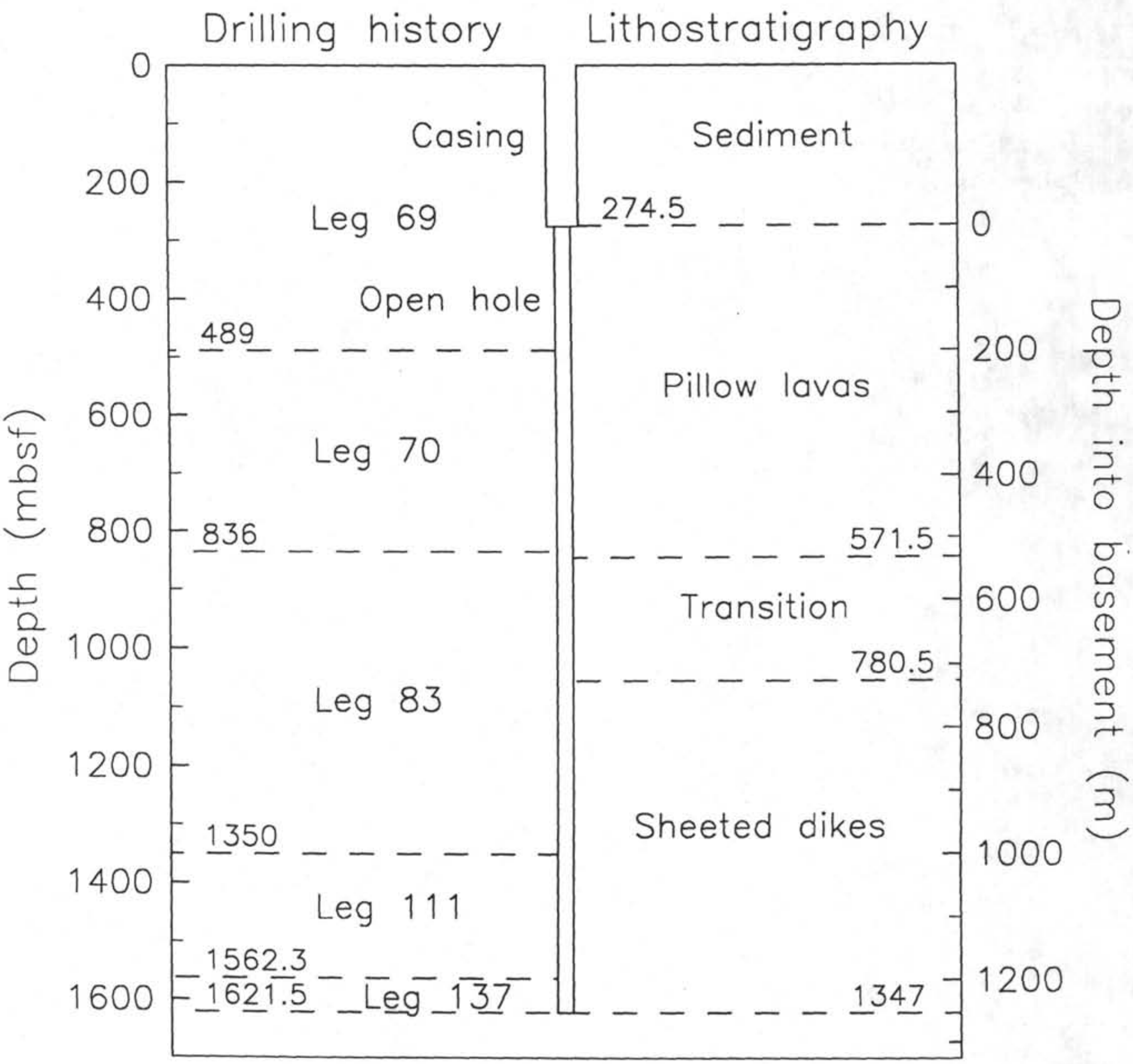

Figure 2. Schematic of drilling history and lithostratigraphy of Hole 504B as of the end of Leg 137.

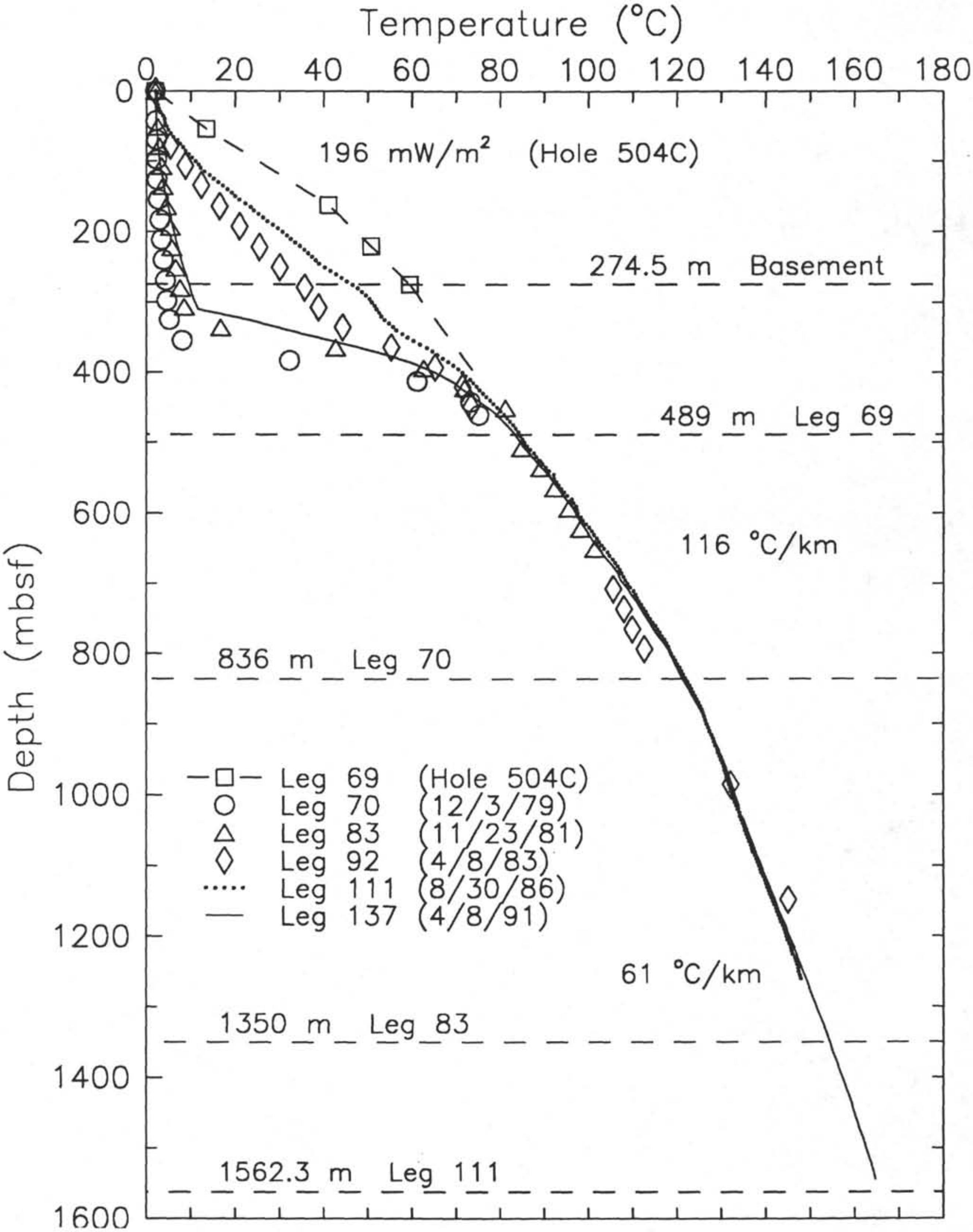

Figure 3. Composite of temperature logs obtained in Hole 504B during Legs 69, 70, 83, 92, 111, and 137.

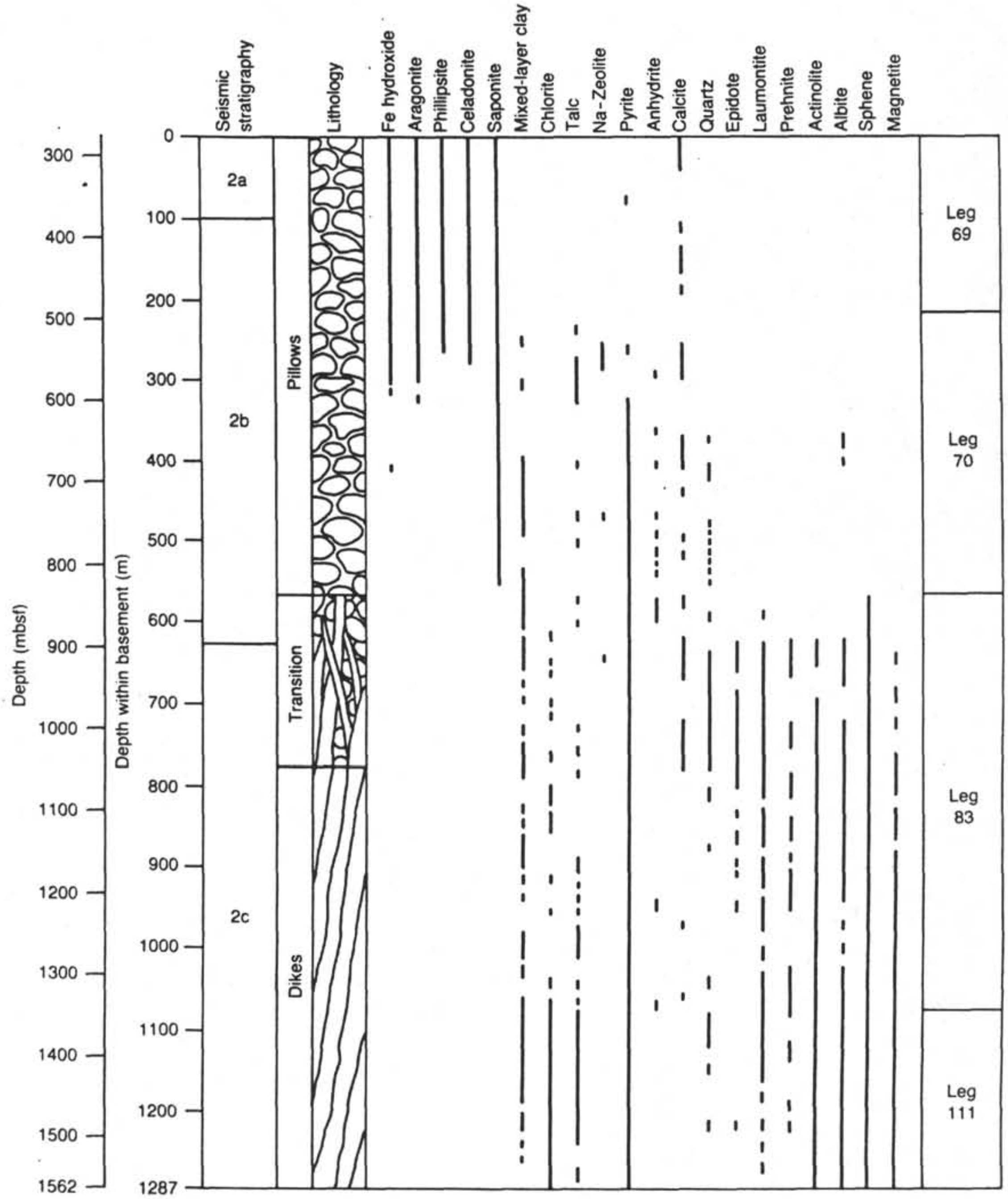

Figure 4. Distribution of secondary minerals with depth in Hole 504B. Seismic stratigraphy is based upon sonic logs collected during Leg 83. From Becker, Sakai et al. (1989a).

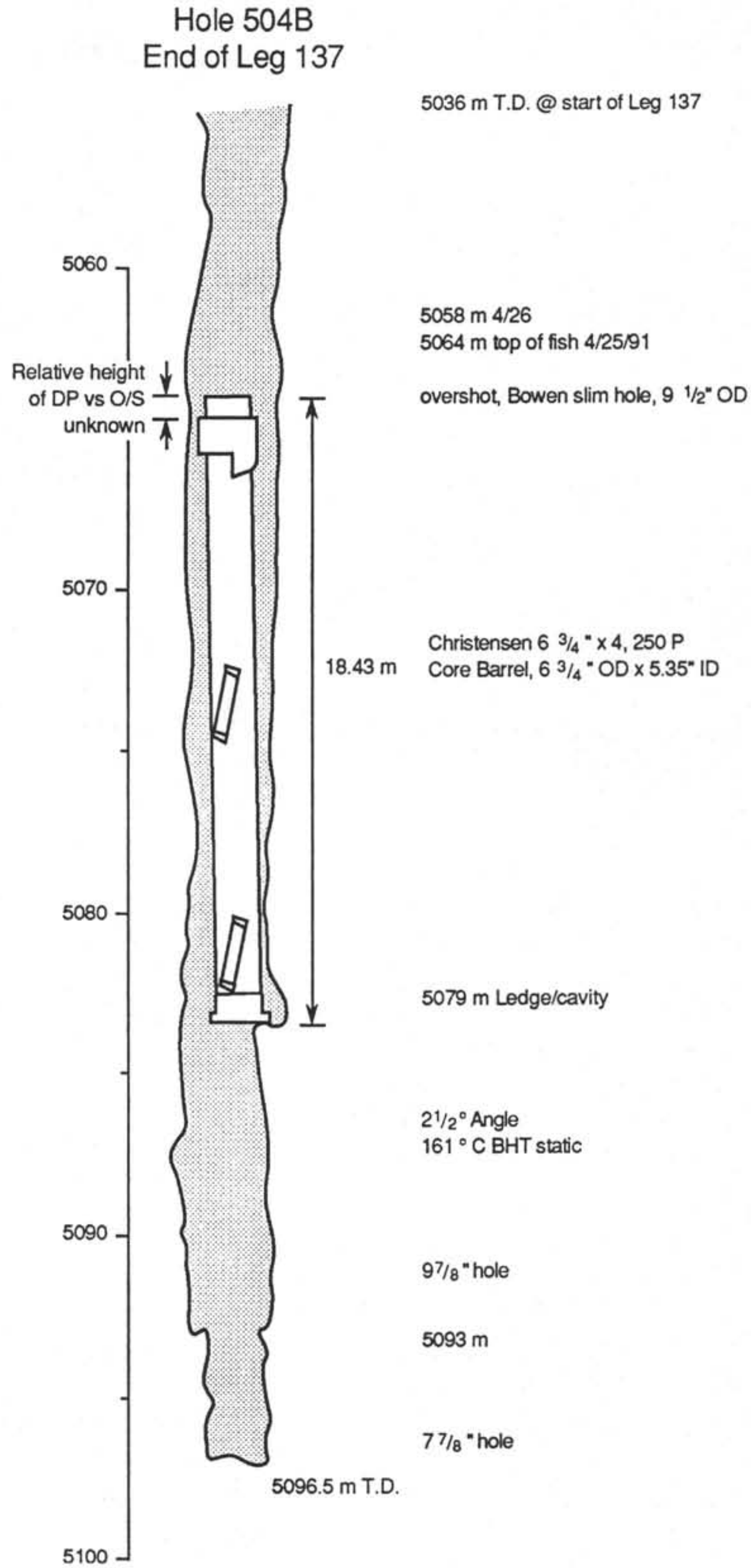

Figure 5. Schematic diagram of the inferred position of the Christensen core barrel and Bowen overshot grapple, which constitute the "fish" left in the hole at the end of Leg 137. The grapple has probably slid down the outer surface of the core barrel some distance. It is impossible to tell for certain the position of the overshot grapple relative to the top of the core barrel, but ribs on the outside of the core barrel restrict the grapple's position to the top 8 m of the core barrel. DP = drill pipe (Christensen core barrel); O/S = overshot.

Site: DSDP Hole 504B **Priority**: 1

Position: 1°13.611'N, 83°43.818'W
Sediment Thickness: 274.5 m
Water Depth: 3475 m

Proposed Drilling Program: Reenter existing reentry cone, then complete fishing operations. RCB core into basement to deepen through the layer 2/3 transition. At the end, flush the hole and spike it with one hole volume of NaBr solution.

Logging: Before fishing/coring, run formation microscanner and temperature logs. After coring, run quad combo (gamma-ray, velocity, resistivity, density/porosity), digital borehole televiewer, dual laterolog, formation microscanner, and geochemical combination in newly drilled section. Then test permeability with a combined flowmeter-pressure-caliper tool.

Objectives: Coring through the layer 2/3 transition.

Nature of Rock Anticipated: Basalt (sheeted dikes) and gabbro.

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APPENDIX
DEEP CRUSTAL DRILLING IN FAST-SPREADING CRUST EXPOSED AT HESS DEEP

Introduction

In the Hess Deep, 1.2-Ma East Pacific Rise (EPR) lower crust has been exposed by the westward propagation of the Costa Rica Rift (Francheteau et al., 1990). These exposures offer a unique opportunity to sample lower ocean crust and shallow mantle formed at a fast-spreading ridge and to test different models for the igneous and tectonic evolution of the ocean crust. As a consequence, a long-term program of drilling at the Hess Deep has been proposed to sample a crustal section, from the lavas down to the shallow mantle, formed at the fast-spreading EPR. This would be accomplished by drilling partial offset sections within various tectonic blocks exposing different levels of the ocean crust and mantle in and along the walls of the deep (c.f. proposals by Dick, Gillis, and Lonsdale, 1989; Gillis, Dick, Lonsdale, and Natland, 1990). Whereas a number of sites have been identified to fulfill this objective based on *Nautile* and *Alvin* dives at the Hess Deep, an initial visit by the drill ship has more limited objectives: (1) to obtain the first long continuous core of gabbroic layer 3 formed beneath a fast-spreading ridge for comparison to gabbroic layer 3 drilled at the slow-spreading Southwest Indian Ridge (Hole 735B), (2) to test the feasibility of drilling the tectonic blocks in the Hess Deep, and (3) to drill a hole through the gabbroic layer 3/mantle boundary (petrologic MOHO).

Regional Setting of the Hess Deep

Hess Deep is the deepest segment of a westward-propagating oceanic rift valley opening up the eastern flank of the equatorial EPR in advance of the westward-propagating Cocos-Nazca spreading center (Lonsdale, 1988) (Fig. A-1). The western end of the rift valley is located 30 km from the EPR axis where ~0.5-Ma EPR crust is broken by two 5-km-wide east-west grabens, which join a few kilometers fuarther east (Fig. A-2). As the rift valley is traced eastward, it broadens to 20 km and deepens to >5400 m, while its uplifted shoulders rise to depths greater than 2200 m. Approximately 70 km east of the EPR axis, the Cocos-Nazca spreading center begins to build a volcanic ridge on the rift valley floor, 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 spreading center (50 mm/yr total), and the rift escarpments develop into the "rough-smooth boundary" of the Galapagos gore.

The Hess Deep rift valley is propagating into a random section 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 rapid, with 3250 m of relief created as the rift propagated 30 km over 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 rocks exposed near fracture zones. 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 nontransform 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 0.5-1.0 Ma EPR crust. Rocks observed on these scarps appear to have been freshly exposed and are not encrusted with Mn 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, ~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 Hess Deep. Abyssal hill lineations generally extend up to the scarp except in the area of the rift shoulder horst, where the crustal block has been rotated. Multichannel reflection profiling along the EPR flanks indicates that 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) (Zoneshain 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. A-2).

The northern, south-facing scarp was extensively studied during a series of *Alvin* dives northeast of the Hess Deep where extreme uplift of ~1.2-Ma Pacific-Cocos crust has created a 1.5-km wide rift-shoulder horst whose summit is at 1650 m depth. On the south side of the horst, the talus ramp intersects the scarp near the top of layer 3 at 3200 m depth. The overlying sheeted dike complex is ~1.2 km thick. Mass wasting has left dikes or groups of dikes projecting as walls or ridges out of the cliff face with a mean gradient of 50°-60°. The overlying carapace of eruptive rocks (pillow lavas and interlayered sheet flows) is only 200-300 m thick and highly fractured. On the southern, north-facing rift valley wall, talus ramps extend up into the dike section, and no gabbroic rocks are exposed. The sheeted dike and volcanic sections and the nature of the exposure are comparable to the northern wall.

The floor of the Hess Deep rift valley was investigated during the October 1988 dive series with *Nautile* (Fig. A-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 and between 4500 and 3500 m depth; semihorizontal ledges of dolerite occur in a mainly sedimented terrain higher up. A change in slope marks the southern edge of the east-west trending intra-rift ridge. At the western end of this ridge, the southern and northern slopes are covered with numerous gabbroic outcrops. Farther 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°. Crspinel-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. A-3).

Prospective Drill Sites

A 5-6 km long, 15°-20° slope separates the Hess Deep and the intra-rift ridge (Area 1, Fig. A-2). Along this slope, there is a consistent change in lithology, which suggests that this slope is a coherent, tilted fault block. At ~4500 m depth there is a change in lithology, with basalts and diabases exposed to the north and plutonic and ultramafic rocks to the south. The plutonic and ultramafic rocks include isotropic, two-pyroxene gabbros, layered olivine gabbros, and serpentinized peridotites. Some samples are mylonitized, and locally the distribution of rock types is mixed. Two alternative drilling sites are located in this area.

Hess Deep 2: HD-2 is located south of the intra-rift ridge and north of Hess Deep to the south of HD-3 (2°15.2' N, 101°33' W; 5000 m depth, Fig. A-3). Massive, subhorizontal gabbro outcrops are exposed along a 15-20° slope and are 100-200 m in size. The plutonic rocks should be relatively unfractured and quite drillable; it is possible that the MOHO is structurally complicated and may be difficult to drill. A bare-rock guide base is required. The principal objective is to recover a long continuous section of the lower-level plutonics and the transition across the MOHO into the shallow mantle.

If crustal models based on geophysical data are accurate, one might expect the lower portion of the plutonic sequence here to be similar to the continental layered intrusions, with large layered sequences characterized by rapid changes in lithology at centimeter scales, and superimposed longer wavelength changes that reflect melt fractionation. The igneous stratigraphy should also vary with the relative size and geometry of the chamber and crystal mush zone. If there is a large long-lived crystal mush zone beneath the EPR, rather than a large open magma chamber, the interval could consist largely of a monotonous sequence of isotropic gabbros. The presence of a long-lived melt body and underlying crystal mush zone would probably fix brittle-ductile transition at the roof of the small axial magma chamber. This may mean that extension in the magma chamber is taken up by simple flow of the crystal mush, and there may be little ductile shearing within the plutonic sequence. Thus, unlike slow-spreading ridges, formation of brittle-ductile shear zones, tectonically enhanced cracking, and hydrothermal alteration may not be as important in the lower crust beneath fast-spreading ridges.

Although the MOHO is generally viewed as a simple igneous stratigraphic boundary, investigations of ophiolites demonstrate that the MOHO is more likely to be a tectonic rather than an igneous contact. Stretching and deformation in the zone of lithospheric necking would occur in response to the change in mantle motion from vertical to horizontal. A well-preserved intact igneous MOHO is most likely to occur beneath fast-spreading ridges as extension accompanying divergence of the plates may be simply accommodated by flow in a crystal mush zone and partially molten mantle.

Hess Deep 3: HD-3 is located on the crest of the intra-rift ridge (2°18' N, 101°31.6' W; 3075 m depth, Fig. A-3). The objectives and expected results are the same as those for HD-2. The crest of the ridge is relatively flat and large enough to facilitate placement of a guide base. It may be difficult to drill the basaltic rubble that covers the ridge; the plutonic rocks should be relatively unfractured and quite drillable. A bare-rock guide base is required.

Hess Deep 4: HD-4 is located in Area 2 in Figure A-2, south of the intra-rift ridge and north of the Cocos-Nazca ridge, at 2°16.8' N, 101°26.6' W in 4100 m of water. Plutonic and ultramafic rocks are exposed between 4500 and 3500 m depth along a gentle slope that is locally ≤10°. Dunites with Cr-spinels and serpentinized foliated harzburgites (up to 50% serpentinized) crop out in subhorizontal ledges that dip to the north. The continuity of peridotite outcrops observed during a *Nautile* dive indicates that this slope is an intact block (scale of kilometers) of the shallow mantle. The abundance of dunites in the section, by analogy to similar regions in ophiolite complexes, and their proximity to gabbros, suggests that these dunites represent the critical transition zone to the mantle at the base of the crust.

The principal objective of this site is to drill the transition zone across the lower plutonics and MOHO into the shallow mantle. A section of alternating dunite and harzburgite tectonites, with the proportion of harzburgite increasing downward, should reflect increasing distance from the transition zone at the MOHO. The petrofabrics and stress-strain history of the rocks will provide our first direct look at the flow and creep processes in the shallow mantle beneath rift valleys. The internal stratigraphy and composition of dunites will provide direct information on the processes of melt migration and extraction critical to understanding the evolution of ocean ridge basalt. The extent to which these processes occur beneath ocean ridges is a key unknown in modeling the generation of ridge basalts. A major question we would like to answer is whether the dunites reflect the early fractional crystallization of tholeiitic magmas in the shallow mantle, in which case they will have variable iron contents, lower than the surrounding harzburgite country rocks. Alternatively, do they reflect chemical exchange between migrating melts and mantle, in which case they will be similar in composition to olivine in the wall rocks? Are there wehrlites in the shallow residual mantle beneath the crust at fast-spreading ridges? Is there a compositional gradient of any kind in the shallow mantle? How does melting vary with depth in the shallow mantle section? How extensively is the upper mantle serpentinized?

Drilling Strategy

In the event that part of Leg 140 is devoted to operations at Hess Deep, the ship will proceed to proposed site HD-3 (or HD-2) and deploy the underwater television camera to do a mini-survey around the proposed drill site. Based on this survey, a test hole will be attempted using the mud-motor. Following a successful test hole, a bare-rock guide base will be deployed, and drilling will proceed at the site until the end of the leg. If a hole deeper than 200 mbsf is achieved, a standard suite of logs will be run at the end of drilling prior to departure. In the event that the initial test hole is unsuccessful, the ship will move to the other of these two sites to conduct an additional mini-survey and test hole. In the event that the second test hole is unsuccessful, the ship will proceed to HD-4, where a third mini-survey and test hole will be made. It is anticipated, from the success in drilling serpentinites during Leg 109 and the visual descriptions of near-continuous massive blocky outcrops of peridotite in this area, that drilling at the last site is unlikely to fail. Based on the submersible surveys, however, the abundant dunite exposed in the region suggests that drilling would begin below the seismic MOHO, rather than above it, but within the petrologic transition zone between crust and mantle. Thus, this site has been assigned the lowest priority of the three Hess Deep sites proposed for this leg.

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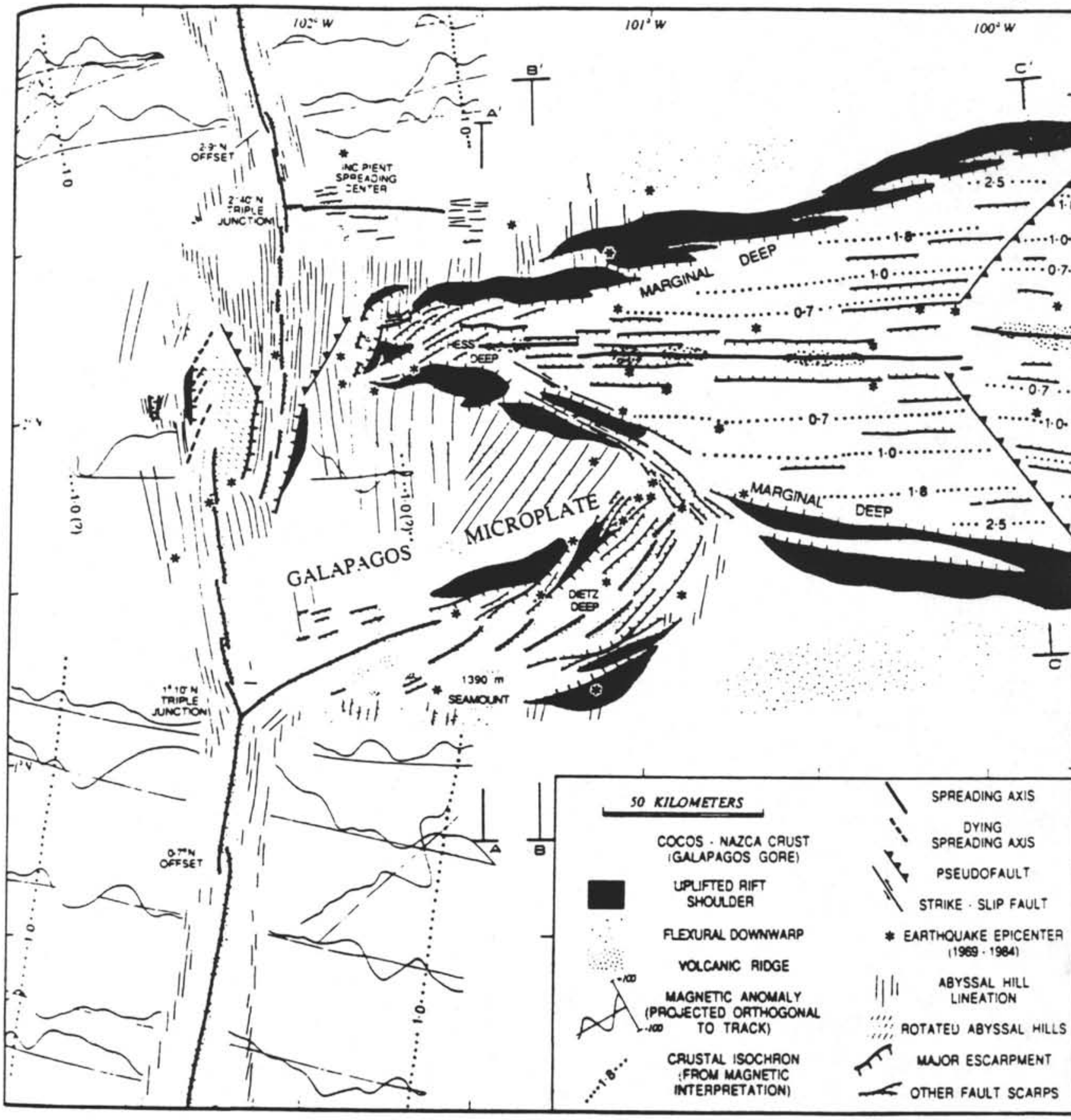

Figure A-1. Location of Hess Deep at the western end of the propagating Cocos-Nazca spreading axis (from Lonsdale, 1988).

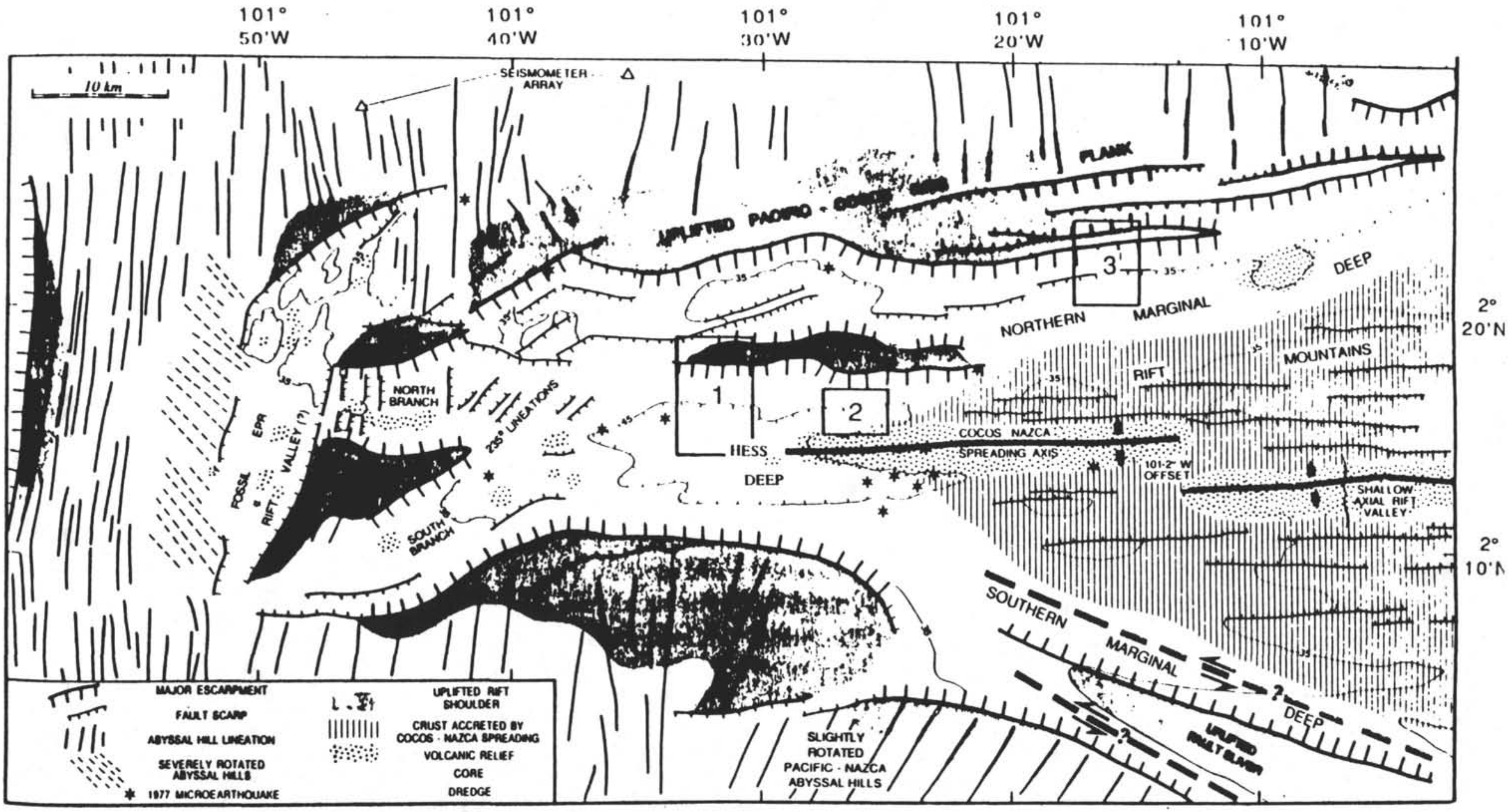

Figure A-2. Tectonic sketch map of the Hess Deep rift valley (from Lonsdale, 1988). The three areas proposed for drilling are outlined.

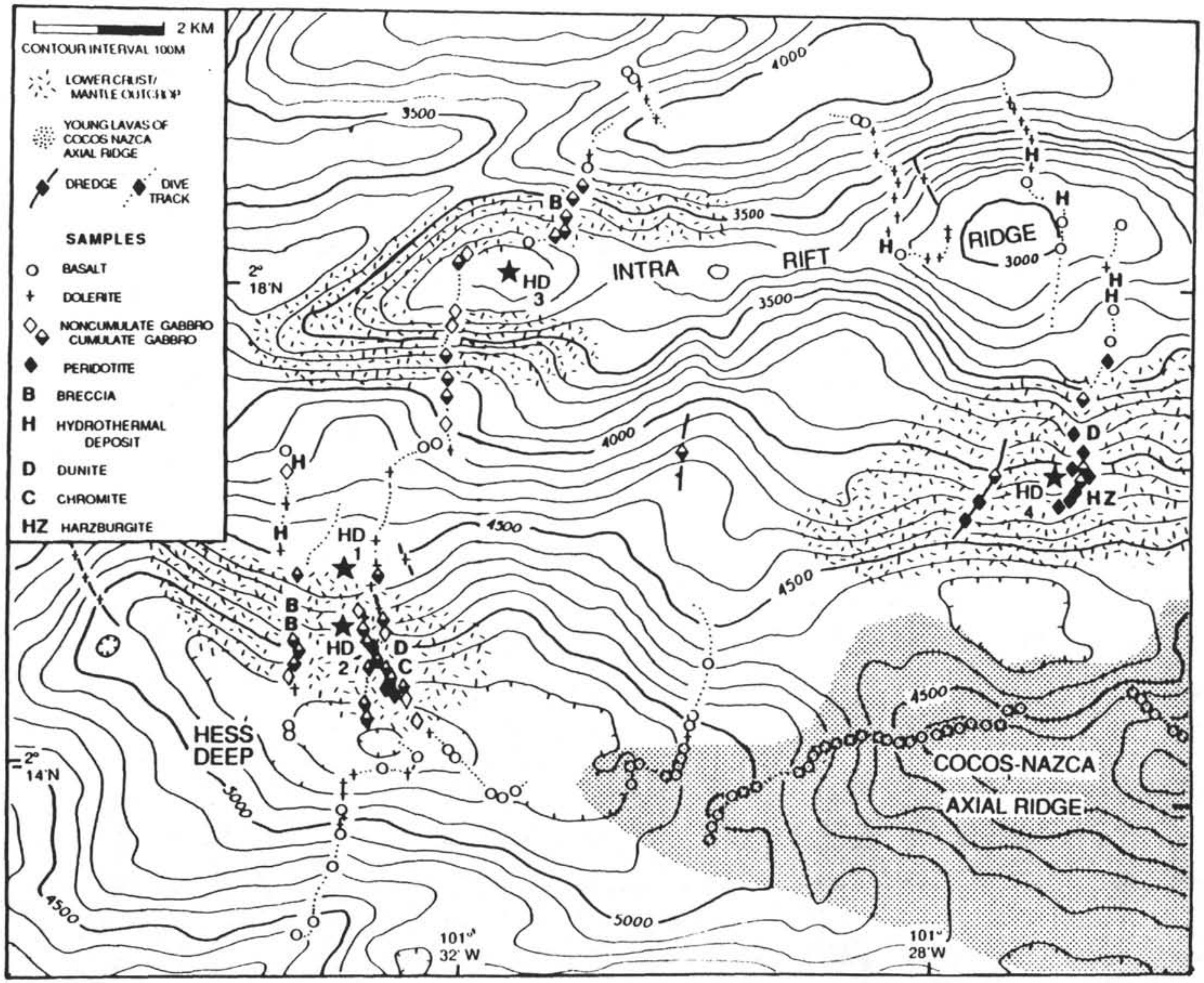

Figure A-3. Geologic and bathymetric map of the Hess Deep rift valley. Geology (modified from Francheteau et al., in press) is based upon results of dredging from the F/S *Sonne* and the R/V *Atlantis II*, as well as observations made during the *Nautile* dive series. Stars indicate the locations of the proposed drill sites.

Site: HD-2 **Priority**: 2

Position: 2°15.2'N, 101°33.0'W

Water Depth: 5000 m **Sediment Thickness**: none

Seismic Record: Complete SeaBeam coverage; and multichannel seismic profile along rift-valley scarps (Zoneshain et al., 1980).

Proposed drilling program: Test hole using the motor-driven core barrel ("mud motor"), followed deployment of a hard-rock guide base if the test hole is successful.

Logging: If a hole deeper than 200 mbsf is achieved, a standard suite of logs will be run prior to departing the site.

Objectives: Rotary coring to 1000 mbsf to recover a long, continuous section of the lower-level plutonics and the transition across the MOHO into the upper mantle, in order to characterize the igneous, metamorphic, and structural evolution of the lower gabbros and the transition into the mantle in young oceanic crust generated at a fast-spreading ridge, and to determine the vertical variation in physical and magnetic properties of the lower crust and upper mantle.

Nature of rock anticipated: Massive plutonics and, possibly, massive peridotites. The transition across the MOHO may be tectonic and thus may be highly fractured.

Site: HD-3 **Priority**: 2

Position: 2°18.0'N, 101°31.6'W

Water Depth: 3075 m **Sediment Thickness**: none

Seismic Record: Complete SeaBeam coverage; and multichannel seismic profile along rift-valley scarps (Zoneshain et al., 1980).

Proposed drilling program: Test hole using the motor-driven core barrel ("mud motor"), followed deployment of a hard-rock guide base if the test hole is successful.

Logging: If a hole deeper than 200 mbsf is achieved, a standard suite of logs will be run prior to departing the site.

Objectives: Rotary coring to 1000 mbsf to recover a long, continuous section of the lower-level plutonics and the transition across the MOHO into the upper mantle, in order to characterize the igneous, metamorphic, and structural evolution of the lower gabbros and the transition into the mantle in young oceanic crust generated at a fast-spreading ridge, and to determine the vertical variation in physical and magnetic properties of the lower crust and upper mantle.

Nature of rock anticipated: Massive plutonics and massive peridotites. The transition across the MOHO may be tectonic and thus may be highly fractured.

Site: HD-4 **Priority**: 2

Position: 2°16.5'N, 101°27.0'W

Water Depth: 4100 m **Sediment Thickness**: none

Seismic Record: Complete SeaBeam coverage; and multichannel seismic profile along rift-valley scarps (Zoneshain et al., 1980).

Proposed drilling program: Test hole using the motor-driven core barrel ("mud motor"), followed deployment of a hard-rock guide base if the test hole is successful.

Logging: If a hole deeper than 200 mbsf is achieved, a standard suite of logs will be run prior to departing the site.

Objectives: Rotary coring to 1000 mbsf to recover a long, continuous section of the lower-level plutonics and the transition across the MOHO into the upper mantle, in order to characterize the igneous, metamorphic, and structural evolution of the lower gabbros and the transition into the mantle in young oceanic crust generated at a fast-spreading ridge, and to determine the vertical variation in physical and magnetic properties of the lower crust and upper mantle.

Nature of rock anticipated: Massive plutonics and massive, quite fresh peridotites. The transition across the MOHO may be tectonic and thus may be highly fractured.