# OCEAN DRILLING PROGRAM

# LEG 148 SCIENTIFIC PROSPECTUS

# DEEPENING HOLE 504B


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October 1992

Scientific Prospectus No. 48
First Printing 1992

Distribution

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. Orders for copies may require payment for postage and handling.

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

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This Scientific Prospectus is based on pre-cruise 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 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 148 is to deepen Hole 504B, the deepest hole ever drilled into oceanic crust, through the dike/gabbro and/or layer 2/3 transition to clarify the relationship between lithologic and seismic crustal structures. 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 148 is scheduled for 26 January to 10 March, 1993. About 39 days on site will be devoted to coring and downhole measurements.

## Introduction

During Ocean Drilling Program Leg 148 (26 January to 10 March, 1993), *JOIDES Resolution* will return to deepen Hole 504B in the eastern equatorial Pacific (Fig. 1). The primary purpose of this leg is to core through the dike/gabbro and/or layer 2/3 transition. Hole 504B is now the deepest hole ever drilled by DSDP/ODP (Deep Sea Drilling Project/Ocean Drilling Program), and extends almost three times as deep into oceanic basement as any other hole.

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

Leg 148 will be the eighth DSDP/ODP expedition to occupy Hole 504B (Fig. 2). The hole was originally spudded during DSDP Leg 69 in 274.5 m of sediments overlying basaltic basement, and was then deepened and/or logged during parts of six other DSDP/ODP legs: 70, 83, 92, 111, 137, and 140. 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); Becker, Foss, et al. (1991); and Dick, Erzinger, Stokking et al. (1992).

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 relatively low rates of core recovery. These 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. Leg 137 cleaned the junk out of Hole 504B lost at the end of Leg 111, but left an 18-m outer core barrel with a diamond drilling bit at the bottom of the hole. After successfully cleaning the hole, operations during Leg 140 deepened Hole 504B to 2000.4 m. Coring with improved RCB bits was straightforward, and, at the end of the leg, Hole 504B was stable, open, and clean.

## 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 1725.9 m of basement, for a total penetration

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

of 2000.4 m. 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.

Seismic surveys, heat-flow measurements, and 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 (Fisher et al., 1990) 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 1725.9 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 945.4 m of sheeted dikes and massive units (Fig. 2). The lithostratigraphy was determined from a core recovery averaging 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.

The basement rocks recovered from Hole 504B are fine- to medium-grained, plagioclase-olivine ± clinopyroxene ± chrome spinel phyric basalts, with aphyric types more abundant with depth. The coarsest unit recovered during Leg 140 has an average grain size of 1.5 mm, but in terms of texture and grain-size, is clearly a diabase and not a gabbro.

While there is not a simple systematic increase in grain size with depth, coarser grained diabases do become more common, whereas glassy chilled margins virtually disappear, consistent with generally deeper dike emplacement at higher temperatures.

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 cores.
2. A lower alteration zone in the pillows (584.5-836 mbsf) that was presumably produced by reactions with reducing, low-temperature solutions at low seawater/rock ratios. This zone is characterized by smectite and pyrite.
3. A hydrothermally altered zone (898-2000.4 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 across the top of the transition from pillow lavas to underlying dikes. This is attributed to the mixing of high-temperature (~ 300 °C) hydrothermal fluids upwelling through the relatively "tight" dikes with larger volumes of lower temperature (≤ 100°C) seawater fluids circulating in the pillow lavas, which have orders of magnitude greater values of bulk porosity and permeability than the underlying dikes.

Rocks in the dike section are generally only partly altered (about 20%), but are more extensively recrystallized (up to 100%) along veins and in cm-sized patches around former pore space, indicating permeability and porosity controls on alteration. Some significant variations in mineralogy and chemistry occur with depth in the dikes, however. Fibrous actinolite in the upper dikes gives way to well-crystallized pleochroic green amphibole in the lower 300 m. In the upper dikes, plagioclase is altered to albite and pyroxene is mostly unaltered, whereas in the lower 400 m plagioclase is only slightly altered and pyroxene is extensively replaced by actinolite and amphibole. Olivine is totally altered in the upper dikes, but relict olivine is present locally in the lower 350 m, particularly in the interval 1710-1790 mbsf, reflecting locally more restricted circulation and lower water-rock ratios in the lower dikes.

The changes in mineralogical effects with depth in the dikes are consistent with increasing temperatures of hydrothermal alteration downward, and with penetration into the top of the transition from dikes to underlying gabbros.

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. Chemically, the rocks can be classified as olivine tholeiites with compositions that are similar to moderately evolved mid-ocean ridge basalts (Leg 140: $MgO$ = 7.7-10.1%, $Fe_2O_3^{total}$ = 8.1-11.4%, Ni = 79-189 ppm, Mg value = 0.60-0.75). However, they are strongly depleted in incompatible elements (Leg 140: $TiO_2$ = 0.67-1.1%, Nb $\leq$0.3-0.7 ppm, Zr = 35-58 ppm), suggesting that they may be the products of multistage melting of a normal MORB source. These characteristics encompass over 98% of all investigated samples recovered from Hole 504B, through 2000 mbsf. There appear to be no major igneous enrichment or depletion trends with depth, nor are there large-scale fractionation trends throughout this crustal section, suggesting the presence of a steadily replenished magma chamber.

The transition zone is enriched in Cu, Zn and S due to sulfide mineralization, whereas there is a systematic Zn loss with depth at the bottom of the core, from an average of 70 ppm at

1500 mbsf to 30 ppm at 2000 mbsf. This Zn depletion is similar to the metal depletion observed in the basal dikes of ophiolites and may be a source for hydrothermal Zn and the Zn-enrichment in the mineralized transition zone.

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. 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.

Temperature profiles measured on several previous legs indicate variable drawdown of bottom seawater through the hole and into the upper 100 m of basement. The rate of flow decreased from Leg 69 through Leg 111, but was found to be vigorous again on Leg 137, and then decayed to Leg 140 values (Fig. 3). A gradient inversion between 283 and 288 m measured prior to operations on Leg 140 may be due to differential thermal rebound of the wallrock or possibly to local fluid inflow from the basement into the borehole. The linear temperature gradient in the deeper hole is still 61°C/km, which extrapolates to a temperature of 195°C at 2000 mbsf.

A vertical seismic profile experiment conducted in Hole 504B during Leg 111 shows a relatively weak seismic reflector between 1660 and 1860 mbsf, which was interpreted as the transition between sheeted dikes in seismic Layer 2C and gabbros in Layer 3. Leg 140 clearly penetrated through this depth section, but this "boundary" was not the transition from the dike complex into the gabbros at Site 504. The observed changes in intensity of alteration and in physical rock properties may have caused an impedance difference somewhere around 1750 mbsf, which resulted in the observed reflector. The changes in alteration mineralogy, the increasing average grain-size, the general increase in amphibole abundance, and the absence of glassy chilled dike margins in the newly drilled section of Hole 504B suggest that Leg 140 has reached the lower part of the sheeted dike section.

## Operations Plan

Leg 148 is scheduled to leave Panama City on 26 January 1993 for a two-day transit to Hole 504B and return to Panama City on 10 March. The schedule includes a total of 4 days of transit between Hole 504B and Panama City, and 39 days on site for coring, logging and special experiments (Table 1). Prior to coring, borehole temperatures will be measured and water samples will be taken.

Legs 137 and 140 demonstrated that Hole 504B can be cored using improved 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 148, the RCB system will be used exclusively. Operations on Leg 148 will employ RCB bits specially hardened to increase rotating time from about 15 to 40-45 hr per bit. In this way, we plan to continuously core at least 300-400 m deeper in Hole 504B in the time available, with acceptable levels of core recovery inferred from past experience.

Five days of logging are planned. Three days have been allocated for logging with the quad-comb, formation microscanner (FMS), geochemistry, borehole televiewer (BHTV), magnetometer, and possibly the temperature tool. Two days have been scheduled for vertical seismic profile (VSP) and packer/flowmeter experiments.

Depending on coring progress, the logs and experiments may be conducted slightly before the end the end of allocated coring time, allowing for a final coring trip at the end of operations. Logs are to be run only in previously unlogged sections, as recommended by PCOM. The order of logging may be adjusted depending on thermal conditions. Possible additional logs include a shear wave tool, the Von Herzen high-temperature borehole instrument, the CSM high-temperature resistivity tool and the Gieskes' NaBr experiment, all pending time availability, successful land tests before Leg 148 and endorsement by the scientific party.

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**Table 1: Proposed Schedule for Leg 148**

| | | | (days) |
|---|---|---|---|
| 1. | Transit Panama to Hole 504B | | 2.0 |
| 2. | Run temperature logs and borehole water sampling | | 2.0 |
| 3. | Coring 504B (estimated 500 m penetration) | | 32.0 |
| | Meters/RCB Bit | = 42.0 rotating hours x 1.25 m/hr avg | |
| | | = 52.5 m/bit | |
| | Cores/RCB Bit | = 52.5 m/bit /9.2 m/core | |
| | | = 5.7 cores/bit | |
| | Hours/RCB Bit | = 14 hr RIH + 42 rotating hr + | |
| | (1.5 hr/core x 5.7 cores/bit ≈ 9 hr/bit) + 12 hr POOH | | |
| | | = 77 hr/bit | |
| | To core 500 m | = (500 m /52.5 m/bit) | |
| | | ≈ 10 bits | |
| | 10 bits x 77 hr/bit | = 32.08 days | |
| 4. | Log w/ quad combo, FMS, geochemistry, BHTV, magnetometer, and possibly temperature tool | | 3.0 |
| 5. | VSP Experiment | | 1.0 |
| 6. | Packer/flowmeter experiment | | 1.0 |
| 7. | Transit to Panama City | | 2.0 |
| Hole 504B, total days at sea | | | 43.0 |

## Figure Captions

Figure 1. Location of DSDP/ODP Site 504 south of the Costa Rica Rift in the eastern equatorial Pacific Ocean (after Hobart et al., 1985).

Figure 2. A. Schematic of drilling history and lithostratigraphy of Hole 504B through Leg 140. B. Generalized lithostratigraphy of selected deepest DSDP/ODP holes from hard rock cruises.

Figure 3. Composite of temperature logs obtained in Hole 504B during Legs 69, 70, 83, 92, 111, 137, and 140. The depressed temperatures in the upper 400 m reflect the downhole flow of cold ocean bottom water through the casing into the upper 100-150 m of the basement.

Figure 4. Distribution of secondary mineralogy with depth in Hole 504B. From Alt, et al. (1986); Becker, Sakai, et al., (1989a). Seismic stratigraphy is based upon sonic logs collected during Leg 83.

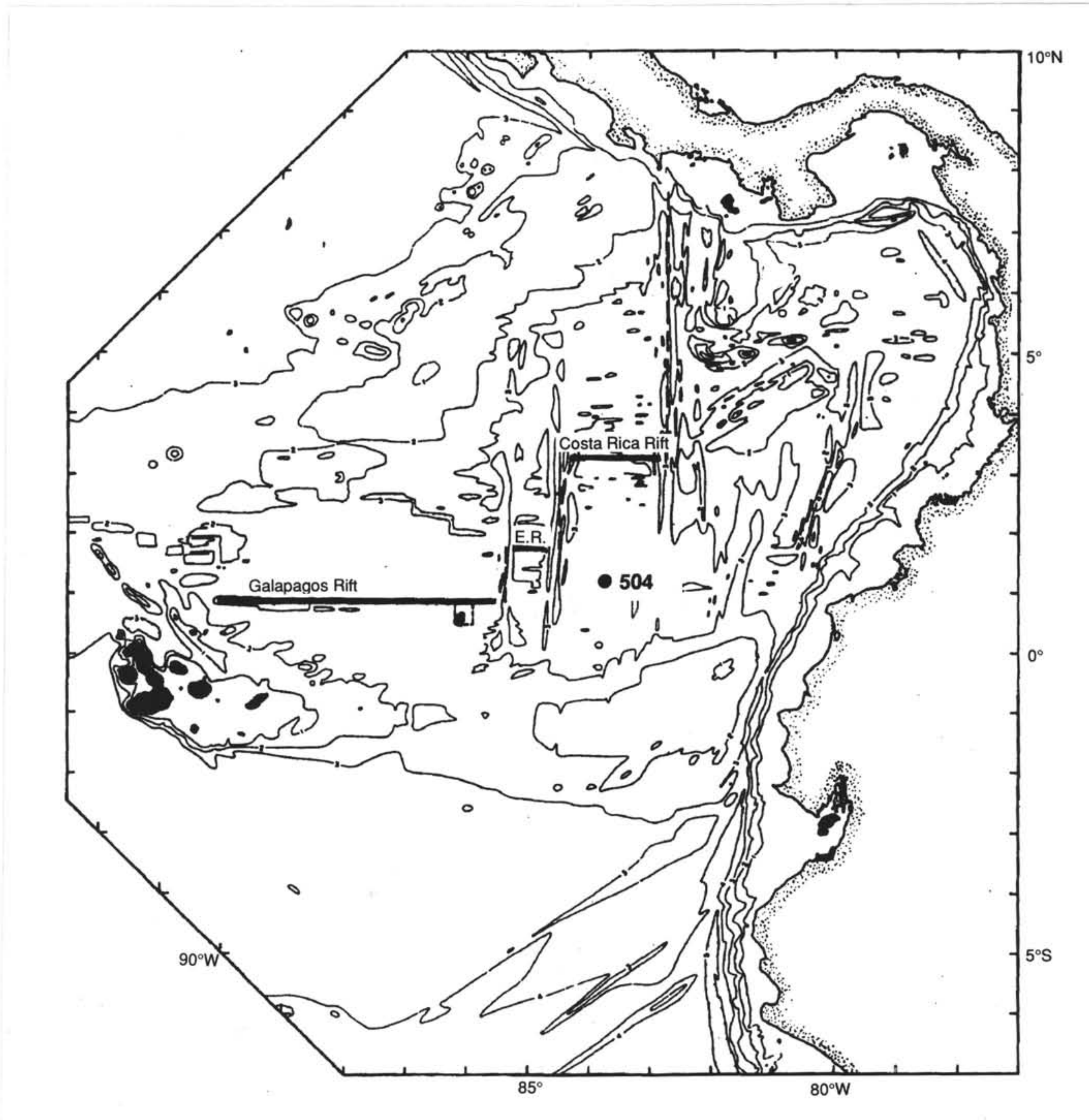


**Figure 1**

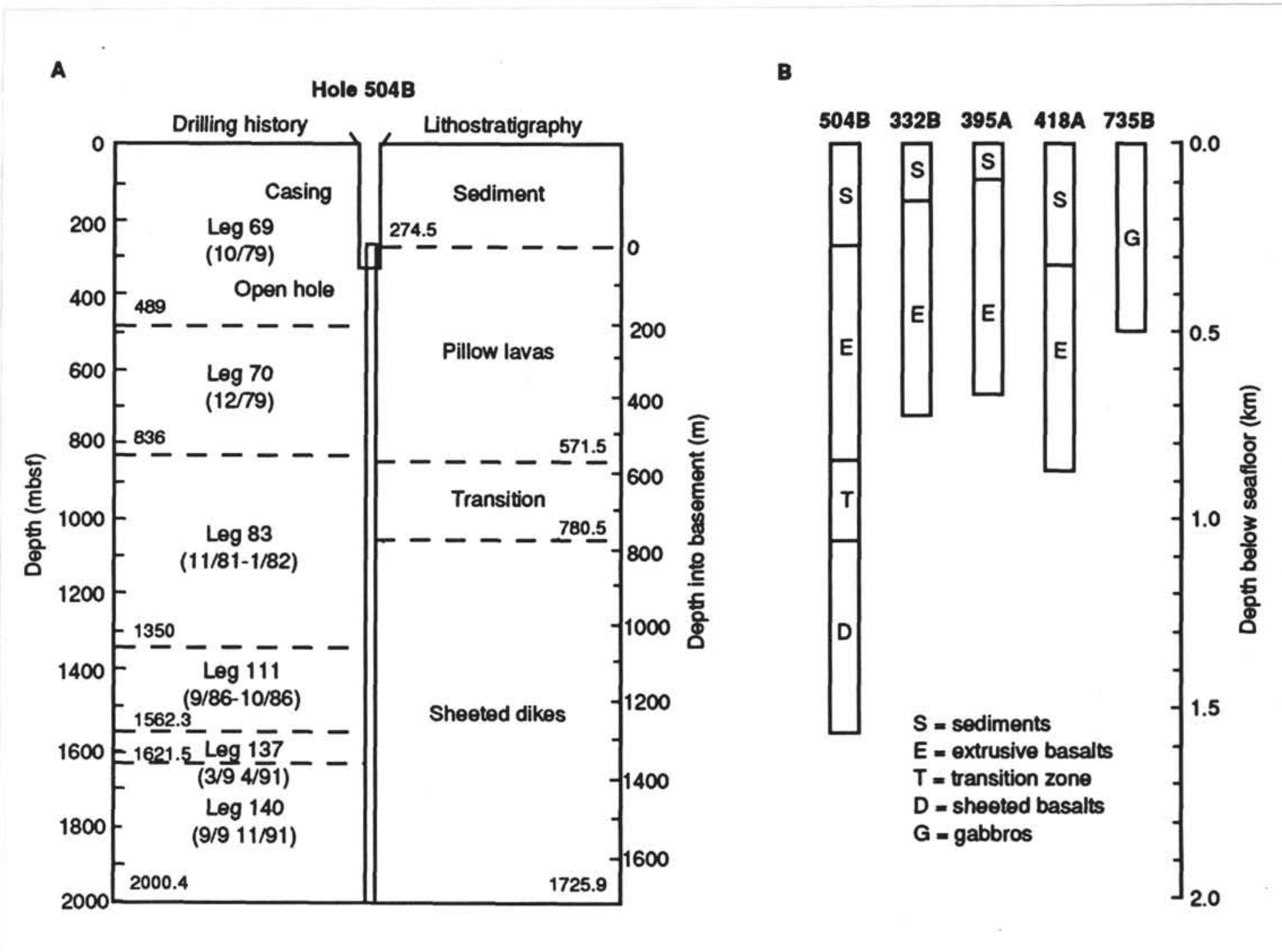
A
Hole 504B
Drilling history
Lithostratigraphy
Casing
Sediment
Leg 69
(10/79)
274.5
Open hole
489
Pillow lavas
Leg 70
(12/79)
836
571.5
Transition
780.5
Leg 83
(11/81-1/82)
1350
Leg 111
(9/86-10/86)
1562.3
Sheeted dikes
1621.5
Leg 137
(3/9 4/91)
Leg 140
(9/9 11/91)
2000.4
1725.9
Depth (mbsf)
Depth into basement (m)
B
504B
332B
395A
418A
735B
Depth below seafloor (km)
S = sediments
E = extrusive basalts
T = transition zone
D = sheeted basalts
G = gabbros

Figure 2

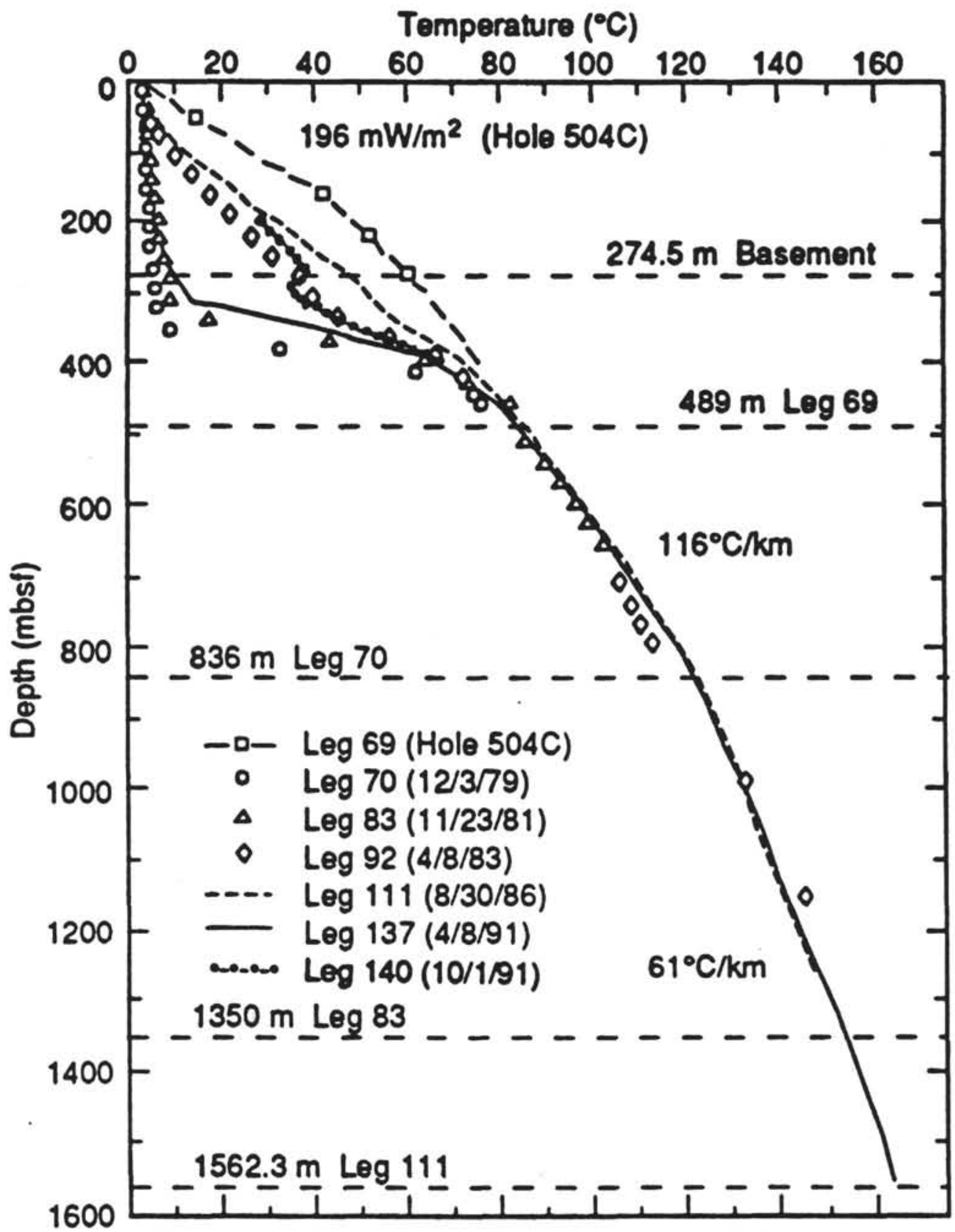
Temperature (°C)
0
20
40
60
80
100
120
140
160
196 mW/m² (Hole 504C)
274.5 m Basement
489 m Leg 69
116°C/km
836 m Leg 70
61°C/km
1350 m Leg 83
1562.3 m Leg 111
Depth (mbsf)
0
200
400
600
800
1000
1200
1400
1600
Leg 69 (Hole 504C)
Leg 70 (12/3/79)
Leg 83 (11/23/81)
Leg 92 (4/8/83)
Leg 111 (8/30/86)
Leg 137 (4/8/91)
Leg 140 (10/1/91)

Figure 3

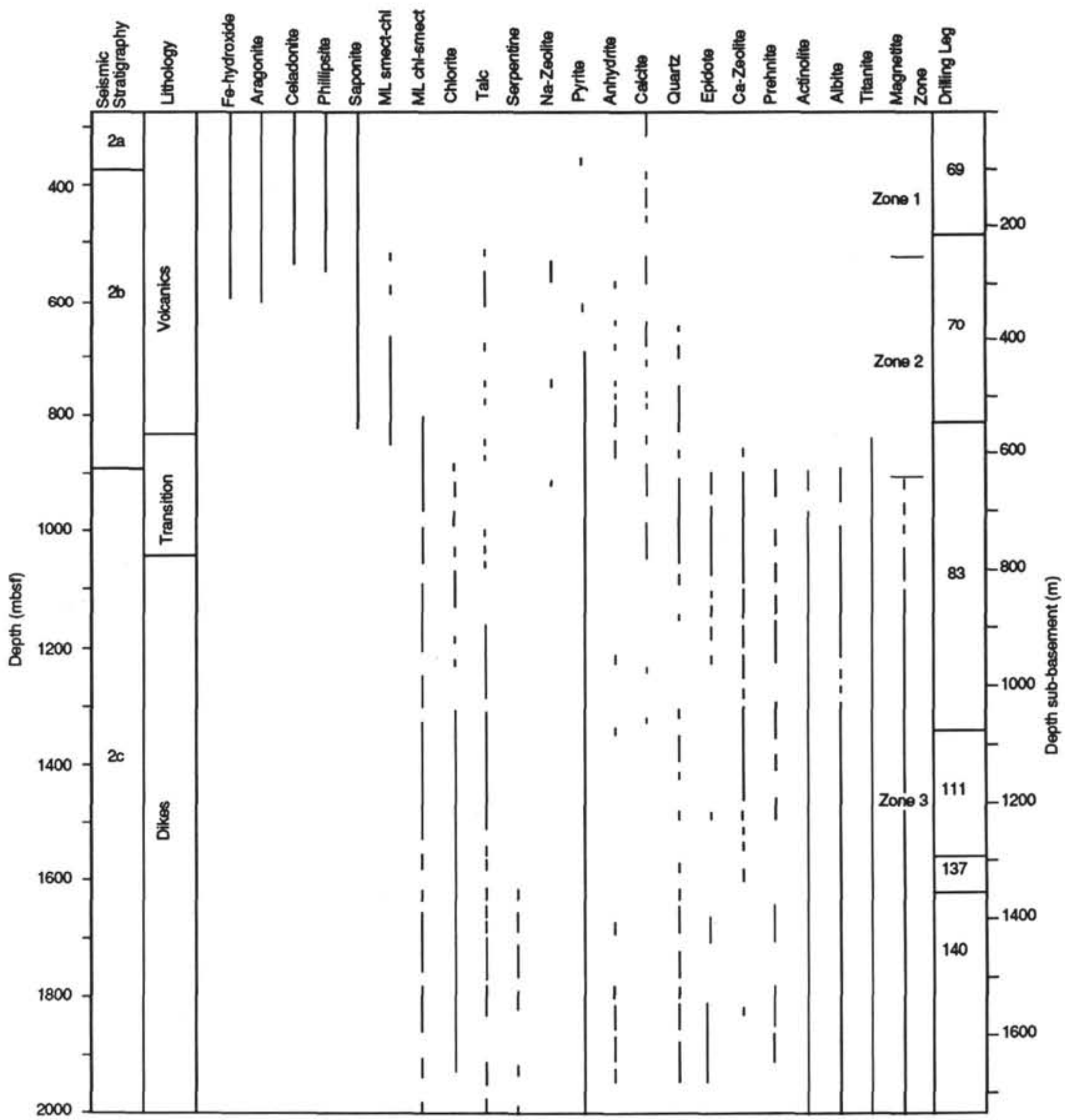
Seismic Stratigraphy
Lithology
Fe-hydroxide
Aragonite
Celadonite
Phillipsite
Saponite
ML smect-chl
ML chl-smect
Chlorite
Talc
Serpentine
Na-Zeolite
Pyrite
Anhydrite
Calcite
Quartz
Epidote
Ca-Zeolite
Prehnite
Actinolite
Albite
Titanite
Magnetite
Zone
Drilling Leg
2a
2b
2c
Volcanics
Transition
Dikes
Zone 1
Zone 2
Zone 3
69
70
83
111
137
140
Depth (mbsf)
400
600
800
1000
1200
1400
1600
1800
2000
Depth sub-basement (m)
200
400
600
800
1000
1200
1400
1600

Figure 4

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

**Position:** 1°13.611'N, 83°43.818'W
**Sediment Thickness:** 274.5 m
**Water Depth:** 3460 m

**Proposed Drilling Program:** Reenter existing reentry cone. RCB core into basement to deepen through the layer 2/3 transition.

**Logging:** Temperature measurements and borehole water sampling prior to coring. After coring, run quad combo (gamma-ray, velocity, resistivity, density/porosity), formation microscanner, geochemical combination, digital borehole televiewer, magnetometer, and temperature log in newly drilled section. Then conduct VSP and test permeability with packer and a flowmeter tool. Spike borehole with NaBr tracer if time allows.

**Objectives:** Coring through the layer 2/3 transition.

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

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