OCEAN DRILLING PROGRAM

LEG 148 PRELIMINARY REPORT

HOLE 504B

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ABSTRACT

During Leg 148 of the Ocean Drilling Program, *JOIDES Resolution* deepened Hole 504B, already the deepest hole ever drilled into oceanic crust, to a total depth of 2111.0 m below the seafloor (mbsf). Located in 5.9-m.y.-old crust, Hole 504B represented the best opportunity for studying the transition between the sheeted dike complex and the underlying gabbros and its relationship to the seismic Layer 2/Layer 3 boundary. The newly drilled section is a continuation of the variably altered massive diabases that compose the sheeted dike complex drilled by previous legs. Sonic velocities logged in the sheeted dikes are in the upper range for seismic Layer 2, but the velocity recorded (6.8 km/s) in the lowermost 100 m of the hole is more typical of Layer 3. Deeper penetration was prevented because the drill string became stuck when a fault was encountered. Although the string was eventually freed, the equipment necessary to clean the hole was not on board, and coring was halted to avoid jeopardizing the hole. A partly milled drill bit and rubble remain at the bottom of the hole, which could be cleaned on a future leg.

Hole 896A, drilled into a basement topographic high and a heat-flow maximum, was initially a contingency hole drilled while awaiting the arrival of fishing equipment for Hole 504B. Massive basalt, pillow lavas, breccias, and two dikes were noted in the cores recovered. Lithological differences between the two sites include more abundant breccias and massive units in Hole 896A vs. a greater proportion of pillow units in Hole 504B. No detailed lithologic correlations yet exist between the two holes. The greater abundance of recovered breccias from Hole 896A, the thicker and more abundant smectite and carbonate veins in the upper half of Hole 896A, the lack of flow of bottom seawater down into Hole 896A (compared to the occurrence of such flow into Hole 504B in the past), all suggest that, although still permeable, the Site 896 section is more extensively sealed than at Site 504. This effect may be related to location of the site on a heat-flow maximum.

INTRODUCTION

The primary objective of Leg 148 was to revisit Hole 504B in the eastern equatorial Pacific (Fig. 1) and deepen it through the dike/gabbro and/or seismic Layer 2/3 transitions. Site 504 is located 201 km south of the Costa Rica Rift, the easternmost arm of the Galapagos Spreading Center, in 5.9-m.y.-old crust. An early pilot hole, Hole 501, was drilled 73 m into basement during Leg 68.

Hole 504B was spudded in October 1979 during DSDP Leg 69, several hundred meters east of Hole 501. Hole 504B was subsequently deepened and/or logged during parts of six other legs, including Leg 70 (1979), Leg 83 (1981-82), Leg 92 (1983), Leg 111 (1986), Leg 137 (1991), and Leg 140 (1992), as shown in Figures 2 and 3. These legs provided a wealth of scientific results, many of which are summarized by CRRUST (1982); Cann, Langseth, Honnorez, Von Herzen, White, et al. (1983); Anderson, Honnorez, et al. (1982); Anderson, Honnorez, Becker, et al. (1985); Leinen, Rea, et al. (1986); Becker, Sakai, et al. (1988, 1989a, 1989b); Alt et al. (1986); Becker, Foss, et al. (1992); and Dick, Erzinger, Stokking, et al. (1992).

At the end of Leg 140, Hole 504B extended through 274.5 m of sediment and 1725.9 m into basement. The Hole 504B basement section consisted of 571.5 m of pillow lavas and minor flows, underlain by a 209-m transition zone of mixed pillow lavas, thin flows and dikes, and 945.4 m of sheeted dikes and massive units. Results from recent drilling in Hole 504B during Leg 140 near the end of 1991 plus seismic evidence suggested that at that time the bottom of the hole lay within the lower portion of the sheeted dike complex, close to the seismic Layer 2/Layer 3 boundary. Many believe that the Layer 2/Layer 3 transition coincides with the change downward from sheeted dikes to underlying gabbros as is observed in ophiolites, but this seismic transition may be a metamorphic boundary within gabbros or within the lower sheeted dikes. Although the transition from sheeted dikes to gabbros has been observed by submersible in tectonic exposures of both Atlantic and Pacific ocean crust, this transition has never been observed in-situ in undisturbed ocean crust, and its relation to the Layer 2/Layer 3 boundary remains unproven.

Site 896 was a contingency site initially occupied while awaiting the arrival of fishing tools for further work at Site 504. The first drilling objective at Site 896 was to examine local variability in volcanic stratigraphy, areal extent of flows, and horizontal and vertical variations in igneous geochemistry. The second objective was to examine the effects of off-axis hydrothermal activity on the basement, relating the composition of upwelling fluids (determined on Leg 111 and from a Leg 111 site survey) in a high heat-flow area to alteration of basement rocks. Physical properties and hydrogeology of the site could also be examined to test models of off-axis convection. The third objective was to drill the second of a pair of deep basement sites. Hole 504B penetrates two possible faults (at about 800 mbsf in the lower volcanics and at 2111 mbsf in the lower dikes), whereas Site 896 is located on the inferred footwall, south of Hole 504B. Variations in alteration between uplifted and downdropped basement and the possible role of the fault in alteration were examined, as well as the possible influence of the fault on volcanism and volcanic stratigraphy. The new site also provides the opportunity for future geophysical experiments between the paired Holes 896A and 504B.

SITE 504

Site 504 is located at 1°13.611'N, 83°43.818'W, at a water depth of 3460 m. Upon reentering Hole 504B on 28 January 1993, temperatures were logged from seafloor to just above the total depth of the hole (2000.4 mbsf). The gradient through the cased section was close to the background value in the sediments, indicating that presently there is no downhole flow like that observed in the past. A slight dip in temperatures immediately below the bottom of casing is similar to that observed during Leg 140, indicating some hydrothermal activity in the uppermost basement. Deep in the hole, the gradient is generally linear and consistent with logs taken during Legs 137 and 140, and indicates a maximum temperature of about 180°C at the bottom of the hole.

Following temperature measurements, borehole waters were sampled on 28-29 January. Water was collected in 6 of 8 runs, at 560, 796, 1031, 1266, 1501, and 1970 mbsf. One sample (1501 mbsf) clearly displays chemical characteristics of seawater that has reacted with basalt at elevated temperatures, whereas the compositions of other samples are close to seawater. Following drilling operations, the hole was spiked with a NaBr tracer, so future water sampling can detect fluid movement from basement or overlying seawater into or out of the borehole.

Fifteen cores (148-504B-239R through -253R) were drilled from 30 January to 9 February, penetrating from 2000.4 to 2111.0 mbsf (110.6 m), for an average recovery of 10.4%. Twenty-five lithologic units were identified on Leg 148, for a total of 294 units in Hole 504B. The recovered rocks are massive diabases and are a continuation of the sheeted dike complex drilled on previous legs. Five chilled-dike contacts were found, and other units were identified by differences in mineralogy, grain size, and texture. All rocks are fine-grained, with average grain size ranging from 0.4 to 1.0 mm. Fourteen units are sparsely to moderately phyric plagioclase-olivine-pyroxene diabase; four units are sparsely to moderately phyric olivine-plagioclase ± pyroxene diabase; three units are aphyric; and four units are sparsely phyric plagioclase-olivine diabase. A trace of chrome spinel is also present in about half the units. Intergranular material is primarily plagioclase and pyroxene, with opaque oxide minerals and olivine in small amounts. Titanomagnetite ranges from

0.02 mm up to 0.45 mm in size, and the larger grains contain exsolution lamellae of ilmenite. Plagioclase and pyroxene phenocrysts are generally 1.0-1.5 mm in diameter, but range up to 5 mm, and olivine phenocrysts are generally 1 mm in size. Coarse-grained glomerocrysts of plagioclase ± clinopyroxene, olivine, magnetite, or spinel occur in many units, and some of these glomerocrysts have gabbroic textures.

Alteration of the rocks is heterogeneous (Fig. 3). The diabases are affected by a pervasive slight to moderate background alteration (10%-40% recrystallized), with locally more intensively altered zones (40%-100% recrystallized) in centimeter- to decimeter-sized patches, and in centimeter-sized alteration halos around veins. Patches and halos make up a few percent of the recovered core. Actinolite (±magnetite) replaces interstitial material, and olivine is totally replaced by talc + magnetite, chlorite + quartz, and actinolite. Clinopyroxene is slightly to totally replaced by actinolitic amphiboles, whereas plagioclase is the least altered phase, and is partly replaced by secondary anorthite, chlorite, albite, actinolite, and rare epidote. Titanite(?) partly replaces igneous magnetite, but the ilmenite exsolution lamellae generally remain unaltered. Cr-spinel is partially altered to magnetite around the margins and along internal cracks. Other secondary minerals include traces of pyrite and chalcopyrite, and single occurrences of secondary clinopyroxene, Fe-pumpellyite, and laumontite.

Actinolite (±titanite) veins are the most common veins, and range from 0.05 to 3.0 mm in width. Dips of actinolite veins are variable, but maxima occur at 20°-25° and 85°-90°. Chlorite ± actinolite forms thin (< 0.5 mm wide), mainly steeply dipping (75°-90°) veins. Single occurrences of chlorite + quartz + titanite, chlorite + quartz + pyrite, chlorite + laumontite, and epidote veins were also observed. There is an average of 21 veins per meter of recovered rock, and veins account for about 1.2 vol % of the total recovered material. The abundance of alteration minerals continues depth trends noted during previous legs to Site 504, consistent with generally higher alteration temperatures in the lowermost 400 m of sheeted dikes.

Three oriented dike margins were recovered during Leg 148, and dip from 76° to 88°, similar to shallower dikes cored on previous legs. All diabase samples show well-preserved primary (igneous) characteristics, and no shape fabric or preferred orientation of grains related to crystal-plastic deformation were found. Observed structures include veins, microfaults, fractures, chilled margins and rare <1-mm-wide cataclastic zones. Open fractures are common and tend to have gentle or steep dips, and probably formed by decompression during drilling. Vein orientations are similar to those recovered in shallower dikes, and are predominantly dike-parallel and dike-normal, the latter possibly shrinkage cracks that formed during cooling of the dikes. The morphology and the internal fabric of the veins suggest that they formed as extension fractures, possibly by the crack-seal mechanism. Subsequent compression of some veins is indicated by kinked actinolite and chlorite fibers. Shearing, possibly associated with formation of very fine-grained amphibole, appears to have affected some of the veins.

Magnetic measurements were made on 11 oriented minicores and were supplemented by measurements of natural remanent magnetization (NRM) and bulk susceptibility on 11 small unoriented samples. Magnetic susceptibilities average 0.018 ± 0.013 SI units, similar to values for shallower dikes. The Leg 148 cores lack the steeply inclined drilling-induced remanence observed in shallower dikes. Instead, a relatively weak viscous component is observed, which is generally removed by AF demagnetization at 20 mT. As a result, natural remanent intensities (mean = 0.48 $\pm$ 0.39 A/m) and Koenigsberger ratios (mean = 2.2) are lower, and mean destructive fields are higher, than those for shallower dikes. The saturation anhysteretic remanent magnetism is greater than the NRM, which suggests that the Leg 148 rocks may carry a chemical remanence rather than a thermal remanence. Measurements of anisotropy of magnetic susceptibility are consistent, despite low degrees of anisotropy. The observed fabric has a minimum axis which is horizontal and north, and a maximum axis which is horizontal and east (corrected using the stable remanence direction). This may be interpreted as horizontal, dike-parallel, flow at the dike margins and crystal settling at the dike center.

The wet bulk densities range narrowly from 2.88 to 3.05 g/cm^3, with most >2.90, and compressional wave velocities range from 5.4 to 6.0 km/s in response to slight variations in olivine abundance and alteration over the cored interval, consistent with values obtained for the immediately overlying dikes. The velocities are too low for rocks of this density, suggesting the opening of microcracks during decompression as the rocks were brought to the surface. Resistivities range from 80 to 250 ohm-m in response to changes in porosity (1%-5%) and alteration. The thermal-conductivity values range from 2.0 to 2.2 W/mK, within the limits observed throughout the overlying sheeted dikes.

Microfaults are common in Leg 148 cores, leading to an abundance of flat, platy-shaped fragments in the recovered cores. The microfaults are lineated and have steps, but are discontinuous and show no resolvable displacement in thin section. The microfaults are steeply dipping, and slickenlines suggest both dip-slip and strike-slip senses of movement. The penetration rate for the last core (148-504B-253R) was very fast (7 m/hr), and after picking up the bit off bottom to retrieve the core, the drill string became stuck near the bottom of the hole. The high penetration rate for this core and the recovery of tabular rock pieces with microfaults and slickenlines in this core and most of the preceding cores indicate that drilling penetrated a fault.

Approximately 30 hr was spent in various efforts to free the string. When it became clear that we were making no progress in getting free, and in order to avoid damaging the drill string, it was backed off near the top of the bottom-hole assembly (BHA). Operations at Site 504 were discontinued to await arrival of fishing tools (fishing jars, mill bits), which took 9 days. Hole 504B was not logged at this time in order to avoid jeopardizing fishing operations by knocking wallrocks onto the junk in the hole or leaving additional junk from logging tools in the hole. Because the most interesting part of the hole was the newly drilled section, and the BHA left in the hole extended through the Leg 148 section and up to 100 m into the overlying Leg 140 section (to 1900 mbsf), the scientific benefit of logging at this time was also minimized. After setting a reentry cone and coring at nearby Site 896, the fishing tools arrived on 20 February, and operations were continued in Hole 504B. The stuck drill string was freed using the fishing jars, and all of the string was recovered on deck except the drill bit, which had broken off and remained at the bottom of the hole. Mill bits were then run to grind up the drill bit and clean the hole. The first mill run was successful, but the second mill run encountered rubble filling the hole up to 19 m above the lost drill bit, and after we pulled out of the hole we discovered that the fishing jars had broken, leaving the mill bit, various subs, and a drill collar in the hole. This material was actually stuck in the hole, and fishing operations were nearly abandoned, but the junk was ultimately successfully fished out using an overshot and the fishing jars. The seals on the jars were damaged and leaking oil, however, rendering the jars unusable after this operation. Because of the scientific value of the hole, the high probability of getting stuck again, and the lack of any usable fishing jars, it was decided to log Hole 504B at this time rather than attempt cleaning the rubble and milling the lost drill bit without any means to free a stuck drill string. Such hole cleaning and milling operations were left to a future leg equipped with the proper tools, and any time remaining after logging Hole 504B was to be devoted to the contingency Hole 896A.

Four days were spent logging Hole 504B in two parts: the geophysical, FMS, and magnetometer logs were run over the entire length of basement, and two unsuccessful attempts at the VSP were made 25-27 February; the VSP was finally run successfully on 4 March.

The various logs give a consistent and clear picture of the Hole 504B basement section (Fig.4). Sonic velocities from the log generally fall between 4.5 and 5.5 km/s in the volcanic section and transition zone above 1100 mbsf, but are greater (6.0-6.5 km/s) in the dikes from 1200 to 1800 mbsf. Below this depth velocities drop slightly and then increase steadily to a value of 6.8 km/s at the lowermost depths measured (2060 mbsf). The velocities of the sheeted dikes fall in the upper range for seismic Layer 2, but the maximum velocity recorded (6.8 km/s) near the bottom of the hole is a typical Layer 3 velocity. Rocks recovered from this interval are fine-grained diabase dikes, suggesting the possibility that the transition to seismic Layer 3 may begin within sheeted dikes and may not necessarily correspond directly to the appearance of gabbros.

A VSP experiment was run using the Schlumberger WST vertical-component seismic tool from 1516 to 2076 mbsf. Combined with the data from the VSP run on Leg 111, this provides complete coverage of the entire basement section. Preliminary interval velocities below 1550 mbsf range from 5.5 to 7 km/s with an average of 6.58 km/s, in good agreement with data from the sonic log and for high pressure measurements on recovered samples. No reflector that could be attributed to the fault at the bottom of the hole was observed, however.

The resistivities are generally low in the volcanic section and increase downward into the dikes. Spikes of low resistivity at 1925 and 1935 mbsf suggest the presence of locally intense horizontal fracturing. The generally high resistivities in the dikes decrease below 2040 mbsf where microfaults are common in the recovered core, consistent with increased fracturing leading up to a larger fault at the base of the hole.

The uncorrected profile from the magnetometer log can be divided into three zones: the volcanic section from 275 to 850 mbsf with amplitudes of up to 5000 nT; the transition zone from 850 to 1050 mbsf with anomalies less than 100 nT; and the sheeted dikes from 1050 to 2079 mbsf with anomalies of up to 1000 nT. The extrusive zone produces predominantly negative horizontal and positive vertical field anomalies, indicating reverse remanent magnetization of the basalts and consistent with location of the site within a reversed magnetic anomaly. The anomalies in the sheeted dikes appear also to be mostly negative in the horizontal component, but detailed analysis must await final corrections of the raw data.

The FMS recorded excellent images in the lowermost 20 m, and somewhat lesser quality images in the rest of the hole due to the lack of response from one of the pads. The tool provided a caliper log of the borehole, showing increased diameter above 1000 mbsf, local enlargements in the dikes, and relatively uniform hole size of less than 12-in. in the lowermost 500 m. The tool also showed a change in orientation of breakouts in the hole, from predominantly N122° in the upper portion of the hole to N015° below 1500 mbsf, perhaps indicating a change in stress or in the response to stress in the lower part of the hole.

Results from Leg 148 suggest that Hole 504B has now penetrated into the transition to Layer 3, but actual penetration into Layer 3 was stopped when drilling encountered a fault. Intriguing questions regarding exactly what kind of material makes up the fault zone and, more particularly, what lies on the other side of the fault at present remain unanswered. A partly milled drill bit and some rubble lie at the bottom of the hole, but the hole can be cleaned on a future leg, given the proper equipment to stabilize the bottom of the hole and mill the remaining small amount of junk.

SITE 896

Site 896 is located 1 km southeast of Hole 504B at a water depth of 3439.8 m (1°13.006'N, 83°43.392'W; Fig. 5). The site is situated on a bathymetric high overlying a basement topographic high (Figs. 6 and 7). These coincide with a local heat-flow maximum where low-temperature hydrothermal fluids are upwelling through most of the 179-m sediment section, which was cored during Leg 111.

Site 896 was occupied 11-20 February while waiting for fishing tools to arrive for further work at Site 504, and then again 28 February to 4 March, and 6-7 March. Four days were devoted to setting a reentry cone and casing, 8 days for coring, and 3 days for logging.

Basement was first encountered in Hole 896A at 179 mbsf, where rubbly material was felt by the drill bit, and was cored from 195.1 to 469 mbsf (290 m into basement). Mainly pillow basalts and minor massive flows and breccias were recovered in 30 cores for an average recovery of 27.7% (73.68 m of rock). Igneous lithology and magnetic and physical properties suggest that the core can be divided into upper and lower sections (Fig. 8).

Four types of volcanic units were identified: massive basalt, pillow lavas, breccias, and dikes. Massive units make up about 38% of the drilled section, and may be lava flows or possibly interiors of very large pillows. Two dikes, identified by steeply dipping (74°-78°) margins chilled against host rock, were identified in the material recovered. The dike margins are characterized by a lack of variolitic textures and exhibit a different series of quench crystallization textures than pillow margins. Pillow lavas make up approximately 57% of the drilled section.

Breccias make up 5% of the drilled section, and include several types: 1) Hyaloclastites formed on the seafloor by fragmentation of glassy pillow rims, and consist of clasts of volcanic glass in a matrix of smectite and altered glass. (2) A second type of breccia consists of millimeter- to centimeter-sized clasts of basalt ± glass fragments, cemented by carbonate and/or smectite. Basalt clasts show evidence for alteration, oxidation, and vein development prior to cementation. Such breccias may have formed as talus at the base of a slope or within fissures in the basement. (3) The third type of breccia is characterized by a "jigsaw-puzzle" fabric where the various clasts can be fitted back together, and are cemented by carbonate and smectite matrix and veins. These breccias probably formed beneath the seafloor by fragmentation in the uppermost crust during extension.

The basalts are sparsely to highly phyric tholeiites. Fifty lithologic units were recognized, of which all but two are sparsely to highly phyric plagioclase-olivine basalts or olivine-plagioclase basalts, both commonly containing spinel. The two exceptions are moderately olivine-phyric basalts. The volcanic section can be divided into upper and lower sections: plagioclase-olivine phyric basalts make up 90% of the units in the upper basement (195.1-390.1 mbsf), whereas olivine-plagioclase phyric lavas make up 72% of the lower section (390.1-469 mbsf). Clinopyroxene is also present as a phenocryst phase from 353.1 to 392.1 mbsf. The basalts contain a variety of megacrysts and glomerocrysts, including plagioclase, plagioclase-olivine, plagioclase-clinopyroxene, and plagioclase-olivine-clinopyroxene.

Plagioclase phenocrysts range in size from less than 0.1 to more than 5 mm. Olivine phenocrysts range from less than 0.1 mm microphenocrysts to 5 mm megacrysts, and commonly contain inclusions of glass or spinel. Clinopyroxene phenocrysts range from less than 0.5 to 7 mm, and are partly resorbed. Spinel is a minor mineral, ranging in size from 10 to 200 µm.

There are suggestions of cyclic variations in plagioclase and olivine phenocryst abundances through the core, and the overall abundance of phenocrysts appears to decrease up through the section. Such variations suggest cyclic and/or systematic changes in the magma chamber over the time that the basalts erupted. These changes can also be seen in the composition of the spinel as inferred from its color, in the type of glomerocrysts preserved in the lavas, and in the occurrence of clinopyroxene in some of the deeper units. All of these factors suggest derivation of basalts from increasingly higher temperature magmas upsection.

All of the rocks from Hole 896A are slightly (<10%) affected by low-temperature (<100°C) alteration except for pillow rims, where fresh glass is commonly present. A pervasive background (reducing) alteration is characterized by the gray color of the rocks, and by saponite and rare pyrite replacing olivine and filling pore spaces. Plagioclase is rarely slightly replaced by saponite. Oxidative alteration effects are characterized by dark gray to yellow and red alteration halos, up to 20 mm wide around smectite veins, and which are more common in the coarser grained massive lavas. The red and yellow colors are due to Fe-oxyhydroxides replacing olivine, filling interstitial space and staining the primary silicates.

Dark green and light green saponite are the most common veins in both pillow and massive lavas. Calcium carbonate, commonly aragonite, is present as a later phase following smectite. Analcite was observed in veins of several hand specimens, and one occurrence each of fibrous zeolite (possibly natrolite) and pyrite was observed. Most of the veins are less than 1 mm thick, but some range up to several millimeters in thickness, especially in the upper half of the core. Phillipsite is also present in the cement of the hyaloclastites, where it formed after saponite and before carbonate.

Two types of veins were characterized structurally: fibrous and nonfibrous. Veins filled with blocky carbonate and/or vermicular clay have characteristics suggesting growing of crystals into open spaces. The orientation of all nonfibrous veins are clearly nonrandom, with a tendency toward steeper dips. These veins are common in massive lavas, and may represent steeply dipping cooling joints. Fibrous veins are generally relatively late and formed after filling of cracks and voids by nonfibrous carbonate and clay. Extension occurred within the lava pile in virtually all directions, as indicated by complex vein geometry (especially fibrous veins). Textures of fibrous veins (and some breccias) indicate formation by the crack-seal mechanism, thus implying periods of relatively high fluid pore-pressures needed to cause hydraulic fracturing.

Magnetic properties suggest that Hole 896A can be divided into two sections. The boundary between the upper and lower sections at about 370 mbsf coincides with the top of a thick series of massive units.

In the upper part of the hole the intensity of natural remanence (J_o) is relatively high (11.9 ± 4.0 A/m), the median destructive field (MDF) is high (22.6 ± 12.9 mT), and the bulk susceptibility is high (0.015 ± 0.008 SI units). Isothermal remanent magnetism (IRM) acquisition experiments indicate that the rocks generally saturate in fields less than 0.2 T, consistent with the carriers being very fine-grained single-domain (titano)magnetite and/or (titano)maghemite. These properties are common to both pillow and massive units. Stable inclinations in the upper part of the hole are consistent, with a mean value of -9.5° ± 10.4°.

In the lower part of the hole, J_o is significantly lower (3.9 ± 2.5 A/m), MDFs are lower (12.3 ± 7.3 mT), and bulk susceptibilities are higher (0.033 ± 0.014 SI units). Alternating-field demagnetization often isolates two components: a low-coercivity phase, probably carried by (titano)magnetite and/or (titano)maghemite, and a higher coercivity phase. The presence of a small proportion of high-coercivity material in these samples is also indicated by IRM acquisition experiments. Stable inclination data exhibit a high degree of variation, which may reflect large-scale disruption of the units cored in the lower part of the hole.

Anisotropy of magnetic susceptibility (AMS) measurements reveal weak (< 9%), dominantly prolate, magnetic fabrics. The maximum principal AMS axes are dominantly subhorizontal, toward 283°, but it is unlikely that this represents a flow fabric.

The physical properties of most of the samples from Hole 896A are typical of moderately altered basalt: bulk densities range for the most part between 2.80 and 2.95 g/cm^3; the porosities are moderately high (2%-10%); resistivities are low, ranging between 40 and 250 ohm-m; velocities are fairly low, ranging largely from 5.5 to 6.0 km/s; and thermal conductivities range between 1.6

and 1.8 W/mK. The unusual recovery of glassy pillow margins, interpillow hyaloclastic breccias, and flow breccias cemented by clays and calcite suggests that the crust at Site 896 is at least partially sealed by alteration products. While these materials have very low densities (2.2-2.7 g/cm^3), velocities (3.6-4.7 km/s), and resistivities (10-20 ohm-m), they are much higher than those of seawater (1.035 g/cm^3; 1.5 km/s; 0.2 ohm-m at room temperature) and will strongly affect the overall properties of the formation, causing Vp, density, and resistivity to rise; porosity to decrease; and heat flow to approach conductive values. There is a marked increase in scatter in Vp and thermal conductivity below 350 mbsf, which we attribute to increasingly variable alteration with depth.

Prior to the last bit run and following 8 days of fishing and logging in Hole 504B, which allowed the borehole temperatures to recover from drilling somewhat, a combined temperature and geochemical log was run in Hole 896A . The measured temperature profile suggests a conductive heat flow of 275 mW/m^2, and a temperature of about 50°C at the basement/sediment interface. These values are consistent with detailed surface heat flow measurements and modeling of off-axis convection in the region, and are not indicative of downhole flow as occurred when Hole 504B was first drilled.

Following drilling in Hole 896A, a series of logs, including the sonic density tool, dual laterolog, FMS, magnetometer, and a packer permeability experiment, were run in Hole 896A. Two passes were made with the FMS, which provided excellent images of the borehole walls down to 440 mbsf.

The BRG magnetometer was run to 438 mbsf in Hole 896A. The measured anomalies are generally large, ranging up to 5000 nT, but the bottom 30 m has rather small anomalies, <100 nT. Anomaly amplitudes imply reverse magnetization with negative inclinations, consistent with measurements on minicores and with location of the site within a reversed magnetic interval.

The packer was set at depths of 106 mbsf (in the casing), 233 mbsf, and 385 mbsf. The uppermost few tens of meters of basement appears quite permeable, much like in Hole 504B. Permeabilities decrease deeper in Hole 896A, but probably remain large enough to support off-axis circulation in the uppermost basement.

The most significant lithological differences between Sites 896 and 504 are the more abundant breccias and massive units in Hole 896A vs. the greater proportion of pillow units in Hole 504B (Fig. 9). Clinopyroxene appears as a phenocryst phase only at depths greater than about 100 m into basement at both sites, but no detailed lithologic correlations yet exist between the two holes. Ponding of lavas could account for the thick massive units with cumulate olivine in Hole 896A, and such ponded units would not be expected to be laterally continuous over large areas. The possible presence of a fault between the two sites may have affected lava accumulation at the spreading axis, leading to further differences in lithostratigraphy. The greater abundance of recovered breccias from Hole 896A, the thicker and more abundant smectite and carbonate veins in the upper half of Hole 896A, the lack of flow of bottom seawater down into Hole 896A (compared to the occurrence of such flow into Hole 504B in the past), all suggest that, although still permeable, the Site 896 section is more extensively sealed than at Site 504. This effect may be related to the location of Site 896 on a basement topographic high and a heat-flow maximum.

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FIGURE CAPTIONS

Figure 1. Location of DSDP/ODP Sites 501, 504, and 505 south of the Costa Rica Rift in the eastern equatorial Pacific (from Hobart, et al., 1985).

Figure 2. Generalized drilling history and lithostratigraphy of Hole 504B.

Figure 3. Seismic stratigraphy, lithology, and secondary mineralogy in Hole 504B.

Figure 4. Hole 504B logging results.

Figure 5. Contour map of seafloor bathymetry in the five-site area. Locations of Holes 501, 504, and 504A-C are shown, and Sites 677, 678, and 896 are also shown (from Langseth et al., 1988).

Figure 6. A. Reproduction of the 3.5-kHz record along line A-A' (see Fig. 7). B. Single-channel seismic section along line B-B' (see Fig. 7). From Langseth et al. (1988).

Figure 7. Map showing heat-flow measurements and locations of drill holes in the five-site area. Lines A-A' and B-B' are locations of seismic profiles shown in Figure 6 (from Becker, Sakai, et al. 1988).

Figure 8. Drilling and recovery at Hole 896A. Black bars show recovery relative to core length. Olivine is the dominant phenocryst except where the symbol "P" is used in the minerals column to indicate the dominance of plagioclase. Symbols in the lithology column indicate the eruptive type of the basalt: pillow basalts = convex upward; massive = "V," and breccia = solid. The diagonal solid line indicates a mixture of pillow basalts, pillow-breccias, and breccias.

Figure 9. Lithostratigraphy of Holes 896A and 504B. "Cpx" indicates the position of clinopyroxene phyric lavas. In Hole 896A, "P-O" indicates the dominance of plagioclase-olivine phyric, and "O-P" indicates the dominance of olivine-plagioclase phyric, lavas. The lithologies for Hole 504B are modified from Adamson (1985).

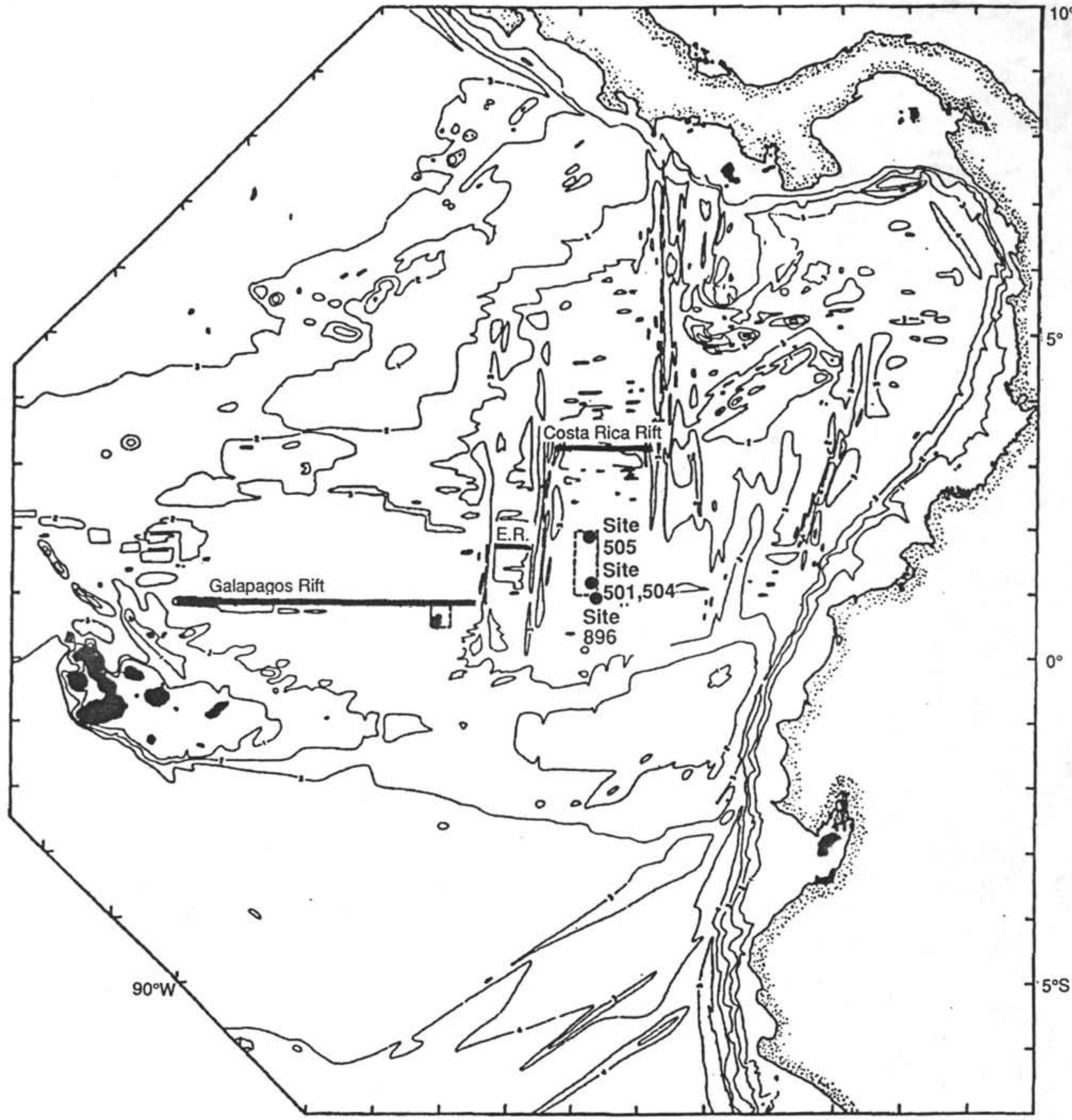

10°N
5°
0°
5°S
90°W
85°
80°W
Costa Rica Rift
E.R.
Galapagos Rift
Site
505
Site
501,504
Site
896

Figure 1

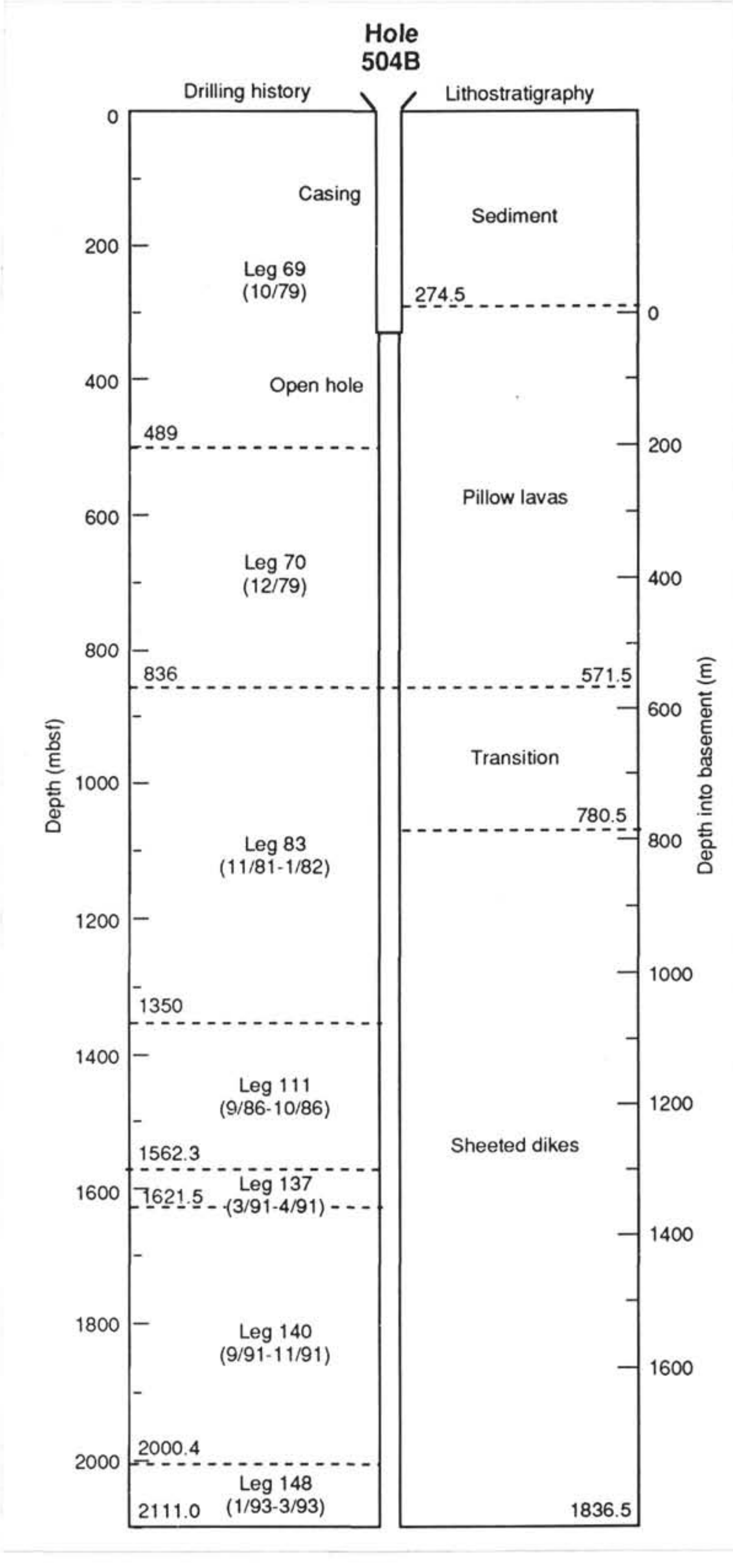

Hole
504B
Drilling history
Lithostratigraphy
Depth (mbsf)
Depth into basement (m)
Casing
Open hole
Leg 69
(10/79)
489
Leg 70
(12/79)
836
Leg 83
(11/81-1/82)
1350
Leg 111
(9/86-10/86)
1562.3
Leg 137
(3/91-4/91)
1621.5
Leg 140
(9/91-11/91)
2000.4
Leg 148
(1/93-3/93)
2111.0
Sediment
274.5
Pillow lavas
571.5
Transition
780.5
Sheeted dikes
1836.5
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
200
400
600
800
1000
1200
1400
1600

Figure 2

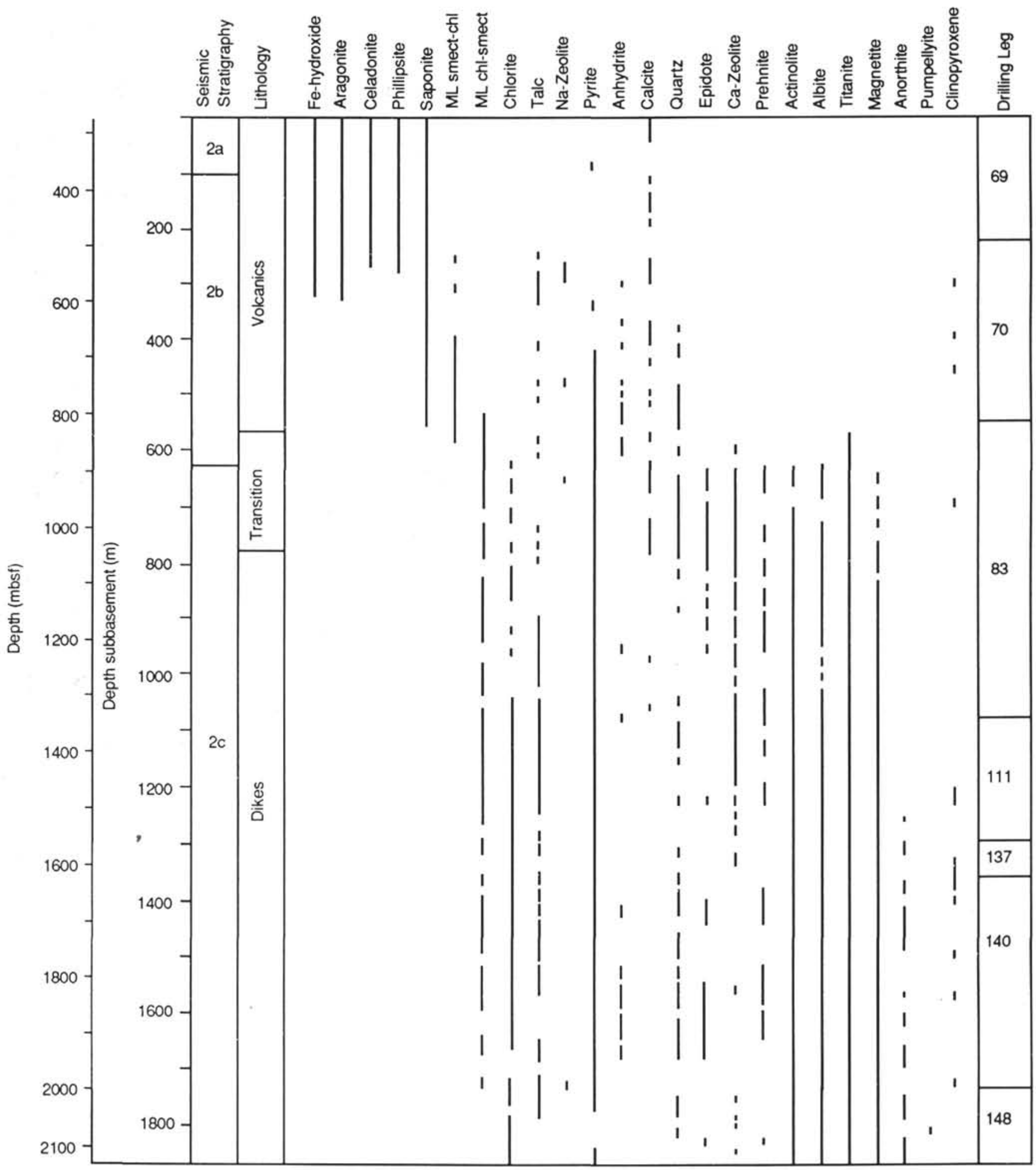

Seismic Stratigraphy
Lithology
Fe-hydroxide
Aragonite
Celadonite
Phillipsite
Saponite
ML smect-chl
ML chl-smect
Chlorite
Talc
Na-Zeolite
Pyrite
Anhydrite
Calcite
Quartz
Epidote
Ca-Zeolite
Prehnite
Actinolite
Albite
Titanite
Magnetite
Anorthite
Pumpellyite
Clinopyroxene
Drilling Leg
Depth (mbsf)
Depth subbasement (m)
400
600
800
1000
1200
1400
1600
1800
2000
2100
200
400
600
800
1000
1200
1400
1600
1800
2a
2b
2c
Volcanics
Transition
Dikes
69
70
83
111
137
140
148

Figure 3

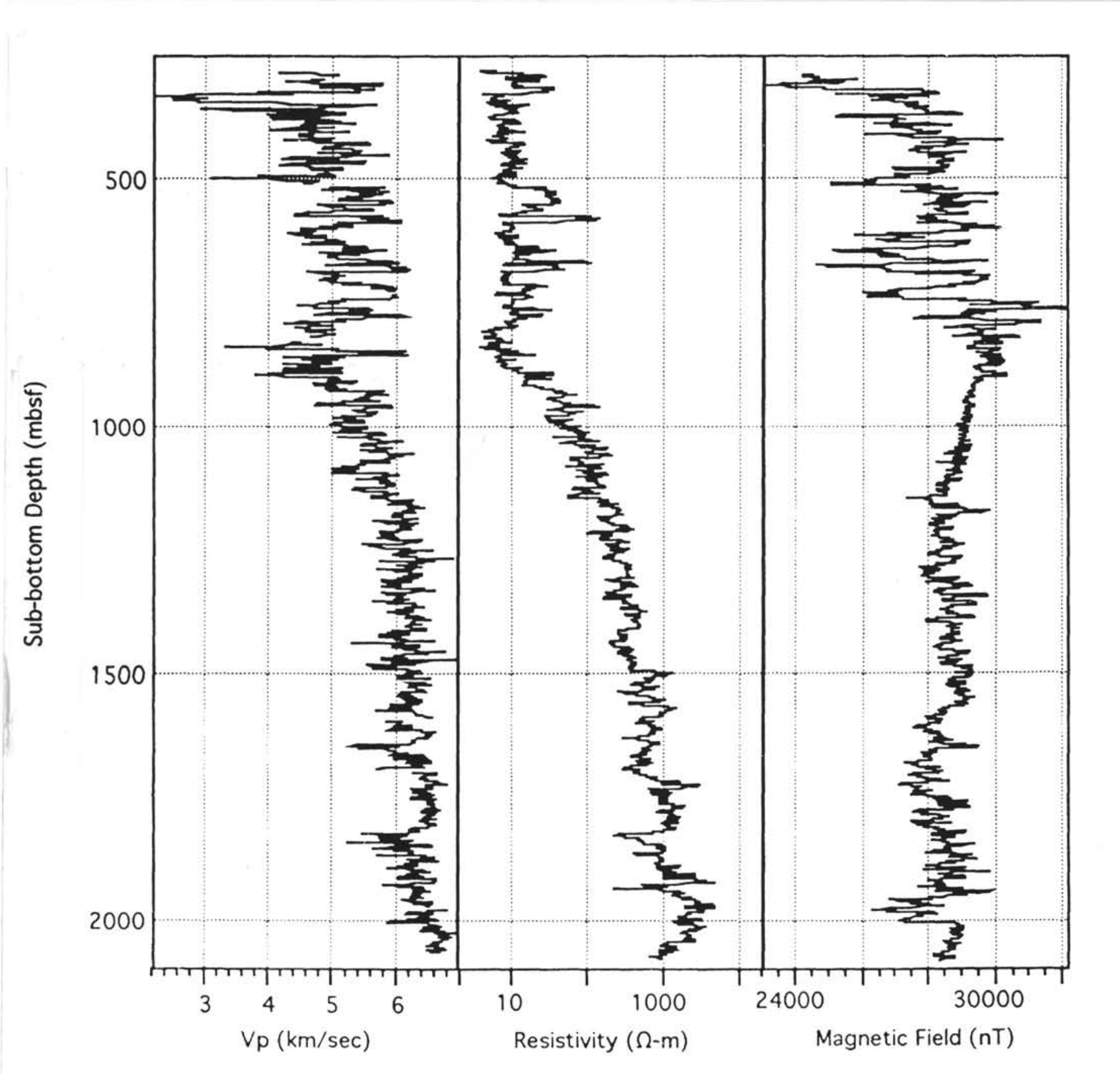

Sub-bottom Depth (mbsf)
500
1000
1500
2000
3
4
5
6
Vp (km/sec)
10
1000
Resistivity (Ω-m)
24000
30000
Magnetic Field (nT)

Figure 4

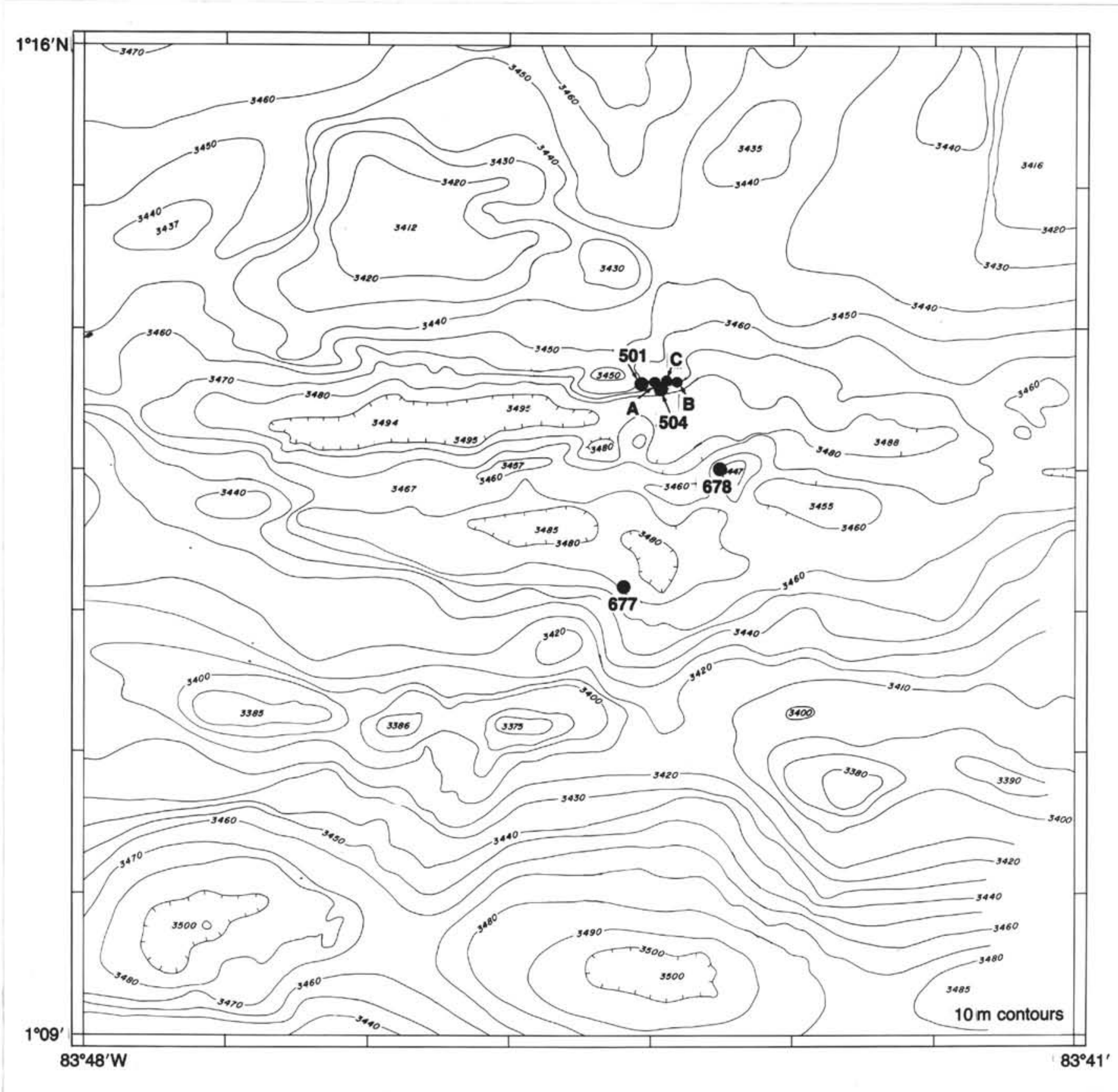


Figure 5

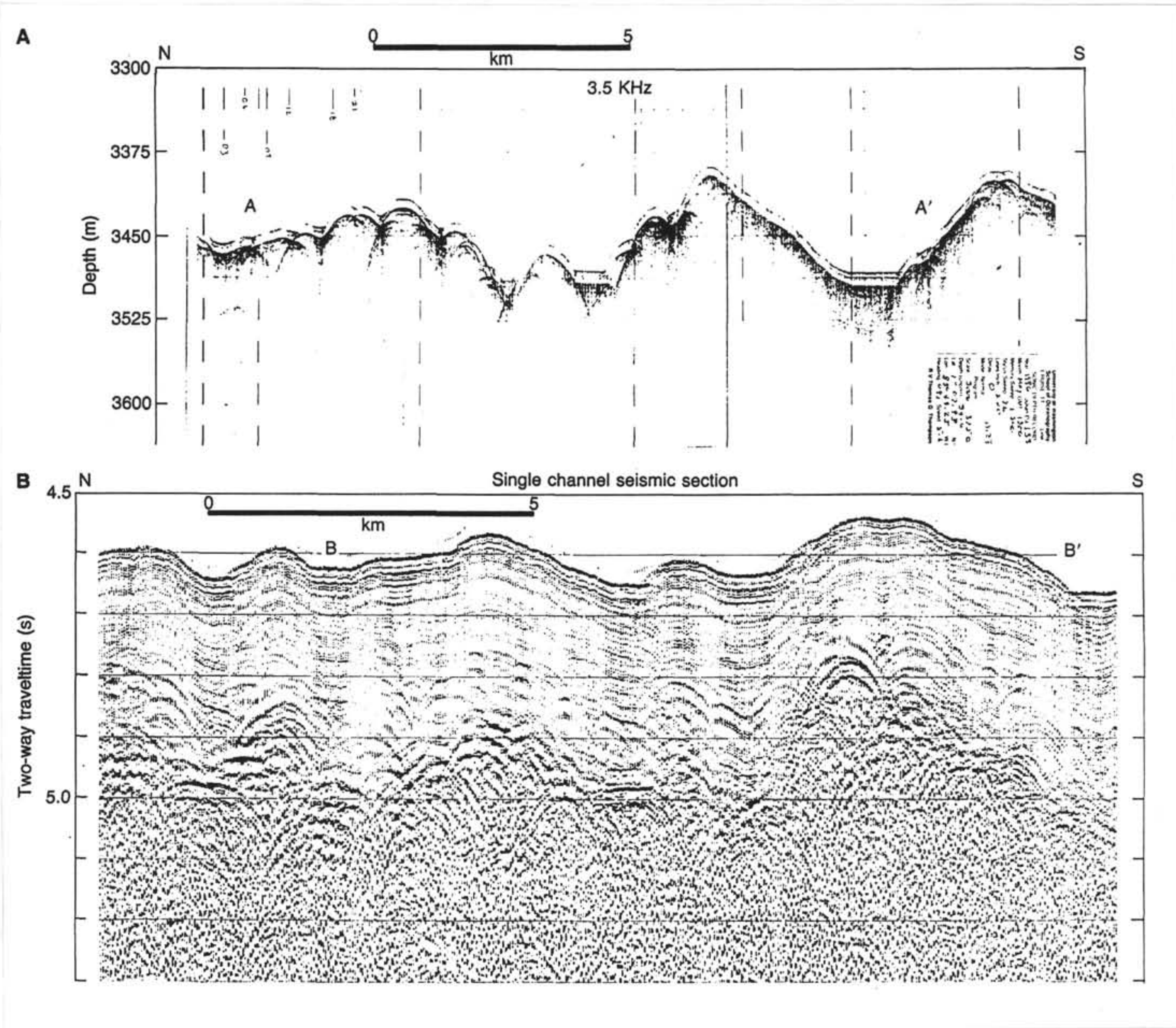

A
N
S
0
5
km
3.5 KHz
3300
3375
3450
3525
3600
Depth (m)
A
A'
B
N
S
Single channel seismic section
4.5
5.0
0
5
km
B
B'
Two-way traveltime (s)

Figure 6

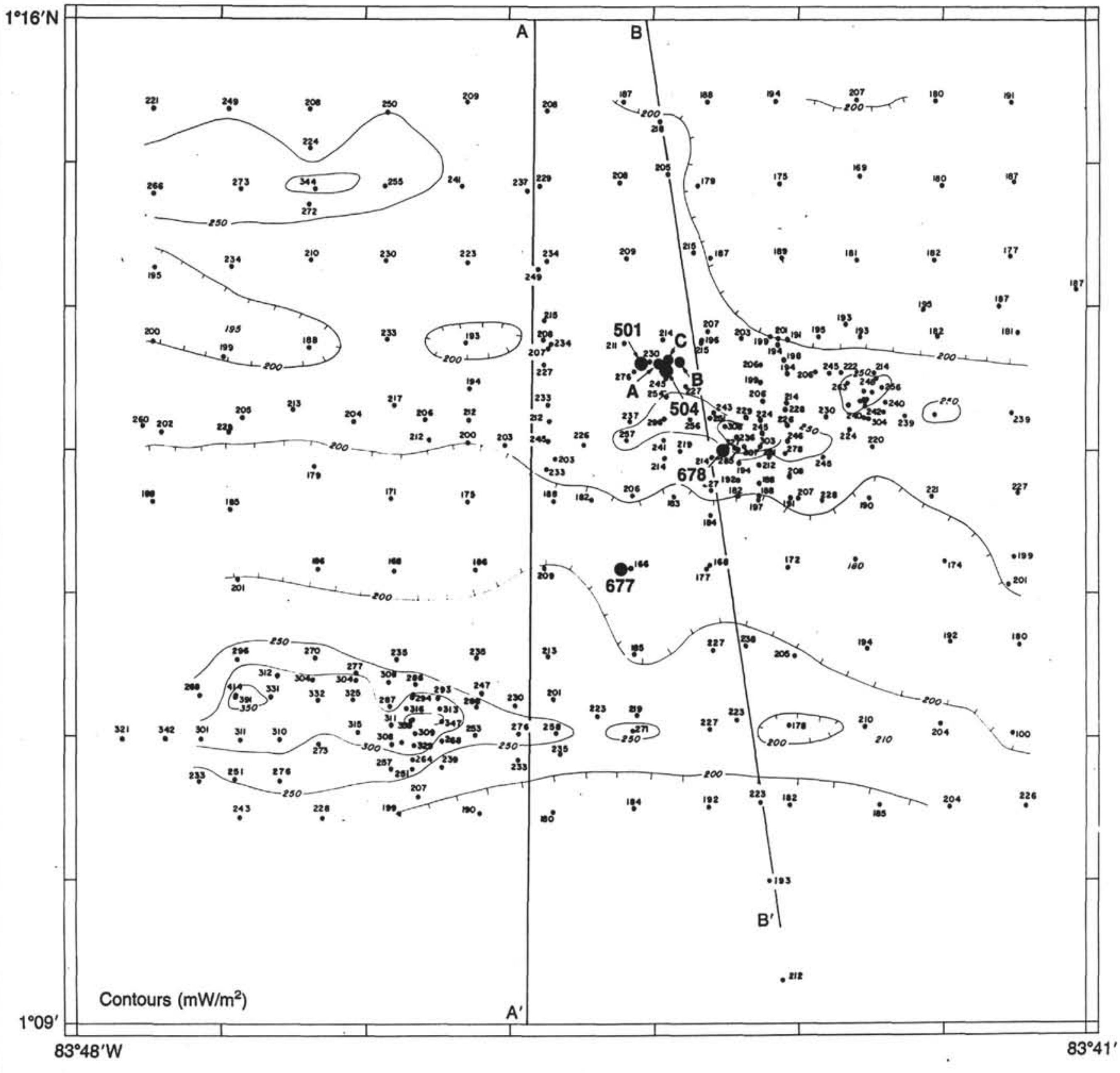


Figure 7

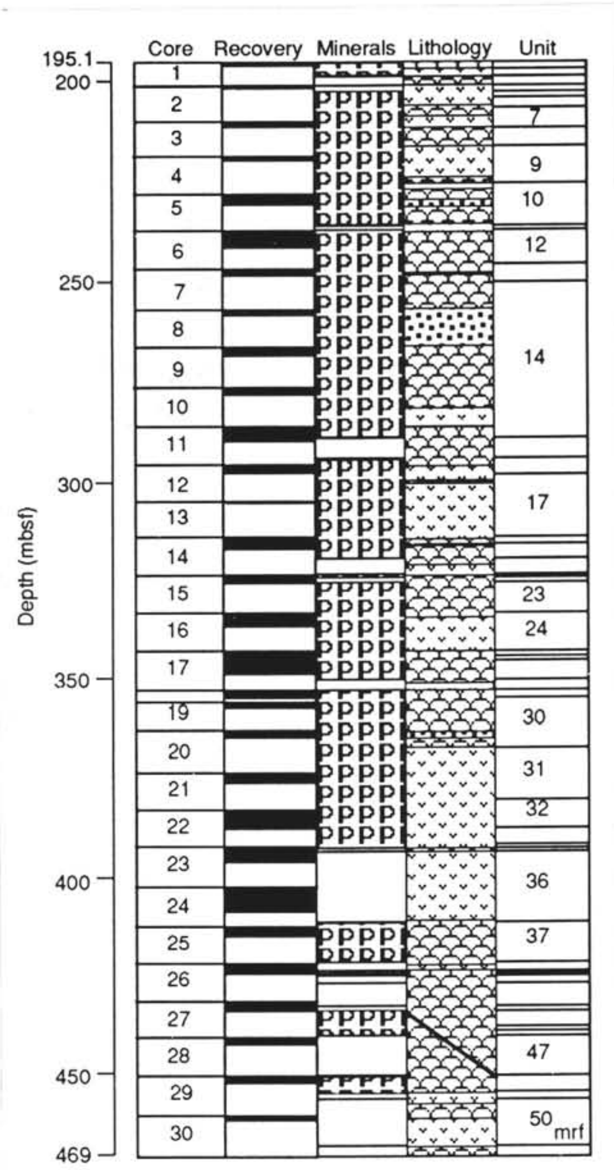

Core
Recovery
Minerals
Lithology
Unit
Depth (mbsf)
195.1
200
250
300
350
400
450
469
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
19
20
21
22
23
24
25
26
27
28
29
30
7
9
10
12
14
17
23
24
30
31
32
36
37
47
50
mrf

Figure 8

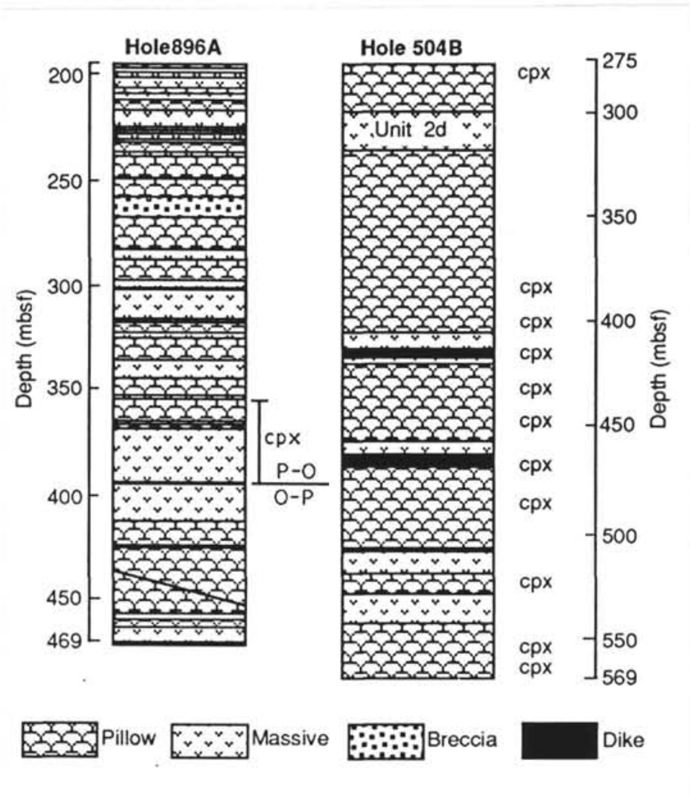

Hole896A
Hole 504B
Depth (mbsf)
200
250
300
350
400
450
469
cpx
P-O
O-P
Unit 2d
275
300
350
400
450
500
550
569
Pillow
Massive
Breccia
Dike

Figure 9

OPERATIONS REPORT

The ODP Operations and Engineering personnel aboard *JOIDES Resolution* for Leg 148 were:

Operations Superintendent:	Barry Harding
Schlumberger Engineer:	Steve Kittredge
LDEO Logging Technician:	Frank Filice

HOLE 504B

Leg 148 began with the first mooring line in Balboa Harbor at 1645 UTC on 21 January 1993. The *JOIDES Resolution* left Panama after completion of port-call activities on 25 January, and approached Site 504 at 0345 UTC on 28 January. Ship control was shifted to dynamic positioning (DP), and the first beacon was dropped at 0450 UTC.

Logging: Phase 1

The initial pipe trip was begun as soon as the beacon was dropped. Prior to reentering Hole 504B, the drill pipe was circulated to clean it of any rust or pipe dope that might contaminate water samples. The drill string was slowly run into the hole to 148.1 mbsf, in order to minimize disturbance of the water column. The Gable high-temperature tool was run to obtain a static borehole temperature profile. The tool failed shortly after its deployment and was pulled from the hole. One water sample was collected while the flooded tool was being repaired, and the temperature tool was then rerun. Water sampling resumed, and seven additional water samples were collected.

Coring

In order to extend bit life and improve core recovery, strengthened tungsten-carbide-insert bits were manufactured by Rock Bits Industries (RBI) for coring at Hess Deep (Leg 147) and at Hole 504B. Two versions of the bits were available on Leg 148: C-7 bits, with longer tungsten-carbide inserts, designed to drill softer material, and C-9 bits, with shorter inserts for drilling harder rocks. The BHA used during Leg 148 consisted of a 9-7/8-in. four-cone rotary coring bit and core barrel, 11 8-1/4-in. drill collars, McCullough jars (Coring Run 1 and Milling Run 1), two control-length drill collars, one 7-1/4-in. drill collar, two stands of 5-1/2-in. drill pipe, 150 stands of 5-in. drill pipe, and 41 stands of 5-1/2-in. drill pipe at the top of the string. The BHA was designed to provide a weight on bit of 40,000 to 45,000 lb. Because of the high temperatures expected in the hole, butyrate liners were not used; instead, the core was received directly into either the steel or chrome barrel.

Coring Run 1

A Security 9-7/8-in. rotary coring bit (the type used during Leg 140) was run from 2000.4 to 2038.17 mbsf, coring 36.77 m in 20.5 rotating hr for an average rate of penetration of 1.79 m/hr. The bit was run with 30,000 lb weight on bit, at 50 rpm. High torque was measured while drilling Cores 148-504B-239R and -243R. After the penetration rate decreased while cutting Core 148-504B-243R, the bit was pulled after having been run for over 20 hr. Two intervals of constricted hole were experienced while pulling out of the hole: one at 2028-2031 mbsf and the other at 2010-2013 mbsf. Once the bit was on deck, examination revealed that one of the four cones was lost in the hole as well as several roller bearings.

Milling Run 1

The milling assembly included a 9-9/16-in. concave mill with two junk baskets. The trip to bottom was interrupted periodically by stopping to cool the hole for 15-min intervals. Once on bottom, the hole was washed and reamed from 1955.93 to 2036.66 mbsf, then milled at 95 rpm with 8000 to 10,000 lb of weight on bit. The hole was constricted, and the mill became stuck at the bottom, requiring 115,000 lb overpull before it was freed. Drag of 25,000 to 30,000 lb was experienced on the trip out of the hole. The junk baskets contained large pieces of bit cone material, 33 bearings, 16 bit inserts, klusterite from the mill, and miscellaneous junk (173.3 g). Cracks in the McCullough jars were observed while inspecting the BHA, and the jars were removed.

Coring Run 2

Because the Security bit was destroyed in only 20.5 rotating hr, an RBI C-9 bit and a junk basket were used for the second coring run. (In this and all subsequent bit runs, the trip was interrupted to cool the hole, and the lower portion of the hole was reamed.) Core 148-504B-244R was drilled at a penetration rate of 1.41 m/hr. Torque increased while cutting the next core, so the weight on bit was increased from 30,000 to 35,000 lb, and the torque stabilized. Although Core 148-504B-245R recovered 0.63 m of material, it showed no evidence of having cored anything. The average rate of penetration for the first two cores cut by the second bit was 2.0 m/hr. While cutting Core 148-504B-246R, the rate of penetration varied and eventually decreased to about 1.0 m/hr. The bit was pulled after only 11.08 rotating hr. The spiral stabilizers on the bit showed evidence of having drilled junk and the teeth in middle rows of all cones were broken. The junk basket contained 660.7 g of metal, including three large pieces from the cone noses and 11 bit inserts.

Coring Run 3

An RBI C-9 bit and junk basket were used for the third coring run. Drilling parameters for Cores 148-504B-247R and -248R were 30,000 to 35,000 lb weight on bit at 50 rpm. Torque increased while cutting the next core, and the bit was pulled. An overpull of 30,000 lb was required to pull the string through a constriction at 1047 mbsf. The rate of penetration using the third coring bit averaged 1.62 m/hr for a recovery of 10.9%. Teeth were cracked in the middle rows of two cones, and some small bit inserts had been lost. The junk basket contained 94.2 g of metal.

Coring Run 4

The fourth coring run used an RBI C-7 bit with 25,000 lb weight on bit at 50 rpm. Torque increased after cutting only two cores and the bit was unable to support 10,000 lb without further torquing, so the bit was pulled. The rate of penetration averaged 2.09 m/hr for a recovery of 8.75%. Teeth on the heel rows of three of the cones were chipped, and some small bit inserts were missing. The junk basket contained 86.2 g of metal, including nose and gauge inserts. The bit may have been loaded too heavily for the rock that was drilled.

Coring Run 5

The fifth bit was also an RBI C-9 bit. During the trip into the hole, the pipe became stuck at 2006.5 mbsf. It was freed using 190,000 lb overpull, and the hole was reamed.

While attempting to pull the drill string off bottom to retrieve Core 148-504B-253R, the pipe again became stuck. An overpull of 100,000 lb raised the string 3.5 m, but did not free it. The pipe was worked with overpulls of up to 260,000 lb for 2.5 hr with no further movement or rotation. The core barrel was retrieved, but contained only 0.04 m of rock. Because the rate of penetration while cutting Core 148-504B-253R was faster than that of the preceding cores, shipboard scientists suspected that the bit had penetrated a highly fractured interval, perhaps a fault. The drill pipe was worked with overpulls of 290,000 lb. High torque was applied for 10-min intervals while holding 245,000 lb of tension in the drill string.

In an attempt to free the pipe, a small Schlumberger severing charge was shot 2 m below the bit. After detonating the charge, 17 wraps of torque were applied to the top drive, and the drill string was worked both up and down in an attempt to free the pipe. A core-barrel fishing run was made to catch the piece of the Schlumberger severing pressure case left in the hole when the charge detonated. The teeth of the double core catchers returned to the rig floor with no evidence of having engaged the pressure case: the pressure case had fallen through the end of the bit and the flapper from the float assembly had been blown off when the charge fired. The pipe was pulled again using 235,000 to 240,000 lb of tension, but did not move.

A second severing charge was run in the hole; however, the location of the charge in the hole could not be determined. The charge was returned to rig floor, and a damaged cable was repaired. The charge was sent down the pipe again, but would not go through the bit. It was brought up again and discarded over the side of the ship.

A string shot was run to the top of the first 7-1/4-in. drill collar in an attempt to back the pipe off as low as possible in the BHA. Prior to detonating the shot, 19 turns of left-hand torque were applied to the pipe and worked to the bottom. When the string shot was fired, the drill string jumped 3 feet, indicating that the drill string had backed off. The Schlumberger logging line was retrieved, but the 7-ft string-shot rod had been left in the hole. The drill string was pulled out of the hole, and had been severed at the top of the 7-1/4-in. drill collar.

Operations at Hole 504B were discontinued until the arrival of a fishing consultant and a shipment of fishing tools and Bowen jars, which would take about 9 days. Hole 504B was not logged at this time in order to avoid jeopardizing fishing operations by knocking wall rocks onto the fish in the hole or leaving junk from logging tools in the hole. Because the most interesting part of the hole was the newly drilled section, and the BHA left in the hole extended up to 100 m into the Leg 140 section (to 1900 mbsf), the scientific benefit of logging at this time was also minimized. After considering alternatives for drilling near Site 504, the shipboard party decided to drill a new hole at nearby Site 678, which is located on a small basement topographic high about 1 km southeast of Hole 504B. On 11 February, the *JOIDES Resolution* moved to drill at Site 896 while awaiting the arrival of fishing tools, Bowen fishing jars, and a fishing consultant.

Fishing Run 1

After setting a reentry cone and coring at nearby Site 896, the *JOIDES Resolution* returned to Site 504 on 20 February to meet the boat bringing the fishing consultant and equipment. The fishing BHA was prepared with the Bowen Super Jars that had been sent to the ship from Panama, and the drill string was run in the hole. Several stops to circulate and cool the hole were made on the trip down. The top drive was picked up about two stands above the estimated top of the fish. The drill string was rotated slowly, and the fish was engaged within 15 min. Right-hand torque was applied to tighten the connection prior to jarring the fish loose. The first hits with the jars were made using 125,000 lb, and the next two sets used 150,000 lb and freed the fish. The fish and BHA were pulled out of the hole. The bit, float valve, and lower support bearing had been left in the hole (which still contained two pieces of Schlumberger explosive rod). Another milling run was required because the material in the hole could not be fished.

Milling Run 2

On 22 February, a 9-3/8-in. Petco concave mill (which had been sent from Panama along with fishing equipment) was run in the hole with two baskets and a Bowen Super Jar. Several cooling stops were made during the pipe trip. Obstructions encountered at 2047-2072 mbsf and 2102 mbsf were reamed. Milling parameters were 10,000-12,000 lb weight on bit at 90-100 rpm during the early part of the run, and 12,000-14,000 lb at 110 rpm immediately before the mill was pulled off the bottom (2107.2 mbsf), and the drill string was tripped out of the hole. The interval from 2107 to 2026 mbsf was constricted and produced a drag of 25,000-30,000 lb. The bottom of the mill was completely worn, and the junk baskets contained over 1.7 kg of metal.

Milling Run 3

The next milling assembly employed the same type of mill and BHA as the previous run, and also included two junk baskets and a Bowen Super Jar. The mill was tripped into the hole, and the section from 2026 to 2107 mbsf was reamed. The interval from 2087.5 to 2091.25 mbsf was milled and washed using various reaming parameters. While the string and mill were being pulled out of the hole, drag increased in two intervals: 2091-2041 mbsf (up to 20,000 lb) and 2041-2008.2 mbsf (45,000 lb briefly, then 10,000-15,000 lb). The milling BHA returned to the rig floor without the lower section of the Bowen Super Jar, which had failed 15 in. above its pin end. A Petco mill, two junk baskets, a bit sub, three 8-1/4-in. drill collars, and 0.38 m of Bowen Super Jar now joined the collection of junk in the hole. The fish was now 31.9 m long and weighed about 12,000 lb.

Fishing Run 2

An overshot was prepared to engage the 7-3/4-in. body of the failed jar. The second fishing BHA included a 9-1/2-in. Bowen overshot with a 7-3/4-in. basket grapple and mill control, and Bowen Super Jars. The BHA was 176.4 m long. The drill string was run down the hole and engaged the fish within 10 min. The fish was jarred for about 1.5 hr with a maximum jarring overpull of 160,000 lb and a maximum static overpull of 260,000 lb. The jars were then allowed to cool for about an hour, and the fish was jarred again without success. An attempt to pull out of the hole failed when the overshot would not release the fish. Right-hand torque was applied to the overshot. This did not free the overshot, but succeeded in rotating the fish. The drill string, overshot, and fish were pulled out of the hole on 24 February. The hole now contained part of a coring bit, a float valve, and a lower support bearing. The second mill showed no evidence of having milled anything. The borehole had collapsed, depositing 19 m of rubble on top of the fish. The seals on the remaining jars were leaking oil, and could no longer be used.

No functional fishing jars remained on the ship; therefore, any further milling operations would risk the hole unnecessarily. With the proper equipment, milling operations on a return trip to Hole 504B would be simple and straightforward.

Logging: Phase 2

A logging BHA was run to the bottom of the hole (1) to determine the depth to which the logs could be run, (2) to circulate and cool the hole for logging, and (3) to displace the drilling mud and leave a NaBr tracer solution in the hole for future geochemical studies. During the pipe trip into the hole, the string took a weight of 15,000 to 20,000 lb at 2083.4 mbsf. Because the logging bit was not designed for reaming or drilling, the obstruction was not cleared. The bit was pulled up 2 m so the hole could be circulated prior to injecting the NaBr tracer. Two hole volumes of seawater were circulated at 100 strokes per minute and 740 psi (equivalent to 500 gallons per min) to clear the hole of drilling mud. The NaBr tracer solution was then pumped into the hole, and the pipe was pulled to logging depth (134.18 mbsf).

The first logging suite (dual lateral log, caliper log, and sonic log) started down the pipe at 0130 UTC, 27 February, and logged from 134.18 to 2075 mbsf). The next suite consisted of the formation microscanner and the gamma-ray tool and reached a depth of 2081 mbsf. The magnetometer was scheduled next, but malfunctioned. Instead, the Woods Hole vertical seismic profile (VSP) was attempted, but also failed. The newly repaired magnetometer was then run successfully both on the trip into and out of the hole. The borehole televiewer was attempted next, but did not work. The VSP was tried again, and malfunctioned. The borehole televiewer, on its second run, logged the hole successfully to 2076 mbsf. The ship departed for additional coring at Site 896 on 1 March.

Logging: Phase 3

On 4 March, the *JOIDES Resolution* returned to Hole 504B to continue downhole measurements. A WSTP sample was collected at 468 mbsf (below the casing) as a reference for the NaBr tracer. Several attempts were made to conduct the Woods Hole VSP experiment, but all failed. On 6 March, a VSP experiment using the Schlumberger vertical-component seismic tool was performed successfully from 1516 to 2076 mbsf. The drill string was tripped out of the hole, and the *JOIDES Resolution* departed for additional logging at Site 896.

HOLE 896A

On 11 February, the *JOIDES Resolution* left Site 504 to set a reentry cone and to core at Site 896 while awaiting fishing equipment and a fishing consultant.

Jetting, Casing, and Reentry cone

Prior to setting a reentry cone, a test was performed to determine the depth to which the 16-in. casing could be jetted to partially support the 11-3/4-in. casing. The reentry cone was assembled while a 14-3/4-in. bit and bottom-hole assembly (BHA) were run to the seafloor. A smaller truncated reentry cone that had been built several years earlier and left on board was to be used. The eight panels of the cone that compose the octagonal structure are 20 in. shorter than those in a standard reentry cone. Two sonar reflectors were installed on the rim of the cone, and the interior of the cone was painted with black and white stripes. One of the eight panels was painted completely black for orientation during reentries.

The BHA was run to the seafloor for the jet test. The 14-3/4-in. bit was jetted to 96 mbsf with a weight on bit of 15,000 lb. The jetting assembly was returned to the rig floor, and preparations were made to run six full joints of 16-in. casing plus one 8.4-m joint above the shoe. That configuration would achieve the maximum depth that could accommodate the BHA, putting the 14-3/4-in. bit 6 in. inside the casing shoe. The casing was latched into the reentry cone, and the 14-3/4-in. drilling assembly was prepared with the double-J tool in the BHA, and landed in the hanger. Hole 896A was spudded at 0350 UTC on 13 February, and the casing string was jetted in by 0815 UTC with a maximum weight on bit of 20,000 to 25,000 lb. The 16-in. casing shoe was at a depth of 86.15 mbsf, so that the mat of the reentry cone was directly on the seafloor.

The 14-3/4-in. hole was drilled initially using a tri-cone bit. Erratic torque was encountered while drilling a rubbly zone from 179.0 to 186.5 mbsf. When the 14-3/4-in. hole was drilled to 195.1 mbsf, the drill string was pulled to the 16-in. casing shoe. After returning to bottom with no drag, 6.5 m of hole fill was reamed, and a 50-bbl sweep of high-viscosity mud was pumped. This was then displaced with 10.0-ppg mud, which was left in the hole while pulling out to run the 11-3/4- in. casing through the rubbly zone.

A string of thirteen 11-3/4-in. joints of casing was designed to fit both the drilled hole depth and a stinger assembly that included three bumper subs. After reentering the hole and slowly running in the casing, fill was encountered 6.5 m off bottom. The hole was circulated and washed for an hour, but the casing did not move downward. The ship was moved forward in DP mode for about 5 min, and the casing began to slide into the hole. The 11-3/4-in. casing shoe was set at 191.46 mbsf. The running tool was released from the casing, and 77 bbl of cement was pumped and displaced with seawater. Once above the reentry cone on the pipe trip out of the hole, the drill string was circulated thoroughly and tripped to the surface.

OPERATIONS

Coring Run 1

An RBI C-7 coring bit with a center bit was chosen to drill out the cement, plug, and shoe at the bottom of the 11-3/4-in. casing. No progress was made after 6.5 hr of drilling with a center bit, so the center bit was pulled, and a core barrel was sent down the pipe. When this failed to help, the core barrel was pulled, and a chisel-type center bit was dropped into the pipe. The shoe was drilled out in 70 min, and a 40-bbl high-viscosity mud sweep was pumped. The chisel center bit was retrieved, and the first core was drilled. The coring parameters for the C-7 bit were 25,000 lb weight on bit, at 50 rpm. At the end of every core in Hole 896A, a 40-bbl sweep of high-viscosity mud was pumped.

Penetration rate increased from 2.42 m/hr for Core 148-896A-5R to 4.62 m/hr for Core 148-896A-8R. As in Hole 504B, however, as penetration rate increased, the recovery percentage typically decreased. Rates of penetration were only 3.06 m/hr for Core 148-896A-9R and 3.05 m/hr for Core 148-896A-10R. After cutting Core 148-896A-11R, a trip was made for another bit.

Coring Run 2

The second coring bit used in Hole 896A was a Smith series-9 bit. This type of bit had not been chosen to drill Hole 504B because the legs of the cones were long and had insufficient gauge protection. The BHA contained a nonmagnetic drill collar so that the hard-rock orientation system (HRO) could be used to orient alternate cores.

An obstruction at 282.6 mbsf was encountered while reaming the last two stands of drill pipe to bottom and washed through. Over 7 m of rubble at the bottom of the hole was reamed and washed, and Core 148-896A-12R was drilled. Core 148-896A-13R, which required 4.08 hr to cut, recovered only 0.12 m of basalt that had jammed the HRO scribe in the core catcher. Cores 148-896A-14R to -18R were drilled successfully, with a weight on bit of 23,000-28,000 lb, at 50 rpm. The drill string was pulled out of the hole, and the ship departed for Site 504 at 1410 UTC, 20 February, to clean out Hole 504B.

Logging: Phase 1

The *JOIDES Resolution* returned to Site 896 on 1 March to log Hole 896A. The induced gamma-ray spectroscopy tool (GST), aluminum clay tool (ACT), natural-gamma spectroscopy tool (NGT), and temperature logging tool (TLT) were run successfully from 120.73 to 347 mbsf (11 mm above the bottom of the hole).

Coring Run 3

The next coring run in Hole 896A was another Smith series-9 bit, again in conjunction with a nonmagnetic drill collar and with the HRO system used on alternate cores. The drill string was run to the bottom of the hole (356 mbsf), and encountered no rubble. Cores 148-896A-19R to -22R were drilled with weight on bit of 25,000 to 28,000 lb, at 50-55 rpm. Near the end of drilling Core 148-896A-23R, the weight on bit was increased to between 30,000 and 32,000 lb, but did not improve penetration rate, so the weight was decreased to 28,000 lb. Drilling continued until 4 March, when Core 148-896A-30R was cut and coring operations ceased so the ship could return to Site 504 for additional downhole measurements. The rate of penetration for the final bit run averaged 2.91 m/hr, for an overall recovery of 29.4%.

Logging: Phase 2

After completing operations at Site 504 on 6 March, the *JOIDES Resolution* returned to Site 896 to log. The first logging string contained the dual lateral log, the sonic density tool, and the natural-gamma tool. The suite was run successfully from 117.28 to 429 mbsf. The packer experiment was conducted next, with measurements at 105.6, 233, and 396.55 mbsf. The magnetometer then logged from 117.28 to 325 mbsf, and finally, the formation microscanner was run to 373 mbsf.

The drill string was pulled out of the hole, and the ship left Site 896 on 8 March for a 2 day transit to port. Leg 148 ended when the ship docked in Balboa, Panama, on 10 March.

OCEAN DRILLING PROGRAM
OPERATIONS RESUME
LEG 148

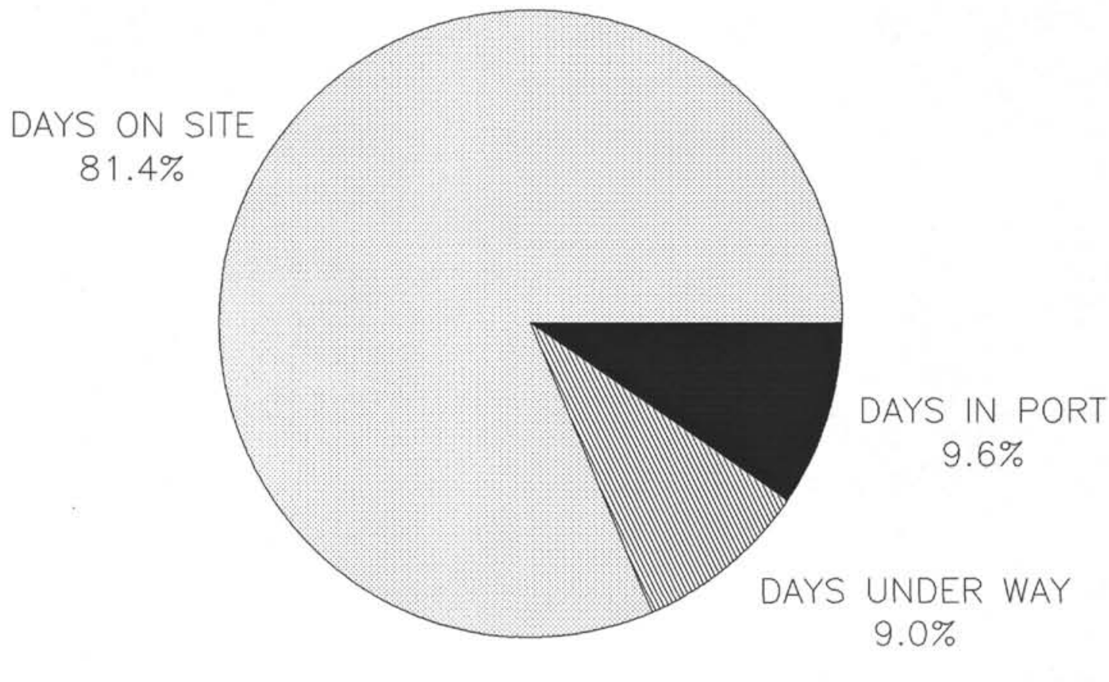
Total Days (21 January - 10 March, 1993)	48.07
Total Days in Port	4.60
Total Days Underway	4.34
Total Days on Site	39.13

Trip Time	8.28
Coring Time	9.11
Drilling or Reaming Time	1.07
Logging/Downhole Time	7.80
Re-entry Time	1.68
Casing/CementingTime	1.98
Fishing/Remedial Time	7.84
Circulate/Cool Hole	0.66
Other	0.69

Total Distance Traveled (nautical miles)	529
Average Speed	9.75
Number of Sites	2
Number of Holes	2
Number of Re-entries	18
Total Interval Cored (m)	384.5
Total Core Recovery (m)	81.43
Percent Core Recovered	21.20
Total Interval Drilled (m)	195.1
Total Penetration (m)	579.6
Maximum Penetration (m)	2111.0
Maximum Water Depth (m from D.E.S.)	3474.0
Minimum Water Depth (m from D.E.S.)	3459.0

SITE SUMMARY--LEG 148												
HOLE	LATITUDE	LONGITUDE	W.D.(m)	No.of Cores	Meters Cored	Meters Rec'd	% Rec'd	Meters Drilled	Total Penetr.	Time on Hole	Time on Site
504B	1Deg.13.60'N	83 Deg 43.8'W	3474	15	110.6	9.58	8.7	------	110.6	24.37	24.37
896A	1Deg.13.02'N	83 Deg 43.4'W	3459	30	273.9	71.85	26.2	195.1	469	14.88	14.88
			TOTALS	45	384.5	81.43		195.1	579.6	39.25	39.25

LEG 148
TOTAL TIME DISTRIBUTION



TOTAL DAYS OF LEG = 48.07

TECHNICAL REPORT

The ODP Technical and Logistics personnel aboard *JOIDES Resolution* for Leg 148 were:

Laboratory Officer	William Mills
Assistant Lab Officer/ XRF-XRD	Kuro Kuroki
Curator	Erinn McCarty
System Managers	Matt Mefferd
	Julio Cesar Flores
Yeoperson	Jo Claesgens
Photography	Shan Pehlman
Chemistry	Dennis Graham
	Anne Pimmel
Electronics	Mark Watson
	Bill Stevens
UWG-FMS	Dwight Mossman
Physical Properties	Jon Lloyd
Storekeeper/FMS	Tim Bronk
Magnetics	Margaret Hastedt
Thin Ice	Jacque Ledbetter

SCIENTIFIC OBJECTIVES OF LEG 148

Leg 148 is the latest of numerous legs to reoccupy Hole 504B. As with previous legs, our objective included deepening Hole 504B into the oceanic crust's dike/gabbro or layer 2/3 transition to study the relationships between lithologic and seismic crustal structures.

Leg 148 departed Balboa, Panama, on 27 January 1993 with a crew of 109 (48 scientists and marine specialists). This leg ended in Balboa, Panama on 10 March after 41 days at sea.

PORT CALL, BALBOA

On 21 January the *JOIDES Resolution* docked in Balboa a day earlier than scheduled, ending Leg 147. On the following day the Leg 148 crew arrived at 9:00 a.m. to begin crossover. During the remainder of our 6 day port call, we discharged Leg 147's freight and onloaded new supplies. Also during this port call, the Colmek technicians repaired the reentry TV system.

After leaving dockside, we waited a day at anchor for a shipment of drill collars. Drill-string losses on Leg 147 had depleted drill-collar supplies to the point at which we had only enough collars to assemble one BHA (bottom-hole assembly). Waiting on this shipment proved to be a wise choice, as we continued to have drilling difficulties.

UNDER WAY TO HOLE 504B

We did not collect underway data, per Co-chief request, as the route between Hole 504B and Panama had already been surveyed extensively. However, we did collect navigational data.

SCIENTIFIC SUPPORT

In general, lab operations were routine for a "hard-rock" leg. Those marine specialists not directly supporting the science party's activities worked on setting up and testing new/old equipment, updating databases, preparing new procedures/manuals, and were involved in general maintenance projects. Legs such as these are rare in our drilling schedule, and we used our time productively.

TECHNICAL HIGHLIGHTS

Physical Properties Lab

The MST bench was split apart, and the support frame for the Natural Gamma Radiation Detector installed. The Natural Gamma System is scheduled for final installation on the Leg 149A transit and should be operational for Leg 149B.

Since Leg 138, scientists have been saving index-property data in various Excel spreadsheet formats. This situation has made data access difficult. During this leg we transferred eight legs of data to the S1032 database.

We successfully installed the first phase of the Pycnometer automation project. This phase consisted of installing a relay, in parallel with the pycnometer's print switch. Using a LabView program, this relay can be controlled to initiate the pycnometer printing routine. The same program will then capture printer output. Up to five runs of data can be collected for averaging the final value. In the next phase of this project these data will be transferred to a 4D spreadsheet.

Paleomagnetics Lab

The beta version of the new spinner program was completed this leg. This version will go back to ODP for thorough testing and documentation, with planned release for Leg 150.

Fantail

We built a prototype hose bundle using air hose as a conduit for the signal lines instead of lashing the lines to the outside of the hose bundle (for use on the 200-in. water gun). The advantages of this design are (1) safer handling - no loops to catch hands, (2) easier handling - less drag in the water, and (3) quicker repairs - signal lines are pulled through the tubing instead of being lashed on and off. If this prototype hose bundle works out, we plan to have hose prefabricated and jacketed.

Chemistry Lab

The chemists installed a new Dionex DX 100 ion chromatograph this leg. The new Dionex was thoroughly tested, and new methods were developed and manuals written. Everyone was pleased with the Dionex's performance on sulfate as well as sodium and potassium ions.

X-Ray Lab

The weighing station for this lab was modified to use a multichannel analogue board to acquire direct readings from the sensors. This board replaces a differential amplifier and a digital multimeter. The functions of these two components are now emulated with software. The advantages of using this board are (1) less drift, (2) zero and gain controls cannot be accidentally jarred, and 3) each individual sensor can be monitored for problems.

EQUIPMENT PROBLEMS

Downhole Measurement Lab

Before coring began in Hole 504B, the marine specialist deployed the Los Alamos National Labs high-temperature water sampler eight times to sample the borehole fluids. Unfortunately, only three runs provided uncontaminated samples, as this tool is not suitable for hot boreholes in the marine environment.

Extensive testing was performed on both the Adara and DCDL electronics (used to collect in-situ formation temperatures) to resolve ongoing problems. We forwarded test results to the shore staff for further evaluation.

We ran the HRO (Hard Rock Orientation) device on eight coring runs in Hole 896A with little success. The HRO consists of three components: a core scriber, a sonic core monitor to record recovery rates, and the tensor tool to measure magnetic orientation. The scribers worked reasonably well, but unfortunately neither the tensor nor the sonic core monitor produced any usable data. The data from the sonic core monitor are being returned to the ODP engineers for further consideration.

X-Ray Lab

The XRF is in the middle of a full upgrade that was started at the Leg 146 port call in Victoria. Work on the upgrade continued at the Leg 147 port call and will, hopefully, be completed by the end of the Leg 149 port call in Panama. In the meantime the XRF has been plagued with numerous problems. Many of these problems are the result of the incomplete upgrade state of the XRF with conflicts between the different versions of firmware and hardware. In addition to these problems the intensities have been steadily dropping to the point at which the lower abundant elements (Na and Mg) are being affected by poor counting statistics, resulting in severe drifting. The XRF service representative has been alerted to these problems and will complete their repair along with completing the upgrade.

Paleomagnetics Lab

Taking advantage of the slow coring pace, marine specialists and scientists conducted extensive testing of equipment in this lab. Several problems were discovered and fixed. A precision check of the cryogenic magnetometer determined that the z axis squid was out of tune with the other two axes. An amplifier was repaired, and the axis re-tuned. The GSD-1/PARM was found to be crossed-wired after careful testing. We switched the wires, and now the instrument is producing good results.

Underway Lab

This lab was used exclusively to support the Woods Hole VSP experiment. Prior to the VSP experiment, we conducted extensive gun signature tests to determine the optimum gun settings. Both the 1000-in.^{3} air and 400-in.^{3} water guns were used. The testing consisted of firing both guns at 1500 and 2000 psi and at four different depth stations, ranging from 3 to 11 m. The results of this test showed that the optimal depths for the air and water guns are 7 and 4.5 m respectively, and the difference between firing at 1500 vs. 2000 psi was negligible.

The actual VSP experiment did not go smoothly. On two attempts, improperly designed amplifiers failed when the arms were deployed. On the third attempt, continuing cable-head problems forced the Woods Hole tool into retirement. We used the Schlumberger VSP tool to complete the experiment.