OCEAN DRILLING PROGRAM

LEG 111 PRELIMINARY REPORT

DSDP HOLE 504B REVISITED

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INTRODUCTION

During Leg 111 of the Ocean Drilling Program (ODP), JOIDES Resolution returned to Site 504 in the eastern equatorial Pacific (Figures 1 and 2). The primary purpose of Leg 111 was to deepen and log Hole 504B, which had been cored and logged during parts of four legs of the Deep Sea Drilling Project (DSDP). Before Leg 111 returned to it, Hole 504B extended 1075.5 m through the pillow lavas of oceanic Layers 2A and 2B and into the sheeted dikes of Layer 2C -- a basement penetration nearly twice that of the second-best 583 m in Hole 332B in the Atlantic. Leg 111 focused on coring and logging the sheeted dike complex, which has been sampled in situ only in Hole 504B, where it is on the order of one kilometer thick.

Sampling from deep within the oceanic crust has long been a major goal of the JOIDES Ocean Crust and Lithosphere Panels, to document the lithostratigraphy, alteration history, and geophysical properties of the crust, and to test the analogy drawn between ophiolites and oceanic crust. This goal went mostly unfulfilled during DSDP, partly because of the technical problems of achieving deep penetration, and because of the great commitment of time and effort required. Hole 504B was a unique exception, where Legs 69, 70, and 83 cased through 274.5 m of sediment and cored 1075.5 m of pillow lavas and sheeted dikes, to a total depth of 1350 meters below the sea floor (mbsf) (Figure 3)(CRRUST, 1982; Cann, Langseth, Honnorez, Von Herzen, White, et al., 1983; Anderson, Honnorez, et al., 1982; Anderson, Honnorez, Becker, et al., 1985). To date, the lithostratigraphy sampled in Hole 504B is the best direct, if limited, verification of the ophiolite model of the oceanic crust; however, the deepest 3-4 km of oceanic crust has never been sampled in situ.

The second, equal-priority, goal of Leg 111 was to spend 5 days coring the 200 to 300 m of sediments near Site 504 with the advanced piston corer (APC) and extended core barrel (XCB). It was important to sample these sediments for two separate purposes: high-resolution studies of Plio-Pleistocene biostratigraphy and paleoceanography of the eastern equatorial Pacific, and geochemical studies of the advection of pore waters in the sediments and its effect on sediment diagenesis. Two sites within 3 km of Site 504 were cored to achieve these purposes: Site 677 in a local heat flow minimum where the sedimentary record was expected to be best preserved, and Site 678 in a sharp local maximum of heat flow where advective processes were expected to be important.

HOLE 504B

Leg 83 cored nearly 300 m into the sheeted dikes of the upper part of Layer 2C, making Hole 504B the only DSDP basement hole to have clearly penetrated through the extrusive pillow lavas and into the underlying sheeted dikes predicted from studies of ophiolites. Layer 2C may extend as much as one kilometer deeper at Site 504, so the nature of the sheeted dike complex remains poorly understood. It is particularly important to sample the dikes in situ, for both geochemical and geophysical reasons:

(1) The critical effects of hydrothermal circulation at temperatures higher than 300°C have never been sampled in situ. Studies of ophiolites indicate that hydrothermal alteration in the dike complex grades with depth from greenschist to amphibolite facies. Sampling these high temperature assemblages is critical to understanding the mass budget and history of the chemical evolution of the oceanic crust.

(2) Seismic Layer 2C is commonly observed as a layer about 1 km thick, whether interpeted as a constant-velocity layer or as a constant-gradient layer, yet it has never been properly sampled in situ. Layer 2C may be more regular in structure and thickness than the overlying Layers 2A and 2B, so sampling and logging it at even one site will provide essential "ground-truth" for the interpretation of geophysical data that bear on the oceanic crust.

Summary of DSDP Results from Hole 504B

Hole 504B is located in 5.9-m.y.-old crust 3460 m below sea level about 200 km south of the Costa Rica Rift (Figure 1). The 1075.5 m of basement cored in Hole 504B before Leg 111 consisted of 571.5 m of pillow lavas and minor flows, underlain by a 209-m zone of transition into 295 m of sheeted dikes and massive units. The lithostratigraphy was determined from a core recovery averaging only about 20% (25% in the pillows, 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 (Anderson, Honnorez, et al., 1982).

Geothermal Setting

Site survey seismic and heat flow measurements (Figures 2 and 3)(Langseth, et al., 1983; Hobart, et al., 1985) indicate that the crust at Site 504 is at a particularly interesting geothermal state: 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. Judging from the present-day pattern of low heat flow closer to the spreading axis, the crust at Site 504 may have recently rebounded to a conductive geothermal state, after undergoing hydrothermal cooling in the past few million years. Site 504 is nicely situated for studies of the sealing effect of sediment cover on a ridge-flank hydrothermal system, yet the crust is young enough that the alteration record from the ridge-axis circulation remains clear.

Downhole temperatures measured during Legs 69, 70, 83, and 92 generally fall on a profile that is consistent with the hypothesis that plate heat transfer at Site 504 is mostly conductive (Becker, et al., 1983a, 1983b, 1985). The equilibrium temperature at the bottom of Hole 504B was estimated to be 160°C, based on extrapolation of disequilibrium temperature logs measured at the end of Leg 83. Crustal porosities and permeabilities decrease sharply with depth, to values that probably do not allow pervasive hydrothermal convection (Anderson and Zoback, 1982; Becker, et al., 1982; Anderson, et al., 1985; Becker, 1985). However, the upper 100-200 m of basement (Layer 2A) is a relatively permeable, porous section, in which the pore fluids were observed to be underpressured by about 10 bars relative to hydrostatic when the hole first penetrated this section (Anderson and Zoback, 1982). As a result, ocean bottom water has been drawn down the casing into the upper levels of basement, at a rate that has noticeably decayed since the hole was first drilled (Becker, et al., 1983a, 1983b, 1985).

Thus, the uppermost basement in Hole 504B is still permeable enough to allow convection of the pore fluids. Indeed, recent detailed heat flow work

(Figure 2)(Langseth, et al., in preparation) and numerical simulations (Williams, et al., 1986) have confirmed that subdued convection still occurs in the permeable, upper levels of basement beneath the impermeable sediment cover, partly controlled by the presence of isolated basement topographic highs. A major purpose of the sediment coring at Sites 677 and 678 during Leg 111 was to investigate the extent and nature of this presently-active convection.

Petrology of Recovered Basalts

The basement rocks recovered from Hole 504B before Leg 111 were fine- to medium-grained, plagioclase-olivine ± clinopyroxene ± chrome spinel, phyric basalts, with aphyric types more abundant with depth (Kempton, et al., 1985). All of the recovered basalts were mineralogically and chemically altered to some extent. Detailed studies of the downhole variation of secondary minerals and mineral assemblages documented the existence of three major alteration zones (Figure 4)(Alt, et al., 1985):

(1) An upper alteration zone in the pillow lavas (274.5 to 584.5 mbsf), that displays typical effects of mostly oxidative "seafloor weathering" commonly observed in DSDP holes;
(2) A lower alteration zone in the pillows (584.5 to 836 mbsf), that was presumably produced by reactions with low-temperature suboxic to anoxic solutions at low water/rock ratios;
(3) A high-temperature alteration zone (898 to 1350 mbsf), from which the first samples of ocean floor basalt containing greenschist-facies alteration minerals were recovered in situ.

The pronounced changes in alteration mineralogy observed from 836 to 898 mbsf were interpreted to have resulted from a steep temperature gradient between low-temperature ($<100^{\circ}C$) alteration solutions circulating in the pillow lavas and very high-temperature fluids ($>300^{\circ}C$) which affected the lower portion of basement at the site (Alt, et al., 1985; Honnorez, et al., 1985). 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 (Figure 5).

Despite the effects of alteration, the primary composition and variation of the recovered basalts could be reliably established. The pillow lavas and dikes sampled from Hole 504B during DSDP were remarkably uniform in composition (Emmermann, 1985). The olivine tholeiites from the hole have high MgO contents (up to 10.5 wt%) and very low abundances of K (<300 ppm). Judging from their high Mg values (0.60 to 0.75), the basalts appear to have undergone only limited high-level crystal fractionation. Glass analyses from Hole 504B and nearby Holes 501 and 504A provided strong evidence for the existence of a magma chamber of nearly steady-state composition along this portion of the Costa Rica Rift (Natland, et al., 1983).

Logging and Geophysical Experiments

During Legs 69, 70, 83, and 92, Hole 504B was logged with an extensive suite of in-situ geochemical and geophysical experiments (Table 1). The geophysical data indicate that the in situ physical properties of the crust change dramatically across the transition from pillow lavas to sheeted dikes

(Anderson, et al., 1982): 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 not by petrology, but by variations in porosity with depth (Salisbury, et al., 1985). The sonic and seismic data are generally consistent with a sharp Layer 2B/2C boundary at the top of the sheeted dikes (Stephen and Harding, 1983; Little and Stephen, 1985). The sonic data, but not the much longer-wavelength seismic data, indicate a thin Layer 2A, consisting of the upper 100-200 m of highly porous pillow lavas (Newmark, et al., 1985). This layer corresponds to the highly permeable, under-pressured zone into which ocean bottom water has been drawn since the hole was drilled. Layer 2B comprises the lowermost 500 m of pillows, in which the original porosity has been partially sealed by alteration products.

Leg 111 Coring and Logging Plan for Hole 504B

Leg 83 cored through the major lithologic transition between pillow lavas and sheeted dikes in Hole 504B, which closely corresponds to both the Layer 2B/2C boundary and the transition between zeolite- and greenschist-facies alteration. The next major structural boundary is that between Layers 2 and 3, corresponding to the transition between dikes and underlying gabbros. Based on studies of ophiolites, the transition between greenschist- and amphibolite-facies alteration should occur within the dike complex, and probably will not correspond to a major seismic or structural boundary. Seismic data from sonobuoys and the oblique seismic experiment suggest that the Layer 2C/3 transition is 2 to 2.5 km into basement at Site 504, or up to 1 km deeper than Hole 504B extended before Leg 111. Based on past drilling experience, Leg 111 expected to core a few hundred meters deeper, predominantly within the dike complex.

In accordance with recommendations from JOIDES PCOM, Leg 111 was planned such that 43-44 of its 48-49 operational days were to be spent in Hole 504B. These 43-44 days were divided into three phases, like the successful Leg 83 program:

(1) Immediately after reentry, measurements of equilibrium borehole temperatures and sampling of borehole fluids, followed by limited logging and packer permeability measurements crucial to the existing section (5 days);
(2) Coring deeper into the sheeted dikes (29-30 days);
(3) Logging and geophysical measurements in the dike section (8-9 days).

Table 2 summarizes the plans for the two phases of logging.

It was important to recover a reasonable proportion of the interval cored during Leg 111, as the dikes probably contain the crucial geochemical and alteration signals of high-temperature, axial hydrothermal circulation. Leg 83 penetrated 514 m of transition zone and dikes during a drilling program of about one month's duration, including coring, pipe trips, bit changes, and contingency time. However, Leg 83 recovery and penetration rates in the dikes were marginal using standard steel rotary bits: The deepest 184 m of the hole required five bits that lasted an average of 20 hours rotating time each, with an overall recovery of 15.3%.

Leg 111 expected better performance using steel rotary bits, simply because the superior heave compensation on JOIDES Resolution allows the proper weight to be maintained on the bit during drilling. In addition, three diamond bits were purchased for Leg 111, in the hopes that they would improve recovery, if not penetration. Based on their own experience and the advice of bit manufacturers, ODP engineers considered a penetration rate of one m/hr to be quite good in dense crystalline rocks like the sheeted dikes.

Modifications to Leg 111 Plans Made during the Course of the Leg

As is always the case, actual operations did not proceed as smoothly as planned, and several important modifications to this plan were made as Leg 111 developed:

(1) During the initial phase of measurements, the Schlumberger Repeat Formation Tester (RFT) failed to return through the bit and lost a clamping arm in the hole, necessitating a pipe trip before the scheduled packer experiments could be attempted. The packer work was then postponed for several days, after running a mill bit and a rotary coring bit.

(2) As extra time was then required to complete the initial phase of logging, insufficient time was left for full completion of the post-drilling logging program. Only the higher-priority logs were run after Leg 111 drilling; these are identified in Table 2.

(3) During the second and third weeks of coring, two consecutive steel rotary coring bits disintegrated, each time leaving all four roller cones in the hole. After the first of these bit failures, four days were spent in fishing and milling operations before the resumption of coring. After the second bit failure, Leg 111 immediately proceeded with the post-drilling phase of measurements and a five-day program of coring sediments at Sites 677 and 678, before attempting to clean the hole and resume coring at the end of the leg.

Leg 111 held fairly closely to the PCOM recommendation to spend 43 days at Hole 504B, roughly 30 for coring and 14 for downhole measurements and logging. Unfortunately, coring the sheeted dikes proved very difficult and Leg 111 deepened the hole only 212.3 m. On the other hand, the logging program was extremely successful, despite the loss of some time due to the RFT failure and despite misgivings about the abilities of logging tools to withstand high temperatures in the hole.

Summary of Leg 111 Coring and Logging Results in Hole 504B

Leg 111 spent 42.9 days at Site 504, including nearly 29 days for coring operations and slightly more than 14 days for logging and experiments. Leg 111 deepened Hole 504B by 212.3 m, to a total depth of 1562.3 m below seafloor (mbsf) or 1287.8 m into basement (Figure 5). Coring was very difficult in the sheeted dikes that were encountered, and a total of 26.42 m of core was recovered, for an overall recovery of 12.6%. Hole 504B claimed parts of three coring assemblies and two logging tools, and much of the leg was spent in attempts to fish and mill junk from the bottom of the hole.

Although the coring results were disappointing, the logging and experiments were quite successful, and provided much of the continuous detail that was necessary to interpret the little core that was recovered. Logging had been scheduled in two phases, the first at the beginning of the leg before any coring, and the second at the end of the leg after the hole had been cored as deep as possible. However, coring operations were suspended earlier than scheduled when the second of two consecutive steel rotary bits disintegrated. The second set of logs and experiments was run when the hole had been advanced only 197.5 m beyond its depth at the beginning of the leg.

Temperature and Permeability Measurements

Before Leg 111 began coring, undisturbed borehole temperatures were continuously logged from seafloor to 1300 mbsf and back up to seafloor. The highest measured temperature was 148.9^{o}C at 1300 mbsf, indicating a temperature of about 152^{o}C at 1350 mbsf, then the total depth of the hole. This was about 10^{o}C less than had been predicted from temperatures measured on earlier legs. The measured gradient extrapolates to an estimated crustal temperature of 165^{o}C at the total depth of 1562.3 m reached by subsequent Leg 111 coring.

Deep in the hole, the temperature gradient is basically linear, but it decreases from 116^{o}C/km in the pillow lavas to 61^{o}C/km in the dikes (Figure 6). Short-wavelength variations in the thermal gradient correlate with the lithology, indicating that conductive heat transfer predominates. The change in gradient between pillow lavas and dikes suggests a puzzling reduction in heat flow, which is discussed below.

Slightly depressed temperatures in the upper 400 m indicate that ocean bottom water still flows down the casing into the upper 100-200 m of basement. The rate of downhole flow was estimated to be 1.1 m/hr or about 80 liters per hour, about 1% of the rate when the hole was first drilled almost seven years earlier during Leg 69 (Figure 7).

The bulk permeability of the sheeted dikes was measured twice after setting a drillstring packer, once at 936 mbsf when the hole was 1406 m deep, and a second time at 1236 mbsf when the hole was 1547.5 m deep. The permeability of the dikes was uniformly low, about 5-20 x 10^{-18} m^{2}. Somewhat unexpectedly, the dikes proved to be as permeable as the relatively impermeable, partially-sealed pillow lavas of Layer 2B. Thus the lower km of the hole, comprising sealed pillow lavas and sheeted dikes, is uniformly impermeable. The only permeable section of basement in Hole 504B is the upper 100-200 m, which is about three orders of magnitude more permeable than the lower km, and is the zone into which the downhole flow of ocean bottom water is directed (Figure 8).

Discussion: the Apparent Reduction in Heat Flow with Depth

The large decrease in the temperature gradient from pillow lavas to sheeted dikes suggests that the vertical heat flow is less in the dikes than in the pillow lavas. As the surface heat flow in the area varies about an average that is consistent with the value predicted for conductive cooling of 5.9-m.y.-old crust, the crustal gradient would be expected to approach the predicted gradient more closely with depth. Thermal conductivities in the dikes are about 20% higher than in the pillow lavas, which would account for only part of the reduction in gradient in the dikes. It is difficult to explain a reduction in heat flow with depth without invoking circulation of pore fluids, yet the measured permeabilities indicate that only the upper 100-200 m of basement is permeable enough to allow such circulation in the vicinity of the hole. The chemistry summarized below indicates that the borehole fluids convect within the hole, yet the temperature gradient shows only signs of conductive processes. More study is required to determine if slow convection within the borehole could produce the observed chemistry and reduce the overall temperature gradient without affecting the otherwise conductive character of the temperature profile.

Borehole Water Chemistry

Prior to renewed drilling in Hole 504B, Leg 111 obtained four reliable samples of borehole waters, from depths of 466, 631, 766, and 1236 mbsf, at temperatures of 81, 101, 115, and 146 ^{o}C, respectively. These samples were collected 1233 days after the hole had been thoroughly flushed with surface seawater at the end of Leg 92, and were free of the bentonite mud contamination that affected Leg 92 samples.

The sampled borehole fluids show a strong vertical gradient in major chemical composition: Mg, SO_4, and (Na+K) decrease with depth, while Ca increases with depth. After a nitrate-based correction for seawater contamination, the concentrations of Mg, SO_4, (Na+K), Ca, and Cl in the borehole endmember of the deepest (146^{o}C) sample are respectively 0.41, 0.00+, 0.97, 4.49, and 1.00 times the concentrations in the local ocean bottom water.

The changes in Ca and Mg from seawater values integrated over the entire depth of the hole were significantly less in samples from Leg 111 than in samples from Leg 83, despite the fact that there was a much longer time period since the last disturbance before Leg 111 than before Leg 83 (1233 versus 711 days). The Leg 111 samples fall on mixing lines between ocean bottom water and the borehole endmember. These observations indicate that the chemical composition of the borehole water is controlled by vertical convection within the borehole and exchange of borehole water with the ocean bottom water that flows downhole and into the upper 100-200 m of basement. The combined effect of these two processes is to dilute the altered borehole water, changing its composition back toward that of seawater. The chemical data indicate that the convection of fluids within the borehole has apparently been more active since Leg 83 deepened the hole from 836 to 1350 mbsf.

As is mentioned above, drilling muds form an insignificant proportion of the borehole fluids. Shipboard XRD and chemical analyses indicated that iron oxide and hydroxide form more than 50% of the solids recovered in the borehole fluids, with the rest being mostly smectite and chlorite. An interesting Leg 111 finding is that the recovered solids contain remains of bacterial filaments similar in morphology to those of iron-oxidizing bacteria found in mounds rich in iron oxides on a seamount near the East Pacific Rise (Alt, 1986). It is likely that iron-oxidizing bacteria live in the upper basement section of Hole 504B, where convecting Fe^{++}-rich borehole water mixes with oxygen-rich ocean bottom water.

Petrology and Geochemistry of Recovered Basalts

The basalts recovered from Hole 504B during Leg 111 are all from massive dike units. Five chilled margins of diabase dikes were sampled. The basalts are aphyric to moderately- (± highly-) phyric; aphyric basalts comprise about one-third of the total of 45 units described. Phases represented as phenocrysts include olivine, clinopyroxene, plagioclase, and rare chromian spinel. These occur together in a variety of assemblages including olivine + clinopyroxene and plagioclase + clinopyroxene, combinations not found in the basalts recovered during Leg 83. The following major crystallization sequence is postulated, based on petrographic observations and on preliminary experiments at one atmosphere carried out using Leg 83 basalts (Autio, 1985): spinel -- olivine -- olivine + plagioclase -- olivine + plagioclase + clinopyroxene -- olivine + plagioclase + clinopyroxene + Fe-Ti-oxides. The occurrence of olivine + clinopyroxene and plagioclase + clinopyroxene assemblages may be ascribed to either inadequate representation of samples by thin section and/or physical separation of phenocrysts during magma evolution and intrusion. However, the possibility that the Leg 111 basalts evolved in more than one way cannot be excluded at this stage.

Shipboard XRF analyses of 24 samples for major and trace elements indicate that the Leg 111 basalts are MgO-rich (>7.5 wt %), K_2O-poor (<0.02 wt %) olivine tholeiites. The Leg 111 basalts are similar to those recovered from the shallower basement section during previous legs. As has been noted on earlier legs, the basalts are extremely depleted in highly- to moderately-incompatible elements (Nb: 0.5-1.9 ppm; Zr: 38-58 ppm; Zr/Nb = 40-50).

Most of the rocks recovered during Leg 111 are only slightly altered (about 10-20% recrystallized), with olivine always totally replaced by talc ± mixed-layer clays ± magnetite ± sulfides or by chlorite + actinolite, pyroxene partly to totally replaced by actinolite + magnetite, and plagioclase replaced by chlorite ± mixed-layer clays ± albite ± rare actinolite ± zeolite.

However, variations in texture and flow of fluids along fractures produced locally more altered rocks (50-100% recrystallized). Veins and fractures are filled by secondary minerals in a consistent sequence: (1) chlorite + actinolite (± spinel and pyrite); (2) quartz ± sulfides and rare epidote; and (3) zeolite and prehnite. These stages may respectively represent (1) reaction with seawater at the spreading axis, (2) cross-cutting veins formed by evolved axial hydrothermal fluids, and (3) veins formed by off-axis, lower-temperature circulation (Alt et al., in press).

Despite the similarity of the Leg 111 and Leg 83 basalts, clinopyroxene is more extensively recrystallized than plagioclase in the Leg 111 samples, whereas the opposite is true in the Leg 83 dike samples. Moreover, in the Leg 111 section actinolite apparently increases with depth in proportion to the other secondary minerals. These observations suggest a possible increase in alteration temperature with depth, approaching the "lower actinolite facies" of Elthon (1981). However, the Leg 111 basalts are characterized by disequilibrium, reaching equilibrium only on a scale of a mm or less, so the use of a metamorphic facies concept must be further defined by chemical and isotopic studies.

Logging Measurements and Vertical Seismic Profile

During Leg 111, Hole 504B was logged with an exceptional suite of tools: Schlumberger ACT/GST neutron-activation/gamma-spectroscopy tool, Schlumberger DLL electrical resistivity tool, Schlumberger LDT/GPIT density/magnetometer tool, LDGO multi-channel sonic tool (MCS), and USGS borehole televiewer (BHTV). When calibrated against the properties of the recovered basalts, the logs yield a nearly continuous geophysical, geochemical, and lithological characterization of the basement, despite the relatively poor core recovery.

The ACT and LDT tools resolved the relative downhole abundances of the major elements Al, Ca, Fe, K, Mg, S, Si, U, and Th, and allowed the construction of a normative mineralogy log (Figure 8). The variation in log-determined geochemistry and mineralogy is a response to both the original chemistry of the phyric versus aphyric units and the presence of alteration products such as chlorite, actinolite, and clays. These logs show that the alteration products are tightly confined to fractures along boundaries between relatively unaltered extrusive or intrusive units of fairly homogeneous geochemistry. In particular, the basalts beneath the stockwork sampled at 910-930 mbsf during Leg 83 are more phyric and contain more Al than the basalts above the stockwork.

Both the MCS and the DLL clearly distinguished individual lithologic units. Deep in the dikes, compressional and shear velocities logged with the MCS reach 6.4 and 3.7 km/s, respectively, and electrical resistivity increases to over 1000 ohm-m. The BHTV revealed major breakouts in this otherwise massive section, and suggested that some of the drilling problems experienced here might have resulted from spalling of wall-rocks as stresses were relieved around the newly-drilled hole.

The DLL measures resistivities at two scales of penetration into the formation; comparison of the two measurements allows determination of both fracture and total apparent porosity. Total apparent porosity ranges from about 15% in the upper pillow lavas to less than 1% deep in the dikes, and apparent fracture porosity ranges from up to 5% in the pillow lavas to less than 0.5% in the dikes. The variation in the logged abundances of alteration products correlates with the apparent porosities calculated from resistivities, suggesting that some of the apparent porosity may represent original porosity that has been filled by alteration products. If this is the case, then the logged apparent porosities in the sealed pillow lavas of Layer 2B are probably too high, and there is probably a better correlation between permeability and true porosity than between permeability and apparent porosity.

The logged abundances of alteration minerals also correlate with changes in logged magnetic intensities. The logged magnetic inclination clearly changes at about 800 mbsf, from 15° in the pillow lavas above to 8° in the flows and dikes below. This observation is interpreted to indicate that the boundary between pillow lavas and dikes in Hole 504B is a relict of early listric faulting of the pillows over the dikes within the rift valley. Such a fault might have been the permeable conduit for circulating hydrothermal fluids that produced the heavily mineralized stockwork at the base of the pillow lavas.

A highly successful VSP experiment was conducted, shooting to a geophone clamped nearly every 10 m up the hole from 1535 mbsf. The results show two important reflectors that might be the contact between the dikes of Layer 2C and the underlying gabbros of Layer 3. These reflectors are about 100 and 450 m deeper than the present total depth of the hole, and are both within reach of the next full drilling leg to Hole 504B.

Prospects for Future Drilling in Hole 504B

Leg 111 encountered very difficult drilling conditions in Hole 504B, probably because of a combination of several factors:

(1) An inability to completely flush cuttings from the very deep hole;
(2) The steady accumulation of steel junk in the hole;
(3) Spalling of wall-rocks into the hole around the coring assemblies;
(4) The dense, crystalline nature of the deepest dikes cored deeper than 1500 mbsf.

During Leg 111 drilling in Hole 504B, two steel rotary bits disintegrated after only 16-17 rotating hours each. Each of the these bits left all four of its roller cones in the hole, and a considerable amount of time and effort was devoted to fishing and milling this steel (as well as lost parts of two logging tools) from the hole. It was hoped that coring with a diamond bit would improve recovery, but a diamond bit could not be run until the hole was cleaned of all steel junk.

Unfortunately, when hole conditions finally allowed a diamond bit to be run near the end of Leg 111, part of this last coring BHA was left in the bottom of Hole 504B. A diamond core bit, float valve, lower support bearing, and inner core barrel were lost when the connection broke between the bit and the stabilized bit sub above. Leg 111 spent its last 5 days trying to fish the hole, and successfully recovered the inner core barrel and part of the lower support bearing. However, Leg 111 had neither the proper tools nor enough time to complete the hole-cleaning operation, and had to leave the hole to be cleaned on a later leg.

SITES 677 AND 678

JOIDES Resolution spent five days coring sedimentary sections in two holes at Site 677 and one hole at Site 678. Site 677 is located at a heat flow low 2750 m south-southwest of Hole 504B, and Site 678 is at a heat flow high 1360 m southeast of Hole 504B (Figure 2).

The objectives of drilling at Sites 677 and 678 were:

(1) To obtain detailed biostratigraphic and paleoceanographic records, including stable isotopic and palynomorphic data, to document environmental changes in the tropical eastern Pacific Ocean and adjacent terrestrial biosphere for the past few m.y. Site 677 was the major target for this purpose because the low heat flow at the site should have resulted in better preservation of microfossils.
(2) To test the widely adopted hypothesis that warm, altered seawater forms and flows laterally in the upper section of the basement of this area and upwells through the sediment column at localized heat flow highs, whereas heat flow lows represent recharge zones of cold seawater into the basement. Depth profiles of pore water chemistry (including helium and its isotopes) and of temperature were critical measurements to be made at both sites.
(3) To study the effect of high heat flow and upwelling warm water on the early diagenesis of pelagic sediments. Comparison of diagenetic alteration of organic as well as inorganic substances in sediments from both sites will document chemical and mineralogical changes that occur in the sediment cover on the ridge flank geothermal areas.

Sites 677/678, a southern extension of Sites 501/504, are covered with 240 to 270 m of sediment that is mainly a siliceous calcareous (nannofossil) ooze of pelagic origin containing continuous biostratigraphic and paleoceanographic records from the late Miocene to the Holocene (Cann, et al., 1983). The sedimentary section at Sites 501/504 is classified into three lithologic units, mainly depending on the degree of diagenetic alteration of carbonate- and silica-fossil remains: Unit I (0 to 143.5 mbsf) consisting of late Pliocene to late Pleistocene siliceous-nannofossil and nannofossil-radiolarian oozes, Unit II (143.5 to 227.2 mbsf) of late Miocene to late [illegible] although the downhole flow has slowed considerably over a period of 7 yrs. The sediment cover in this area is sufficiently thick to prevent regional-scale exchange of seawater with underlying basaltic basement (Anderson and Hobart, 1976). The cooling of the basement is governed predominantly by conductive heat loss across the overlying sediment column. However, the previous studies on the porewater chemistry combined with heat flow data and the downhole flow of seawater in Hole 504B suggest that, in spite of the thick sediment cover, convective heat flow due to circulation of warm seawater through the sediment column may persist where there are isolated heat flow highs.

After Leg 83, extensive heat flow surveys and piston coring for porewater chemistry at Sites 501/504 were conducted during two research cruises, RC 2305 (R/V Conrad) in 1982 and TT-198 (R/V Thomas G. Thomson) in 1986, with M. Langseth and M. Mottl being the co-chief scientists of both cruises. The vertical gradients of porewater chemistry were positively correlated with heat flow at the site, a strong indication of upward advection of pore water in areas of high heat flow (Langseth et al., in preparation). The optimum positions for Sites 677 and 678 were chosen on the basis of heat flow and basement temperature maps provided by M. Langseth using the geophysical data obtained by TT-198, combined with precisely navigated data from RC-2305 and RC-2606 (Figure 2).

Results from Sites 677 and 678

Two holes were drilled at Site 677: Hole 677A to basal sediments and altered basalt at 309.4 mbsf, and Hole 677B to 93.1 mbsf, offset 10-30 m from Hole 677A. The original drilling program at Site 677 had been to core two holes with the APC to refusal, then continue one of them to basement with the XCB. However, because time was short, the second hole, Hole 677B, was terminated when Pliocene sediment was first recovered, thus assuring a complete Pleistocene sedimentary section.

The time problem was more severe at Site 678, where Hole 678B was cored only at 0-7.5, 18.2-27.7, 95.5-105.0, and 169.5-171.8 mbsf, with intervening intervals being washed down. The last core recovered fragments of basal basalt. Hole 678A was abandoned after two successive failures to obtain a good mudline core.

Three major sedimentary units and a basal basalt unit are recognized at Site 677. Unit I consists of alternating clayey biogenic calcareous siliceous oozes and clayey biogenic siliceous calcareous oozes of early Pliocene to late Pleistocene age. Unit II is composed of siliceous nannofossil oozes and chalk of late Miocene to early Pliocene age. Unit III consists of cherty limestone and nannofossil chalk of late Miocene age, and Unit IV consists of iron oxide- and smectite-rich sediments intermixed with glassy basement basalts of late Miocene age. The sedimentary section at Site 678 may be divided into four similar units, although spot coring at this site makes precise comparison with Site 677 difficult.

The boundary between Pliocene and Pleistocene lies within Core 111-677A-9H (72.7-82.2 mbsf) and in Core 111-677B-9H (74.1-83.6 mbsf). The early/late Pliocene boundary is within Core 111-677A-17A. The Miocene/Pliocene boundary is placed in the middle of Core 111-677A-23X. The oldest sediment recovered in Hole 677A has an age of 5.6 to 5.9 Ma. The rate of sedimentation is surprisingly constant with a mean value of 42 m/m.y. over the last 5.6 m.y., although the first 0.3 m.y. of deposition had a much higher rate.

Unit IV in both Holes 677A and 678B consists of dark green and gray muds, intercalated with basalt pebbles and conglomerates, and calcite veins and aggregates. A 2 x 3 cm concretion of pyrite and marcasite was noted within the poorly indurated conglomerates from Hole 677A. Alteration of the basalts represents early diagenesis with very shallow burial, and possibly low pressure-low temperature hydrothermal processes. It is of special interest for interpretation of the pore water chemistry.

Pore waters were squeezed from the sediments, including the smectite- and iron-oxide-rich alteration products from the upper basement sections, at intervals of approximately 10 m in Holes 677A and 677B and at intervals of about 3 m in the spot cores of Hole 678B. The pore waters were analyzed on board JOIDES Resolution for major (Ca, Mg, SO_4, Cl) and minor (Si, NH_4, NO_2+NO_3, PO_4, H_2S) components. Except for the basal alteration products, sufficient amounts of pore waters could be squeezed from the sediments to provide split aliquots for shorebased analyses of stable isotopes of water, trace heavy metals, amino acids, and sugars.

In pore waters squeezed from sediments from Holes 677A and 677B, Ca and Mg maintain almost the same concentrations to about 110 mbsf as those in overlying ocean bottom water. Below that, to just above the smectite-rich alteration products, Ca slowly increases, while Mg decreases, respectively reaching concentrations approximately 2 and 0.7 times those in the ocean bottom water. However, Ca and Mg show drastic changes in concentration in the underlying basal alteration products of 14 m thickness; Ca increases to 7 times and Mg decreases to 0.2 times the concentrations in the ocean bottom water.

In the pore waters from the sediments of Hole 678B, Ca and Mg exhibit depth profiles that contrast sharply with those at the low heat flow site. Ca quickly rises to a concentration close to 5 times that in seawater in the topmost 40 m of sediment, and maintains that concentration down to the basement, where it again sharply increases to the same concentration as that encountered at basement in Hole 677A. Mg shows a correspondingly rapid decrease to nearly 0.15 of the ocean bottom seawater value within the upper 40 m of the Hole 678B sediments. In the basal altered basalt, almost the same concentration of Mg as in Hole 677A was found.

Profiles for NH_4, Si, and PO_4 are dominated by reactions in the sediments. All of these species except PO_4 show large gradients near basement at Site 677 and near the seafloor at Site 678, again showing the contrast between the sites. The alkalinity profile is also convex-upward at Site 678.

These observations clearly indicate that ocean bottom seawater flows down through the 300-m-thick sediment into basement at the low heat flow Site 677, whereas significantly altered seawater formed in basement upwells through the 180-m-thick sediment into overlying seawater at the high heat flow Site 678. The rate of these flows estimated from the depth-composition profiles is approximately a few mm/yr at both sites. However, the similarity in composition of pore water from the basal alteration products at both sites suggests that the advective flow rates in sediment are negligible compared to those in basement.

Several attempts were made to measure temperature-depth profiles at both sites, in order to verify advective flow rate of pore water obtained from the chemical gradients. However, battery failures resulted in only 3 acceptable temperature measurements in the upper 100 m at Site 677, from which the temperature at the sediment/basement contact is estimated to be roughly 60-70°C. The temperature profile at Site 678 could not be determined.

In spite of the limitations in time and problems with equipment, the coring and subsequent shipboard studies at Sites 677 and 678 unambiguously demonstrated that the ocean bottom water and sediment-covered basement still exchange materials and heat, though slowly, through localized advective discharge-recharge systems in the area of Sites 677/678, even though conductive heat loss predominates on a regional scale.

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Table Captions

Table 1. Logs and experiments run in Hole 504B before Leg 111.
Table 2. Logs and experiments planned to be run in Hole 504B during Leg 111. * = actually run. ** - only borehole waters were actually sampled.

Figure Captions

Figure 1. Location of Site 504 in the eastern equatorial Pacific.
Figure 2. Preliminary contours of heat flow (in mW/m^2) in the vicinity of Site 504. Heat flow measured and contoured by M. Langseth, M. Mottl, and M. Hobart, 1986.
Figure 3. Site survey surface heat flow measurements and seismic profile on the southern flank of the Costa Rica Rift. The spreading axis is about 110 km farther north (left) than this figure extends.
Figure 4. Distribution of secondary minerals with depth in Hole 504B. Symbols and abbreviations: + includes analcite, stilbite, thompsonite, and natrolite. ++Gy = gyrolite, AA = aegerine augite, Me = melanite, RML = regular-mixed-layer chlorite plus smectite, Gn = galena, Cp = chalcopyrite, Sl = sphalerite. * mixtures range from chlorite-rich (Type 1) to expandable layer-rich (Type 5). ** mixtures range from pure smectite (a) to pure vermiculite (e).
Figure 5. Schematic of Hole 504B drilling history and lithostratigraphy through the end of Leg 111.
Figure 6. Equilibrium temperatures measured in Hole 504B during Legs 69, 70, 83, 92, and 111.
Figure 7. Equilibrium temperatures in the upper part of Hole 504B and profiles predicted with a constant downhole flow rate model. Note the decay of the downhole flow rate over the seven years since the hole was spudded during Leg 69.
Figure 8. Leg 111 geophysical experiments in Hole 504B. Left to right: bulk permeability measured by the packer experiment, fracture and total porosities determined from electrical resistivities, normative mineralogies and relative MgO and Al_2O_3 contents determined from spectral analysis of neutron activation logs, and magnetic inclination. Normative mineralogies were determined by recalculating elemental contents of Si, Al, Fe, Mg, and Ca into the normative components actinolite (ACT), chlorite (CHL), plagioclase (PLAG), clinopyroxene (CPX), olivine and smectite, assuming typical local compositions for the normative minerals. Normative plot units indicate the fraction (1 signifies 100 normative weight percent) of the rock formed by each normative component. Relative contents of MgO (MG) and Al_2O_3 (AL) are shown as counts, where 1 signifies the maximum observed. Average amount of MgO is 7 weight percent, and of Al_2O_3 is 22 weight percent. ST denotes the 18 m-thick stockwork-like unit.

Table 1. Logs and experiments run before Leg 111 in Hole 504B.

Log/Experiment	Interval successfully logged (m bsf)	
Caliper log	274.5-1287.5	
Neutron log	274.5-1287.5	
Density log	274.5-1287.5	
Sonic logs		
P, S, full waveform	274.5-1287.5	
Multi-channel sonic	274.5-426	
Borehole televiewer	274.5-1287.5	
Oblique seismic experiment	316.5, 546.5, 726.5, 941.5 (geophone)	
Resistivity logs		
Spherically focused laterolog	274.5-1287.5	
Large-scale experiments	274.5-836	(45, 91, 182 m spacing)
	274.5-1287.5	(10,20,40,80 m spacing)
Temperature (11 data sets)	0.0-1287.5	
Borehole fluid samples	451-1204 (many samples)	
Packer - permeability intervals	316.5-489	
	473.5-489	
	536.5-1287.5	
Magnetometer (Russian)	274.5-489	

Table 2. Logs and experiments planned to be run in Hole 504B during Leg 111. * = actually run. ** - only borehole waters were actually sampled.

Measurement	Tool and/or Operator	Depth Interval (m bsf)	Time Estimate
(A) Before drilling --	listed in order of deployment		
*Temperature	France (BRGM)	0-1350	12 hours
**Water Sampling	Schlumberger RFT/Kuster	400-1350	36 hours
*Neutron activation	ACT/GST/NGT	275-1350	
*Multi-channel sonic	L-DGO	275-1350	2 days
*Magnetometer	Japan	275-1350	
*Permeability	U. Miami packer	500-1350	1 day
(B) After drilling --	not listed in order of deployment		
Temperature (2)	France (BRGM)	900-bottom	18 hours
Sonic/Electrical	LSS/DIL/SFL Schlumberger	900-bottom	
*Density/Porosity	LDT/NGT/CNT "	275-bottom	3 days
*Neutron activation	ACT/GST/NGT "	900-bottom	
*Electrical resistivity	DLL "	275-bottom	
*Borehole televiewer	USGS	900-bottom	18 hours
*Multi-channel sonic	L-DGO	900-bottom	12 hours
Magnetometer	Japan	900-bottom	
Large-scale resistivity	U. Miami	900-bottom	18 hours
*Permeability	U. Miami packer	900-bottom	1-2 days
*VSP	U. Texas Austin	275-bottom	2 days

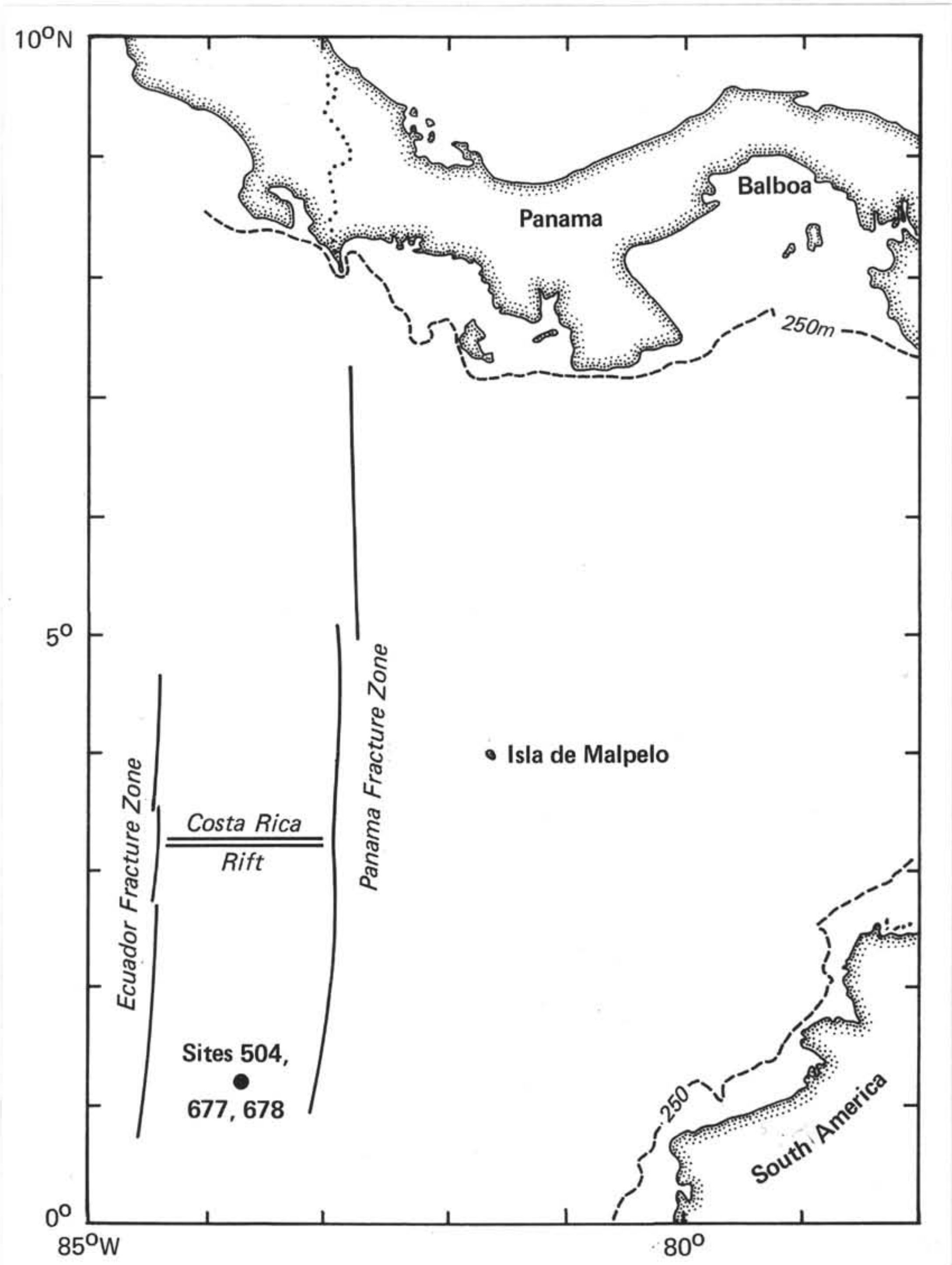
10°N
5°
0°
85°W
80°
Panama
Balboa
250m
250
Isla de Malpelo
Ecuador Fracture Zone
Panama Fracture Zone
Costa Rica
Rift
Sites 504,
677, 678
South America

FIGURE 1.

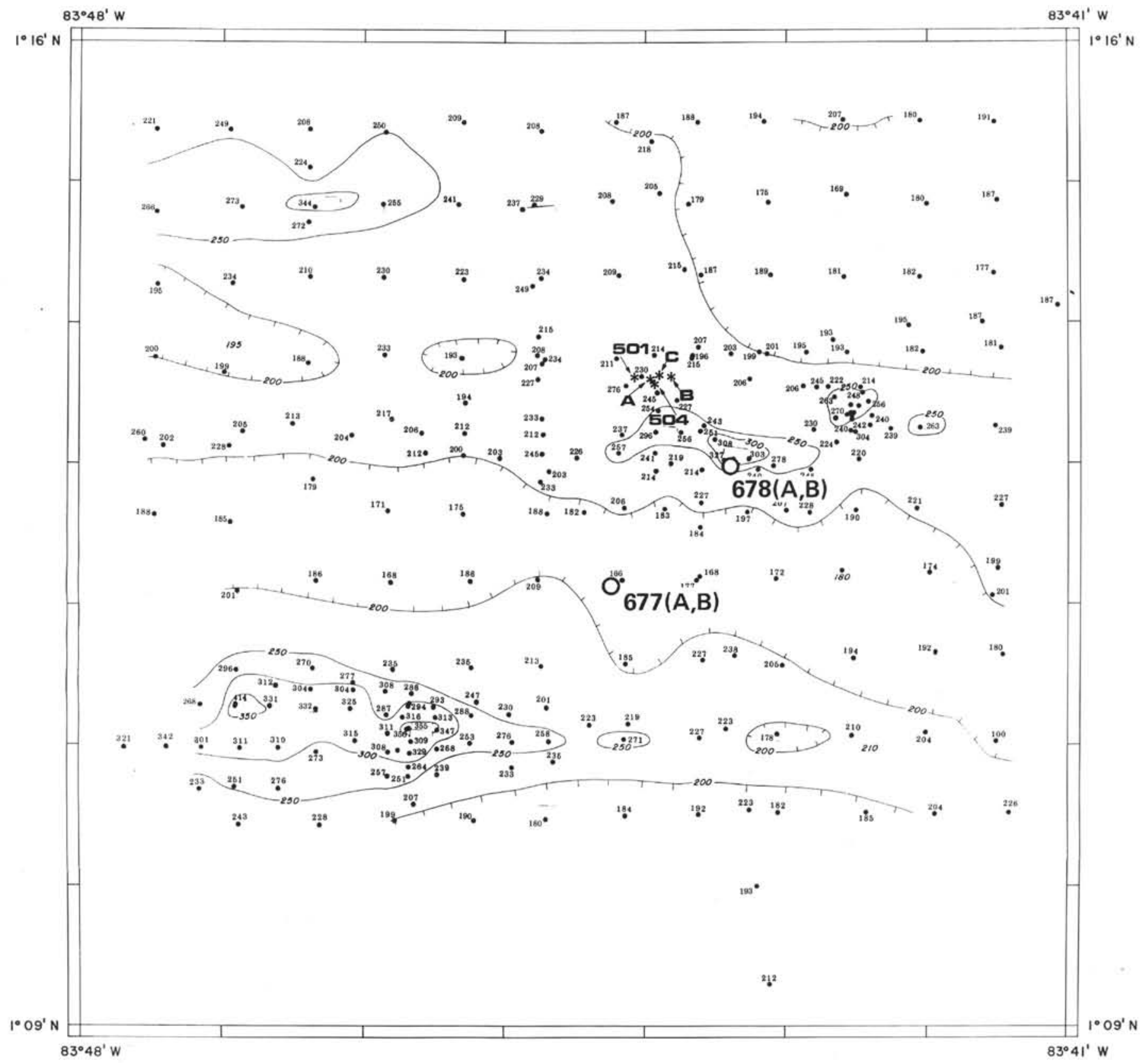
83°48' W
83°41' W
1° 16' N
1° 16' N
1° 09' N
1° 09' N
83°48' W
83°41' W
501
504
A
B
C
678(A,B)
677(A,B)
200
250
300
350

FIGURE 2.

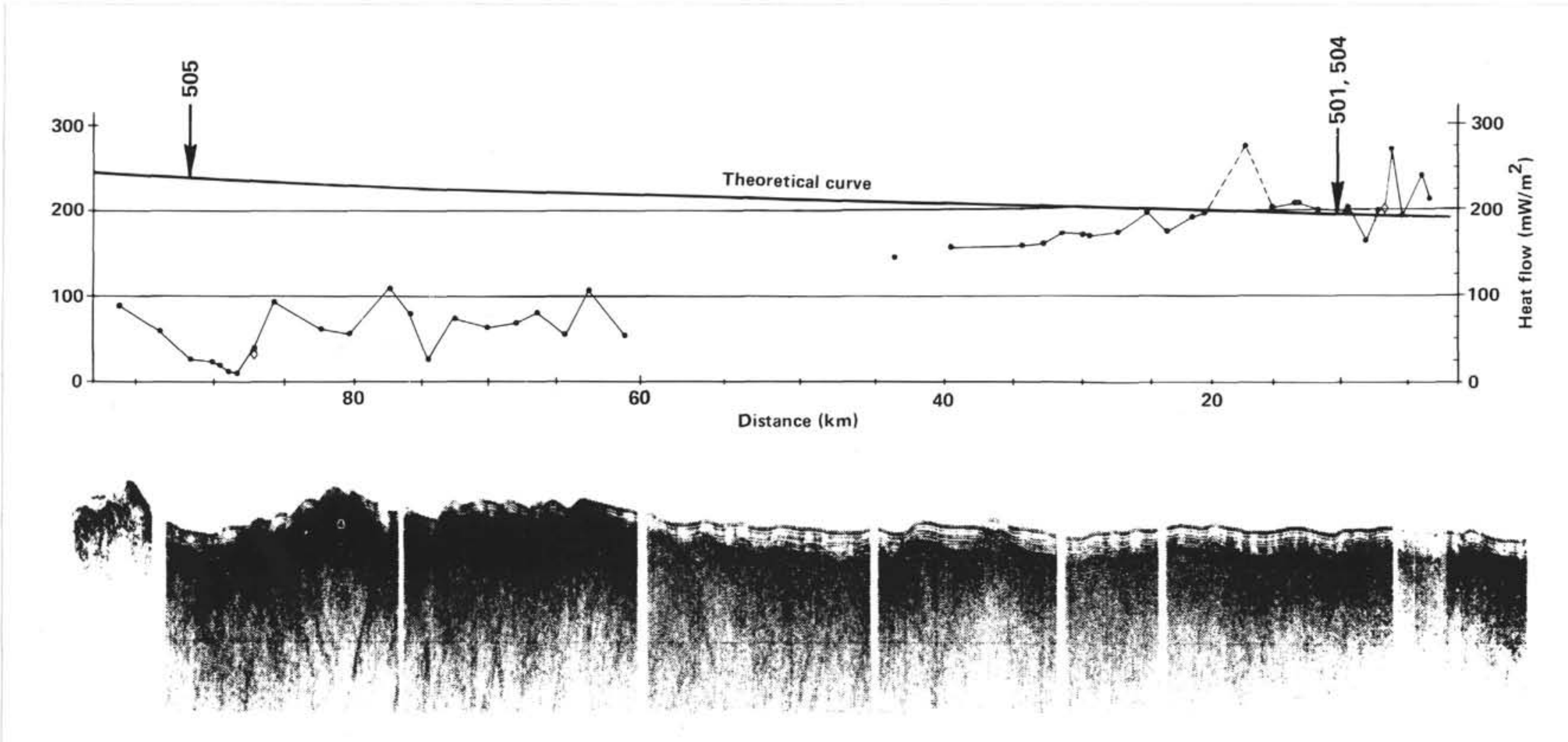
505
501, 504
Theoretical curve
300
200
100
0
80
60
40
20
Distance (km)
Heat flow (mW/m²)

FIGURE 3.

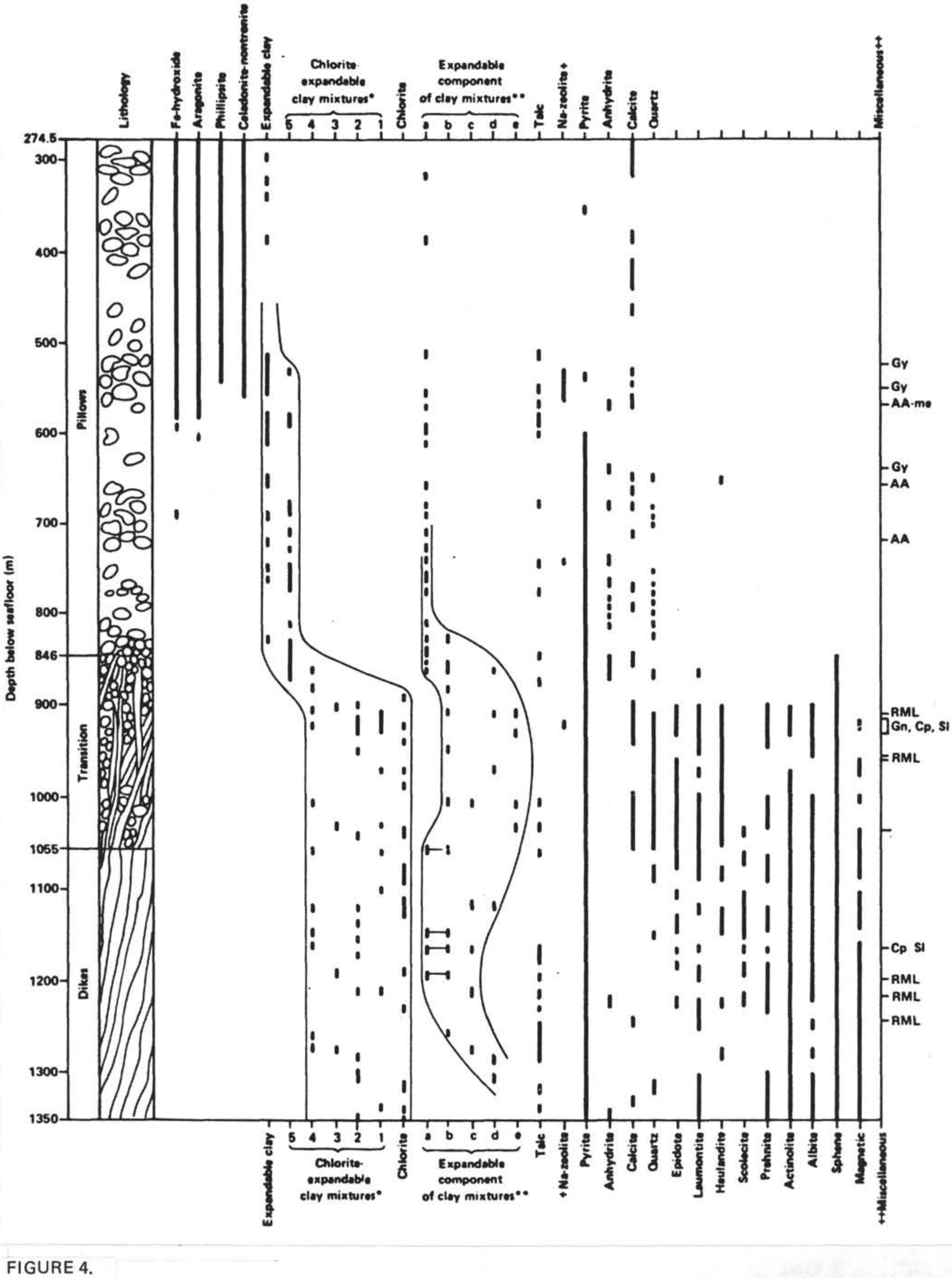
Lithology
Fe-hydroxide
Aragonite
Phillipsite
Celadonite-nontronite
Expandable clay
Chlorite-expandable clay mixtures*
5 4 3 2 1
Chlorite
Expandable component of clay mixtures**
a b c d e
Talc
Na-zeolite+
Pyrite
Anhydrite
Calcite
Quartz
Epidote
Laumontite
Heulandite
Scolecite
Prehnite
Actinolite
Albite
Sphene
Magnetic
Miscellaneous++
Depth below seafloor (m)
274.5
300
400
500
600
700
800
846
900
1000
1055
1100
1200
1300
1350
Pillows
Transition
Dikes
Gy
Gy
AA-me
Gy
AA
AA
RML
Gn, Cp, Sl
RML
Cp Sl
RML
RML
RML

FIGURE 4.

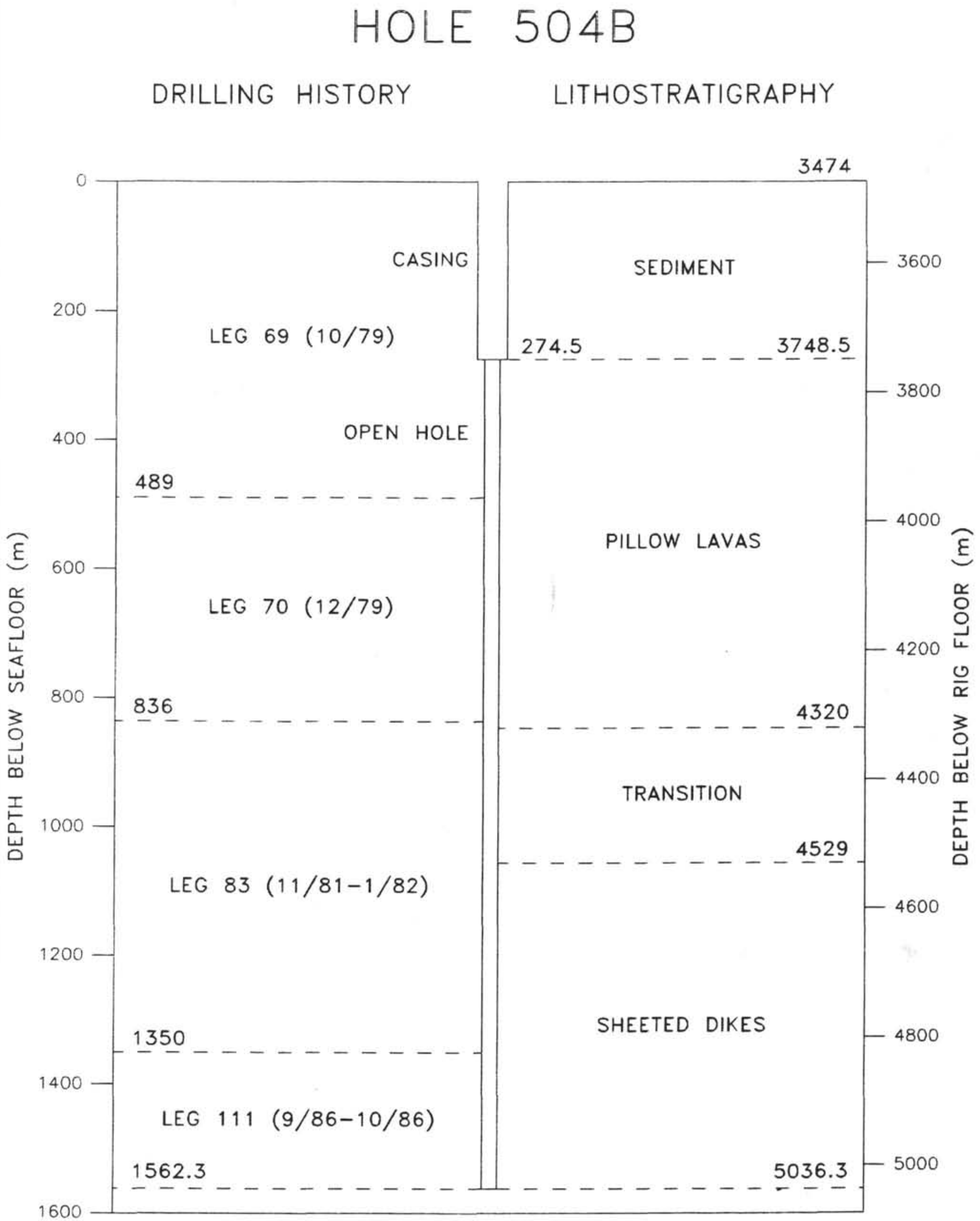
HOLE 504B
DRILLING HISTORY
LITHOSTRATIGRAPHY
0
200
400
600
800
1000
1200
1400
1600
DEPTH BELOW SEAFLOOR (m)
CASING
LEG 69 (10/79)
OPEN HOLE
489
LEG 70 (12/79)
836
LEG 83 (11/81-1/82)
1350
LEG 111 (9/86-10/86)
1562.3
3474
SEDIMENT
274.5
3748.5
PILLOW LAVAS
4320
TRANSITION
4529
SHEETED DIKES
5036.3
3600
3800
4000
4200
4400
4600
4800
5000
DEPTH BELOW RIG FLOOR (m)

FIGURE 5.

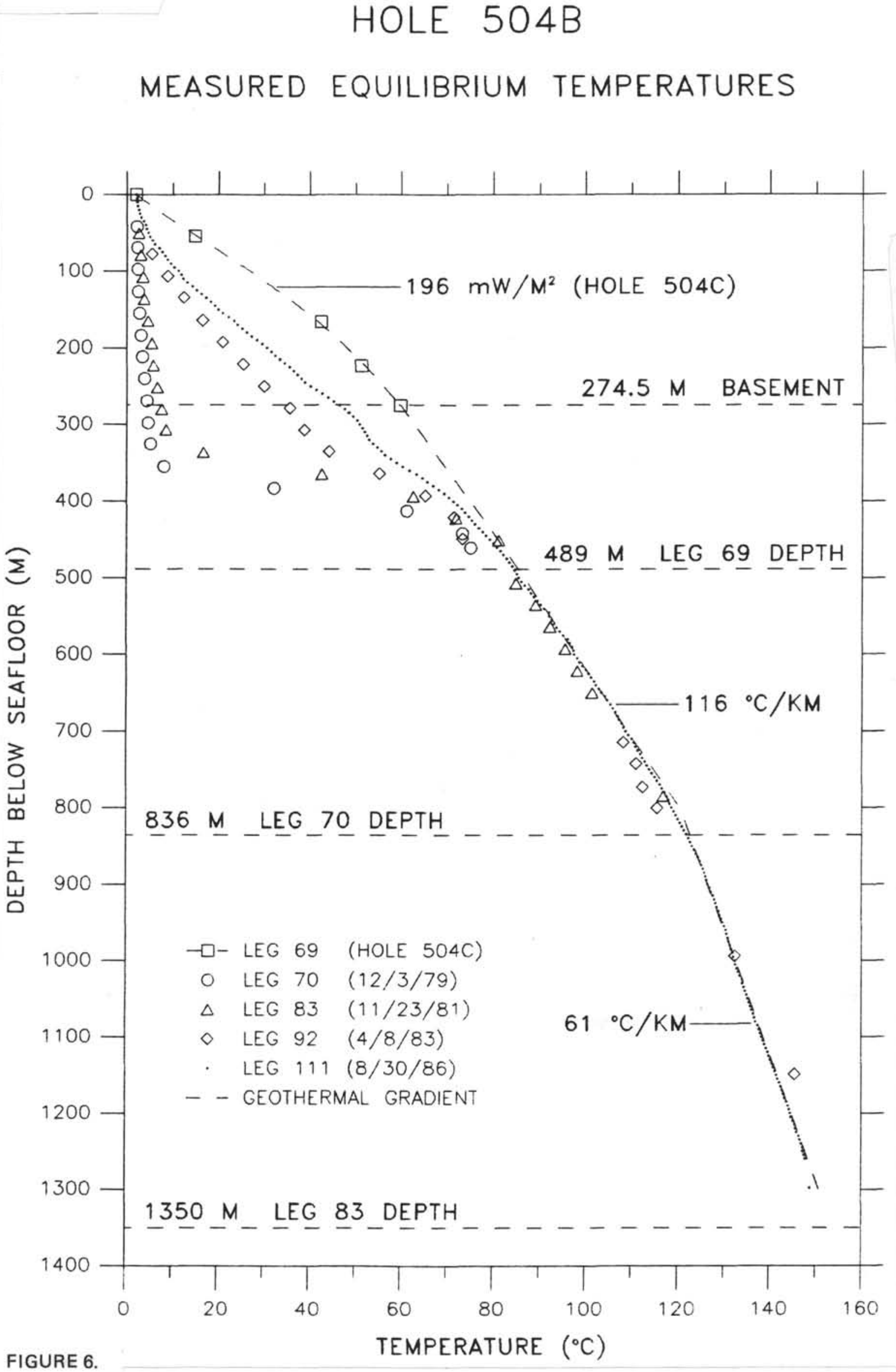
HOLE 504B
MEASURED EQUILIBRIUM TEMPERATURES
196 mW/M² (HOLE 504C)
274.5 M BASEMENT
489 M LEG 69 DEPTH
116 °C/KM
836 M LEG 70 DEPTH
61 °C/KM
1350 M LEG 83 DEPTH
LEG 69 (HOLE 504C)
LEG 70 (12/3/79)
LEG 83 (11/23/81)
LEG 92 (4/8/83)
LEG 111 (8/30/86)
GEOTHERMAL GRADIENT
DEPTH BELOW SEAFLOOR (M)
TEMPERATURE (°C)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
0
20
40
60
80
100
120
140
160

FIGURE 6.

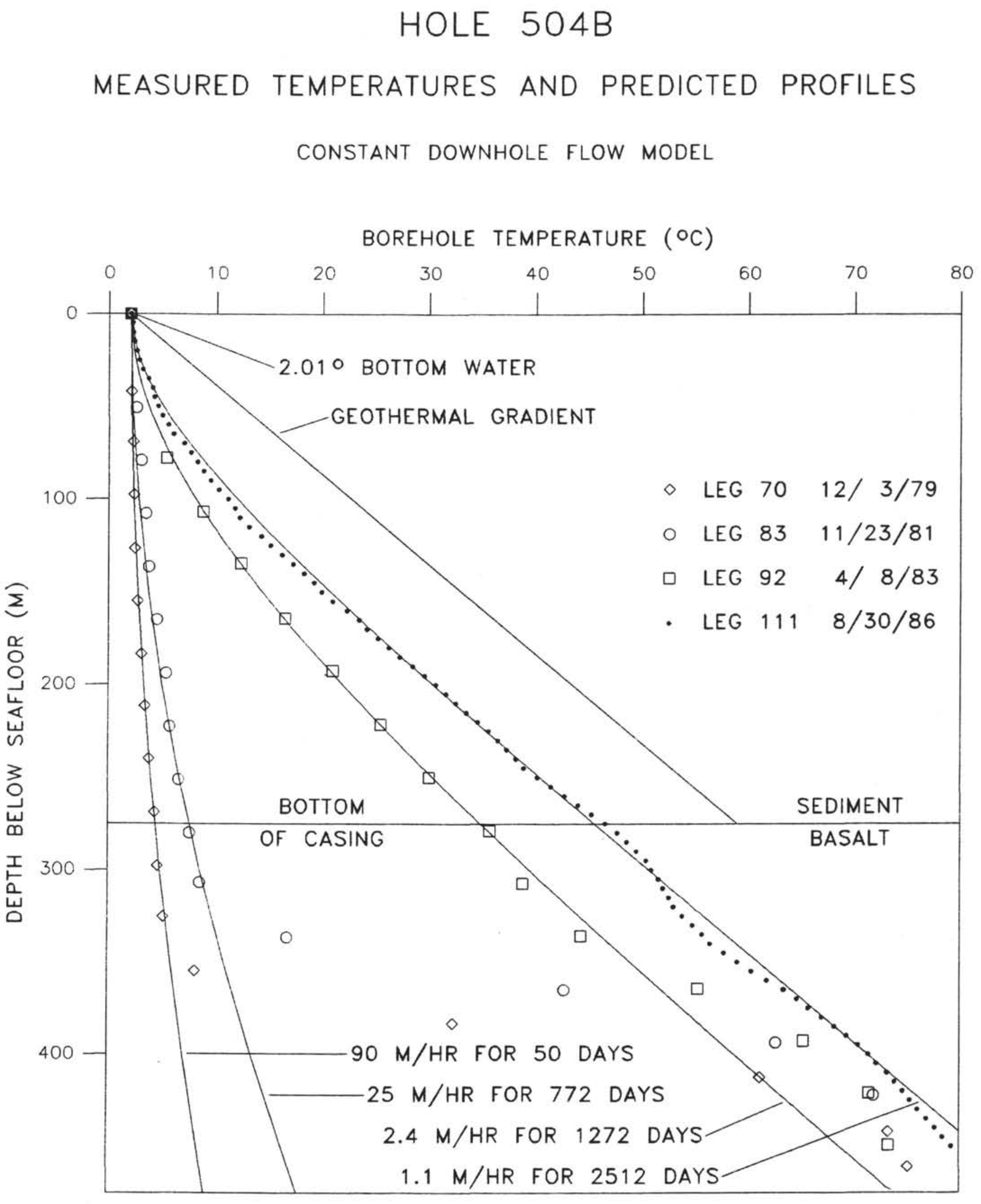
HOLE 504B
MEASURED TEMPERATURES AND PREDICTED PROFILES
CONSTANT DOWNHOLE FLOW MODEL
BOREHOLE TEMPERATURE (°C)
0
10
20
30
40
50
60
70
80
0
100
200
300
400
DEPTH BELOW SEAFLOOR (M)
2.01° BOTTOM WATER
GEOTHERMAL GRADIENT
◇ LEG 70 12/ 3/79
○ LEG 83 11/23/81
□ LEG 92 4/ 8/83
• LEG 111 8/30/86
BOTTOM
OF CASING
SEDIMENT
BASALT
90 M/HR FOR 50 DAYS
25 M/HR FOR 772 DAYS
2.4 M/HR FOR 1272 DAYS
1.1 M/HR FOR 2512 DAYS

FIGURE 7.

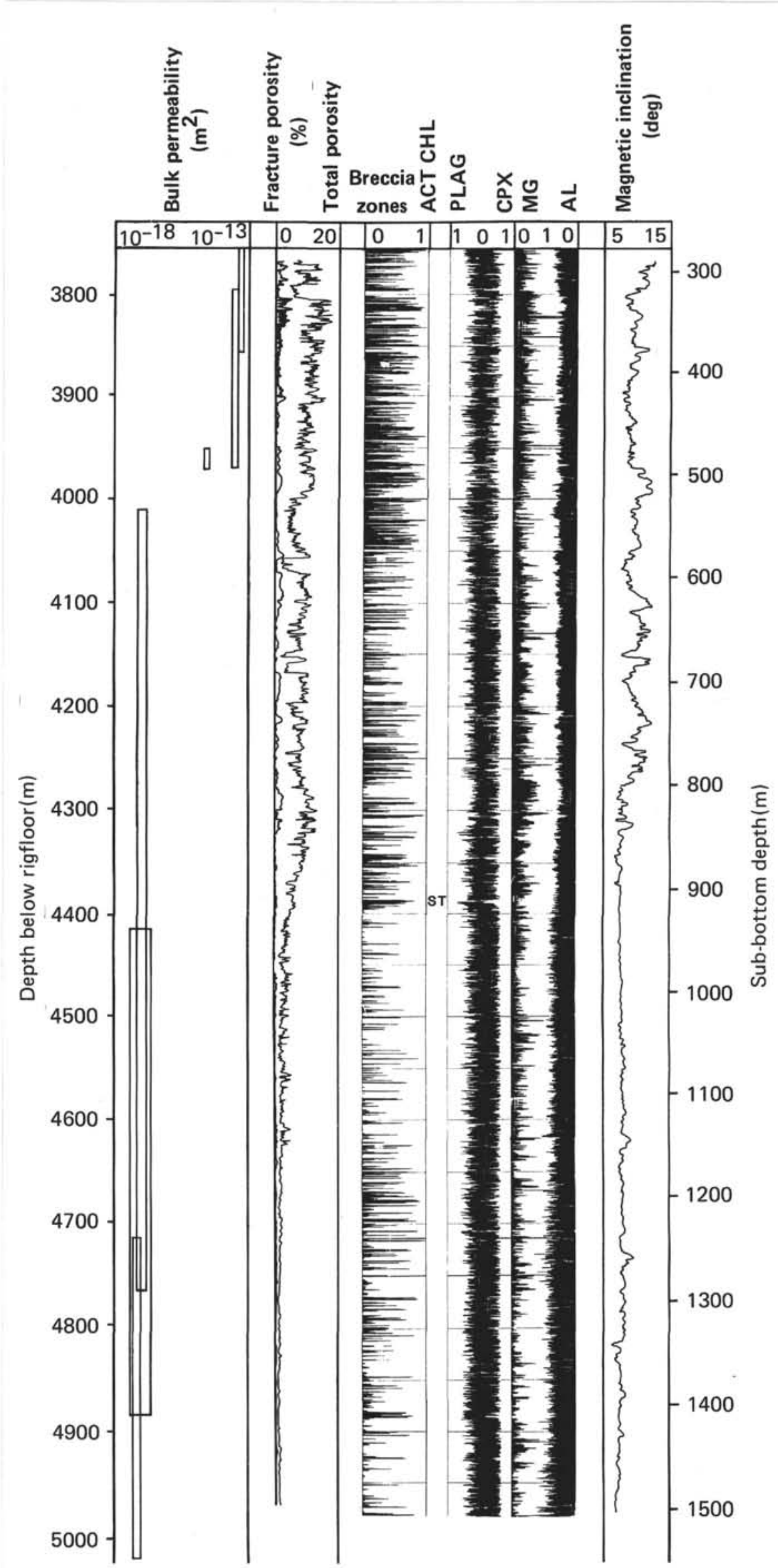
Bulk permeability (m2)
Fracture porosity (%)
Total porosity
Breccia zones
ACT CHL
PLAG
CPX
MG
AL
Magnetic inclination (deg)
10-18 10-13
0 20
0 1
1 0 1
0 1 0
5 15
Depth below rigfloor (m)
3800
3900
4000
4100
4200
4300
4400
4500
4600
4700
4800
4900
5000
ST
Sub-bottom depth (m)
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 8.

OPERATIONS REPORT

OPERATIONS SYNOPSIS--ODP LEG 111

Bridgetown to Balboa

The official beginning of Leg 111 was at 0545 hr 16 August 1986 with the arrival of JOIDES Resolution at Bridgetown, Barbados. The duration of the port call was only 20-1/2 hours, during which freight shipments were loaded and off-loaded. Foodstuffs and drill water were loaded and the UDI/Catermar crew change was accomplished. The Leg 110 scientific staff departed at Barbados, while several ODP personnel and special guests boarded for the transit to Panama.

With the exception of various course and speed deviations for a number of tests on underway geophysics equipment, the transit was a "deadhead" run to the Caribbean entrance to the Panama Canal at Cristobal. During the transit a fire occurred in the step-down transformer of SCR bay F. Deteriorated insulation resulted in ignition of the center coil of the transformer, which led to the loss of half of the power supplying the starboard shaft for the duration of the trip to Balboa. Ironically the fire occurred while a firefighting school was being conducted by a UDI safety instructor.

After a ten-hour wait at the Cristobal anchorage, passage through the canal required an additional 9-3/4 hours. A brief stop was made at the U.S. Naval Station, Panama Canal (Rodman) to off-load a hard rock guide base, casing and other bulky equipment not scheduled for deployment in the foreseeable future. The vessel then moved across the channel and tied up at Pier 18, Balboa Harbor at 1945 hr 22 August.

Balboa to Site 504

During the Balboa port call, fuel, water, sacked bentonite, and other freight were loaded. The fire-damaged transformer was removed and a transformer from one of the two drilling thyrig bays was moved into its place. The derrick A-frame was laid over for clearance under the Bridge of the Americas. ODP crew change was held and participating Leg 111 scientists boarded.

Departure was delayed a little over a day for the arrival of critical parts needed for Leg 111 operations. Departure from Balboa was at 1450 hr 27 August. After passage under the bridge, a brief stop was made at anchorage in the roadstead while the A-frame was raised into position and a small boat brought the final much-needed parts (in the possession of the ODP Logistics Officer) to the ship.

The transit to DSDP Hole 504B was made in rainy weather but with favorable wind and sea conditions. The 526-mile voyage was made at 11.8 knots. The positioning beacon was launched, using real-time Global Positioning System (GPS) fixes, at 1506 hr 29 August.

Hole 504B -- First Phase

The 504B reentry cone was located without undue difficulty by means of the combination television/sonar external guide frame system. The reentry offsets showed that the ship's navigation had placed the beacon only 113 m from the reentry cone.

As initial operations upon reoccupation of Hole 504B were to consist of logging and downhole science, the bottom-hole assembly (BHA) was terminated with an open-ended reentry/cleanout bit. An inflatable open-hole packer was located just above the bit for use in permeability pulse tests. The bit was lowered only to 105 mbsf to avoid disturbing the water column in the hole.

The first downhole tool, a French temperature logging device, reached a maximum depth of 1280 mbsf and recorded a bottom-hole temperature of 148.9°C. It was followed by a suite of water samples at increasing depths. The samples were collected by means of sandline-deployed Kuster samplers and a Schlumberger retrievable formation tester (RFT) that was run on the logging cable. Because of an electrical problem with the RFT, the sampling program was interrupted for additional logging. A multichannel sonic log provided by the ODP Borehole Research Group and a Schlumberger NGT/ACT/GST nuclear log were then recorded over previously unlogged hole intervals. A dual Kuster sampler run was made next, followed by the newly-repaired RFT tool. After the RFT sample, the downhole tool would not pass up into the end of the drill pipe. It was necessary to cut the logging cable, "strip" the pipe out of the hole over the cable, and retrieve and discard the severed cable to recover the RFT tool. On recovery of the tool it was found that a retractable arm of the tool had broken off and been left in the hole. The packer permeability measurements, which had been scheduled to follow the logging, were deferred until a later date.

The missing arm constituted a considerable mass of steel which had to be removed from the hole before coring operations could begin. A junk mill is carried aboard the vessel for such situations; it was made up to the BHA, along with a "boot basket" to capture metal fragments, and a pipe trip/reentry was made to clear the hole of junk. A "bridge" in the hole was encountered and easily cleared at 1290 mbsf and the hole was cleaned of cuttings and rubble to its previous total depth before milling began. When drilling parameters indicated that the junk had been fragmented, the pipe was tripped for coring operations.

The first core bit produced fair core recovery and a better-than-anticipated penetration rate. The run was terminated somewhat prematurely by a stuck inner core barrel after 17-1/2 rotating hours. Some torquing and sticking had been experienced and the bit had been damaged, apparently by junk.

The next round trip/reentry was devoted to the packer permeability tests that had been postponed earlier. The packer performed according to design at the first setting depth of 936 mbsf and four "slugs" were pumped into the formation with the rig's cementing unit. Pressure decay curves were recorded after each pulse with excellent results. The packer was moved down the hole to 1236 mbsf and reset with a downhole go-devil. The element seated mechanically, holding string weight, but achieved no pressure seal against the hole wall. The drill string was recovered and the rubber covering was found to have been stripped from the packer element.

The second core bit run followed. The good rate of penetration continued, but hole problems increased with depth while core recovery decreased. The bit was pulled after a respectable 35 rotating hours. The bearings and cutting structure were in good condition, but there was junk damage to the body. In addition it was found that the welded blades had been peeled from the stabilizer above the outer core barrel. Large flat pieces of steel were found in the boot basket.

Following the subsequent reentry with a core bit, circulation could not be established upon picking up the top drive at total depth. In conjunction with the reentry, the rig pumps had been used to flush accumulated cuttings and sediment from the reentry cone. Enough material had apparently been washed back down the hole that it backflowed into the pipe during the trip into the hole and plugged it. It was necessary to make a complete round trip to clean the sand-like cuttings out of the BHA.

The next core bit again encountered deteriorating hole conditions and very low core recovery. Torquing and sticking became severe after three cores. Unfortunately the torque from hole conditions apparently masked torque from bearing failure, which was not suspected until the bit locked up on contact with the hole bottom on starting the fourth core. On recovery of the bit, all four cutter cones were found to be missing--the result of catastrophic bearing failure after only 16-1/2 rotating hours.

Two trips into the hole were then made with a junk basket with the aim of retrieving the lost bit cones. One cone was recovered on each of the runs, with the first also producing ten large chunks of basalt. A third remedial trip/reentry was made with the junk mill to machine the remaining cones or portions thereof into manageable fragments.

Coring operations then resumed with another roller cone core bit and boot basket. Two fast but rather unproductive cores were cut before the hole again closed in with torquing, sticking, and two meters of fill. After a drop in penetration rate in the adverse conditions and a zero-recovery core, a chisel-type core breaker was pumped down the pipe to clear the bit throat. It stuck at the bit. The pipe was tripped to clear the coring assembly and the bit was again found to have lost all its cones. Rotating time again had been only 16-1/2 hours.

With the junk problem escalating and the on-board remedial tool supply dwindling, coring operations were halted and an emergency request was sent to ODP Headquarters for additional fishing tools.

The logging/packer BHA was again made up and a reentry was made for the completion of the 504B downhole science program. A casing running tool was included in the BHA for landing and immobilizing the drill string in the throat of the reentry cone. Consecutive logging runs were made with the Schlumberger ACT/GST/NGT/CNT/LDT nuclear log, the Schlumberger dual laterolog, the USGS borehole televiewer and the Borehole Research Group's multichannel sonic log. A vertical seismic profile conducted by a University of Texas investigator and Schlumberger was recorded over the next two days. The drill string was immobilized at the reentry cone for the VSP. Upon completion of the VSP, the casing running tool was released and the packer was run to 1234 m for an additional round of pulse tests. Two successful pulse/decay cycles were recorded, but the packer element ruptured as the formation was being pressured on the third pulse. The pipe was then pulled back to logging depth and an additional Schlumberger nuclear log (LDT/NP/NGT/GPIT) was recorded.

Site 677

During the pipe trip for the installation of the hydraulic piston coring (APC) BHA, the vessel was offset about 1.5 miles south-southwest using the Hole 504B beacon and then GPS for navigation. Sediment coring at a site of locally low heat flow was the objective of Site 677, where a new beacon was launched.

Hole 677A was spudded at 1640 hr 30 September with a "mudline" piston core. Oriented advanced hydraulic piston (APC) coring reached refusal at 140 mbsf and extended core barrel (XCB) cores continued to basement at 309 mbsf. Two runs were made within that interval with the combination temperature/ pressure/water sampler probe.

The bit was then pulled clear of the seafloor and a new hole (677B) was spudded. The APC sequence was duplicated, with overlapping core intervals, to 93 mbsf. Again the seafloor was cleared with the bit for the move to a nearby site of locally high heat flow.

Site 678

Another beacon, a command-retrievable model, was dropped at the new site and APC coring operations commenced. A local bathymetric high caused an erroneously shallow reading on the precision depth recorder and two APC attempts were required to capture the sediment/water interface. The second core attempt penetrated only 54 cm into the seafloor, which was not considered adequate for the scientific requirements of the initial core. As the interval was to be duplicated, the short core was designated Hole 678A and a respud was done from several meters deeper.

With the allocated site time running out, Hole 678B was spot-cored with the majority of the interval drilled without coring. A total of three APC cores (with heat flow shoes) were taken to 105 mbsf. The interval from 105 mbsf to basement at 172 mbsf was drilled with one interim XCB core taken.

As the drill string was recovered, several attempts were made to recall the beacon with acoustic commands. They were unsuccessful, but did restart the beacon at nearby Hole 504B (which was set up for a different command code).

Hole 504B--Second Phase

The short offset (1360 m) back to 504B was made during the round trip for the fishing BHA. The first trip again featured the Homco junk basket, assisted by a boot basket and a permanent magnet that was positioned in the top of the junk basket with a retrievable inner core barrel. Fifteen meters of rubble were found in the bottom of the hole and the junk basket captured only three large basalt rocks. The magnet brought out only flakes of casing rust, but the boot basket held several pieces of bit cones and other metal fragments.

A tentative coring venture was then made with a roller cone bit and boot basket. The first core was encouraging, with good penetration rate (ROP) and 20% recovery. The ROP declined and hole problems started on the second core and the bit was pulled after 14.5 m and nine rotating hours. The cutting structure was destroyed and one bearing had failed to the extent that the cone was loose on the shank. The boot basket held a relatively small amount of modest-sized junk.

The emergency hardware boat arrived just as the BHA was being recovered. The BHA was immediately fitted with two newly-arrived commercial boot baskets and a flat-bottomed junk mill. Surface indications promised that the mill run had been effective in clearing the hole of both basalt rubble and large pieces of junk. The hole was flushed thoroughly with drilling mud and a trip was made for a coring BHA. Upon recovery the mill was in good condition and the junk in the boot basket was even smaller in size and volume than on the previous run.

The scheduled deployment and evaluation of diamond coreheads in Hole 504B had been stymied by the continual presence of junk and poor hole conditions. With operating time running out, it appeared that conditions would get no better and a NOR Industries geoset diamond bit was deployed. About two meters of fill and under-gauge hole were found at total depth. On tagging bottom, a series of violent pressure surges were experienced, followed by the expected parameters of pump pressure and torque. The familiar indications of inadequate hole cleaning (torque and drag) appeared in short order, however, and no discernible penetration was made in several hours. Pump pressure was too low and it was suspected that string weight was not being transmitted to the bit. A wireline trip for the inner barrel was made (no recovery) and a "short trip" of five joints was made, all to no avail as sticking tendencies increased. The drill string was recovered and it was found that the pin connection of the bit sub had failed. Remaining in the hole were the bit, the float valve assembly, the lower support bearing assembly and the inner core barrel assembly.

With only five days of site time remaining, the chances of clearing the hole of such a formidable array of junk were exceedingly slim. The process was started, however, by reentering with the Homco junk basket and recovering the inner core barrel assembly by washing over and engaging the latch assembly with another core catcher. The core barrel was retrieved with the coring line. A "rig-engineered" spear was then deployed on another wireline core barrel in an unsuccessful attempt to engage the bore of the bit and recover all remaining components.

A second round trip was made to dress the junk basket with catcher teeth and attempt to engage the 7" diameter support bearing and float assemblies. The wireline spear was again deployed for an internal catch, but both efforts were unsuccessful.

Operations at Hole 504B were concluded with two round trips with a Bowen overshot that was modified for ultra-short catch and dressed with a 7" spiral grapple. The first attempt succeeded in recovering the outer race of the support bearing. In the process, however, the bearing came apart, leaving the inner race, 42 steel balls and other parts in the hole. The second attempt was promising, although nothing was recovered, in that the hole was clean down to the fish and the overshot was apparently scarred by contact with the fish.

Site 504 to Callao

The vessel departed Site 504 at 1815 hr 16 October and arrived at Callao, Peru at 0645 hr 20 October 1986. The 903-mile transit was made at an average speed of 11 knots.

TECHNICAL REPORT

TECHNICAL REPORT

Introduction

Leg 111 began in the Pacific port of Balboa, Republic of Panama, on 22 August 1986 following a five-day transit from Bridgetown, Barbados, across the Caribbean and through the Panama Canal. The leg terminated in Callao, Peru, on 20 October, 1986. The primary scientific objectives of this cruise were to return to DSDP Hole 504B, reenter, and carry out a series of in-situ geochemical, geophysical, and logging measurements, as well as conventional rotary coring operations to deepen the hole. In addition, time was allocated for coring adjacent areas of hydrological, biostratigraphic, and paleoceanographic interest. Four holes were drilled at two site locations near Hole 504B using advanced hydraulic piston coring (APC) and extended core barrel (XCB) coring techniques. Over 420 meters of sediments and basalts were recovered during the cruise and approximately 5000 samples collected for shipboard and shorebased studies.

Balboa Port Call

Routine port call activities commenced the evening of 22 August in Balboa, following a brief stop to discharge a hard-rock drilling base at the U.S. Navy's Rodman dock facility. Technician crossover activities were started the following day. Port-call work included routine logistics, service calls for DEC, HP, ARL, and Xerox equipment, photodocumentary work for SEDCO, CPR training, and preparations for upcoming work at Hole 504B. There were also tours for local officials and students. The ship departed at low tide, mid-afternoon on 27 August for anchorage offshore while awaiting critically needed cable head components being hand-carried from the States.

Cruise Activities

PDR, magnetometer, and HighRes navigation data were collected on the transits from Panama to 504B and to Callao, Peru. Site moves in the vicinity of Hole 504B were accomplished in dynamic-positioning mode with all thrusters down. Sites were selected from third-party site surveys and moves were aimed at specific coordinates. The target sites were located with the aid of shipboard GPS, transit satellite, and bathymetry. A single 80-cubic-inch water gun was deployed on the transit from 504B to Callao, Peru, in an attempt to collect high-speed geophysical data.

Prior to the start of this cruise, the Magnavox GPS system was upgraded with the latest version of I.C. cards and chips. All EDO flatbed recorders have been replaced with new Raytheon 1807M recorders. Several problems with the Masscomp computer were identified and repaired early in the cruise.

Operations

Following a short two-day transit from Panama, DSDP Hole 504B was reoccupied. Initial work prior to drilling involved a French temperature log, geochemical water sampling utilizing a Schlumberger Repeat Formation Tester (RFT), and Kuster water samplers, as well as various logging tools including a Japanese magnetometer. Water sampling was an overall success, but not without some problems. The Kuster water sampler was successful on only 3 of 10 runs.

This was due to operator unfamiliarity with the new tool and to mechanical problems. The RFT tool, which is designed to clamp tightly in the borehole and sample formation fluids, would not seal well against the borehole wall and managed to sample only borehole fluids; however, the geochemists were satisfied with the samples. On the third RFT tool deployment, a clamp arm would not retract properly and was broken off, remaining in the hole. After attempting to mill out the junk, coring operations commenced. A second series of downhole measurements was conducted after coring, which included various logging tools, a vertical seismic experiment, borehole televiewer, and packer tests. All were successful.

Pending the arrival of additional milling and fishing tools via boat from Ecuador, the decision was made to offset the ship and begin sediment coring work. Two holes were drilled at Site 677 using APC and XCB coring techniques. In-situ heat flow measurements and pore water samples were collected at this site with the Von Herzen heat flow tool and the new Barnes pore water sampler. APC cores were oriented using the Eastman multishot downhole survey camera. The success rate for both the multishot and Von Herzen heat flow tool was about 60%. APC core recovery was 100% while XCB recovery was considerably lower. At Site 678 two holes were drilled. Hole 678A consisted of a single mudline core. Hole 678B was washed and spot-cored to basement. The first run in Hole 678B of the Von Herzen heat flow tool was successful; the second run failed due to a faulty battery cell. After completing Hole 678B, the ship was offset back to Hole 504B and the remaining operating time was spent on Hole 504B.

Laboratory Activities

Overall laboratory activities were normal for hard rock and sediment drilling. As on Leg 109, ample time was available to continue technician cross training in most areas. In addition, ODP-authorized laboratory and office conversion tasks were continued. Sampling was surprisingly high for a low recovery cruise, with about 900 samples taken from basalts recovered from Hole 504B. Over 4000 sediment samples were taken from cored sediments at Sites 677 and 678. Large-volume borehole water samples from Hole 504B and extensive interstitial water samples from Sites 677 and 678 were taken for both shipboard and shorebased analysis. A new program for taking routine interstitial water and organic geochemistry samples was implemented. Special sampling for organic geochemistry analyses was conducted on sediment cores from Holes 677A, 677B, and 678B. Numerous organizational meetings were held to clarify sampling and analytical procedures.

Bridge Deck

The cryogenic magnetometer developed problems similar to those encountered during Leg 109. The unit was again vented in a controlled manner and preparations made to ship it to the vendor for intensive troubleshooting and repairs. The remainder of the magnetics lab functioned well. One problem developed with the A/C demagnetizer that warrants attention: It was noted that some samples became corrupted when demagnetizing them while tripping pipe. During troubleshooting, it was discovered that when the draw works were used to pick up, the voltage controlling the A/C demagnetizing field would vary slightly, causing distortions in the magnetic field of the A/C demagnetizer. This has not been seen on previous cruises and is thought to be a result of rewiring the thyrig bay following the loss of thyrig bay-F during the transit from Barbados to Panama.

Physical-properties equipment performed well with only a few minor troubles. Cell three in the pycnometer is giving variable results and is probably in need of an overhaul. Pycnometer documentation is insufficient for detailed troubleshooting or repair; additional information is being requested from the manufacturer. A GDS consolidometer installed on Leg 110 was given a thorough testing and evaluation this cruise, and a detailed manual was compiled.

Foc'sle Deck

Special emphasis on geochemistry kept the chemistry laboratory quite busy. The large-volume borehole water samples were subsampled for both shipboard analyses and a number of shorebased laboratories. Approximately 300 sediment samples were analyzed for carbonate and total carbon, and 72 interstitial water samples were squeezed, analyzed, and subsampled for further shorebased analysis. All standard titration and spectrophotometer measurements were run on board, along with analyses for H_2S and iron. New applications routines have been made available to display specified hydrocarbon-gas data to the terminal in the operations office. This will be useful on Leg 112.

The X-ray fluorescence (XRF) system operated well without any major problems and was busy the entire cruise. XRF work is continuing to improve in all areas as sample preparation techniques and various other procedures initiated on Leg 109 are implemented. A trace element calculation program for determining element concentrations was developed and fine-quality data were obtained this cruise. Petrographic microscope stations were relocated to a new bench in the SEM laboratory in order that a special XRF clean bench and sample preparation area could be installed adjacent to the X-ray laboratory. Additional benches will be installed and minor modifications made to the clean bench when materials arrive. The X-ray diffraction equipment (XRD) ran extremely well this cruise.

The SEM was used moderately as an aid in distinguishing nannofossils and in studying bacteria found in some borehole water samples. The thin section laboratory work load was light: about fifty thin sections of excellent quality were produced.

Other Areas

Following a major DEC service call in Panama, the VAX system suffered no major problems. The system was "down" only once, when high equipment-room temperatures set off the room temperature sensor during routine air conditioning maintenance by ship's engineers. The system usage was high, and ample time was available this cruise to assist users. PicSure continues to be the prime VAX service used by visiting scientists; the system is also used as an intermediary between other systems and for data processing using high-level languages. VAX system usage was routine for laboratory and ODP staff work. Blast satellite communication usage is increasing. Minor deck modifications in the system manager's office were started.

No major problems were encountered in the photo laboratory during the cruise. In addition to routine work and P.R. photographs, special requests for copy work related to logging and other scientific needs as well as photodocumentary work for operations and SEDCO were done as requested.

The hold reefer was reorganized this cruise in preparation for the vast amounts of core recovery anticipated on Leg 112. Unistrut laterals were removed to make possible a more complete utilization of space. This will allow dense packing of cores and other bulk items as required.

The bridge deck "customer stateroom" was converted into office space for the lab officers, and the old lab-officers' office was vacated to be used temporarily "as is" by the co-chief scientists. It will be fully converted during the transit from Callao to Punta Arenas, Chile, following Leg 112. The old co-chief scientists' office on the new main deck is also scheduled to be converted at that time.

The starboard streamer winch platform on the fantail was extended aft and a manually operated 'poor boy' cable leveler was fabricated and installed.

<u>Personnel</u>

The Marine Emergency Technical Squad (METS) continued to hold weekly meetings and participate in the regularly scheduled weekly drills.

As noted on Leg 109, the entire technician team is to be commended for their professionalism and productive use of time.