OCEAN DRILLING PROGRAM

LEG 137 PRELIMINARY REPORT

HOLE 504B CLEANOUT

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SCIENTIFIC REPORT

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SCIENTIFIC REPORT

Abstract

The principal objective of ODP Leg 137 was to recondition Hole 504B for future deepening and downhole measurements. Hole 504B is by far the deepest reference section for the structure and composition of oceanic crust, but its status had been jeopardized when a diamond coring assembly was lost at the bottom of the hole near the end of Leg 111. The highest priorities for Leg 137 included remedial measures to clean this junk from the hole and tests to prove the feasibility of continued coring.

Before these operations were begun, undisturbed borehole temperatures were logged and seven fluid samples were collected. Cleaning the troublesome junk from the bottom of the hole required less than one week of straightforward fishing, milling, and drilling operations. Coring tests with the ODP rotary coring system and a conventional diamond core barrel yielded mixed results, suggesting that future drilling will require trade-offs between penetration and recovery. Unfortunately, these tests terminated when an outer core barrel with diamond bit broke off in the hole, and this equipment was not recovered during the leg due to lack of time and appropriate fishing tools. Nevertheless, the lost equipment can easily be retrieved with proper fishing tools, probably represents only a minor impediment to future deepening, and therefore should not detract from the essential Leg 137 success in reconditioning Hole 504B.

Introduction

The principal objective of Leg 137 of the Ocean Drilling Program (ODP) was to revisit Hole 504B in the eastern equatorial Pacific (Fig. 1) to recondition the hole for future ODP operations. Hole 504B is by far the deepest penetration into oceanic crust and perhaps our most important *in-situ* reference section for the structure of the upper oceanic crust. However, its status had been jeopardized when a coring assembly was lost at the bottom of the hole near the end of Leg 111. Therefore, the highest priorities for Leg 137 involved engineering operations, including remedial measures to clean this junk from the hole and tests to prove the feasibility of continued coring on a subsequent expedition. If these objectives were successfully achieved during Leg 137, Leg 140 was committed to returning to the hole for a full scientific leg of coring and downhole measurements.

Leg 137 was the sixth expedition of the Deep Sea Drilling Project (DSDP) or ODP to occupy Hole 504B. The hole was originally spudded during Leg 69 in 274.5 m of sediments overlying 5.9-m.y.-old crust formed at the Costa Rica Rift, and was then deepened and/or logged during parts of four other DSDP/ODP legs: 70, 83, 92, and 111. These legs provided a wealth of scientific results, much of which is summarized by CRRUST (1982); Cann, Langseth, Honnorez, Von Herzen, White, et al. (1983); Anderson, Honnorez, et al. (1982, 1985); Leinen, Rea, et al. (1986); and Becker, Sakai, et al. (1988, 1989a, 1989b).

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

Leg 137 departed Honolulu on 20 March 1991 and began with a 17-day transit to Site 504. The leg ended in Balboa, Panama, on 1 May 1991 after 21 days of operations and a two-day transit. During its scheduled operations at Hole 504B, Leg 137 was to focus upon removal of the existing junk (Fig. 2), assessment of the condition of the hole and its casing and reentry cone, and development of more efficient coring and drilling techniques for the projected deepening of the hole on Leg 140. Additional objectives involved high-priority downhole measurements that could not be deferred to a later leg, including temperature logging, borehole-fluid sampling, and permeability measurements.

Initial Temperature Log and Fluid Sampling

Before engineering operations were begun, temperatures in the undisturbed hole were logged, and 36 hours was devoted to sampling borehole fluids. Figure 3 shows the Leg 137 temperature log compared to measurements made during past legs in Hole 504B. Temperatures in the deeper kilometer of the hole were consistent with values logged during Leg 111, with a linear gradient of 61°C/km. This gradient extrapolates to a temperature of 165°C at the bottom of the hole at 1562.3 mbsf. In the upper 350 m of the hole, temperatures were considerably depressed, suggesting an unexpected renewal of the downhole flow of ocean bottom water into the upper levels of basement. Such downhole flow was fairly vigorous when the hole was first drilled during Legs 69 and 70 in 1979 but had decayed to about 1 m/hr, or less than 1% of the original rate, when Leg 111 revisited the hole in 1986. The Leg 137 temperatures are slightly higher than those measured during Leg 83 in 1981, suggesting that the downhole flow has increased since 1986 to a rate on the order of 15 m/hr. This is a surprising result that raises many intriguing questions about the hydrogeology at the site. Some of these questions were to be studied with a digital televiewer log and permeability measurements planned at the end the leg, but these measurements were cut short because of developments during coring tests.

Using tools provided by Lawrence Berkeley and Los Alamos national laboratories, eight fluid samples were obtained from the hole at depths ranging from 350 to 1540 mbsf. Initial chemical analyses indicate that seven of these samples contain borehole fluid with characteristics in agreement with past sampling studies of the hole. Some contamination of the samples appears to have occurred, either by entrainment of fluids during the trip down prior to sampling or as a result of leakage during the ascent as the hot sampled fluids cooled and contracted. The fluid chemistry indicates bottom water present down to at least 350 mbsf, corroborating the inference of downhole flow from the temperature log. An interesting note: during subsequent engineering operations at the bottom of the hole, many small pieces of platy anhydrite were recovered, consistent with predictions that anhydrite should reach saturation in the borehole fluids near 150°C and 1500 mbsf.

Hole 504B Cleanout

The primary purpose of Leg 137 was to salvage Hole 504B -- and the cleanout operations succeeded very much according to plan. As noted above, a diamond coring assembly had broken off at the end of Leg 111, which was left with insufficient time to recover all of the lost hardware, necessitating abandonment of the large diamond bit and assorted hardware at the bottom of the hole. There were also suggestions of possible problems with the casing, and it was feared that wall rocks might have caved in on top of the junk since Leg 111.

Despite these uncertainties, Leg 137 was able to run straight to the junk from virtually the beginning of remedial operations. Cleaning the junk from the bottom of the hole required less than one week of straightforward operations (Fig. 4), including one fishing attempt with a junk basket and five mill runs with boot baskets to capture pieces of broken-up metal. These returned with parts or whole pieces of all the lost hardware, including recognizable pieces of the diamond bit. This was followed by a run with a tri-cone drill bit to verify that the hole was clean, which deepened the hole without coring by 8 m to a total depth of 1570 mbsf.

Coring Tests

Another important priority of Leg 137 was to test coring systems, to assess the feasibility of coring ahead during a full scientific leg. Once the hole was verified to be clean, two coring systems were tested: the standard ODP RCB wireline coring system and a conventional oilfield diamond core barrel. (The latter is a standard oilfield system, completely different from the small-diameter wireline diamond coring system under development at ODP.) These tests yielded mixed results and unfortunately ended with a frustrating loss of very fishable coring equipment in the hole.

Two runs with the RCB system in a clean hole yielded penetration rates of 1-2 m/hr and an average recovery of 14%. This is comparable to results with the same system during Legs 83 and 111. The cutting inserts of the bits failed quickly in a manner that suggested that the formation is extremely hard and abrasive and that a more appropriate grade of bit could make more hole. But, while rotary core and drill bits could be used to advance the hole at a reasonable rate, it is clear that the RCB system cannot be expected to yield core recovery any better than 20% in this lithology.

The diamond core barrel also yielded mixed results, with extremely slow penetration but very good recovery. Two runs resulted in a recorded advance of only 3.1 m (which could be in error because of the effects of tides) and a calculated recovery of 79%. The first diamond bit was extremely worn after less than 2 m of penetration, indicating that the bit matrix material was too soft for the hard, abrasive formation. The second diamond bit behaved in a similar manner downhole but was not recovered because all 18 m of outer core barrel broke off in the hole, with the bit at the bottom.

Such a long, narrow piece is normally the easiest kind of junk to fish from a hole with the appropriate tools, and in fact the first fishing overshot apparently did engage and lift it some distance up the hole. However, the fishing overshot itself broke off, leaving a compound fish as detailed in Figure 5. This remains eminently fishable with the appropriate fishing tools. Unfortunately, the proper tools were not on board, although a second fishing attempt was made with a modified taper tap. When this failed, the decision was made not to risk damage to the fish by attempting to retrieve it with a "rig-engineered" solution, but instead to leave the fish in its easily retrievable condition, in a position to be removed with proper equipment during a future leg.

Coring Results

Drilling on Leg 137 deepened Hole 504B by 59.2 m to a total depth of 1621.5 mbsf or 1347 m into basement (Fig. 6). Of this interval, 48.6 m was cored, with a recovery of 8.77 m. The recovered rocks are all interpreted as a continuation of the sheeted dike complex, although no intrusive dike margins were actually recovered. The physical properties of recovered core support the inference that the formation is very hard and dense massive basalt, and therefore difficult to core. Chlorite and actinolite veins and actinolite-bearing alteration halos are common in the diamond cores with good recovery. It would therefore appear that the trend of increasing proportion of actinolite in the secondary mineral assemblage recognized on Leg 111 continues with depth.

Final Logging

Attempts to fish the lost outer core barrel left time for only an abbreviated program of downhole measurements at the end of the leg. The planned open-hole packer inflation was cancelled because it posed the greatest risk of somehow disturbing or compounding the presentation of the fish. A digital BHTV log of the casing was successfully conducted, but the tool failed shortly after logging only 85-90 m of the open-hole section. The complicated flowmeter/injection experiment was an operational success during two packer inflations in casing but each time was cut short by premature packer deflations. The packer was recovered in good condition (with outer rubber fully intact), so the most plausible explanation for the packer deflations is that the inflation pressure was insufficient to maintain the grip against the smooth casing.

The casing inspection by borehole televiewer disclosed that the casing flaw suspected after Leg 111 can in fact be attributed to a casing expansion joint, but that some casing damage, apparently due to wear, does exist. The most severe degradation is in the lower-most 30-40 m, where the casing appears to have several small holes connected by some sort of vertical split or separation. To date this has not affected operations at the hole, and it does not appear to require casing repair for the science leg approved for the 1991 schedule.

Conclusions and Recommendations for Future Operations at Hole 504B

Leg 137 achieved its primary objective, cleaning Hole 504B of the serious junk lost at the end of Leg 111. Operations throughout the leg showed no indication of the supposed problems with the casing, although a borehole televiewer inspection during the last day on site showed flaws with the lower 30-40 m of casing. Leg 137 clearly succeeded in demonstrating that Hole 504B can be advanced to the Layer 2/3 transition, the proposed target for a scientific leg later in 1991.

This important success was tarnished by a frustrating inability to retrieve a much less serious piece of junk lost at the end of coring tests. This disappointment can be attributed to a defective fishing tool and a lack of time to procure and deploy any further appropriate tools, not to any difficult presentation of the junk itself. In fact, such tool losses and fishing jobs are not at all unusual in drilling any deep hole, and in this case it is virtually certain that the lost outer core barrel can readily be fished with the proper tool. Furthermore, Hole 504B has a history of being open to total depth on multiple revisits, so the fish can be expected to remain clean and in easily retrievable condition for a reasonable period of time. With appropriate fishing tools, it should pose little risk to a revisit in the near future.

The more serious dilemma facing future legs to Hole 504B is the inability of both the RCB and diamond coring systems to simultaneously cut core and make hole in this lithology. The RCB system can make hole with recovery on the order of 20%, whereas the diamond core barrel gives excellent recovery with very slow progress. Even with improved bit designs for these coring systems, trade-offs will have to be made between penetration and recovery. While Leg 137 has shown that the key scientific priorities for deepening and logging Hole 504B to the Layer 2/3 and/or dike/gabbro transition(s) can be achieved on a later leg, these objectives may require compromise strategies for drilling, coring, and logging.

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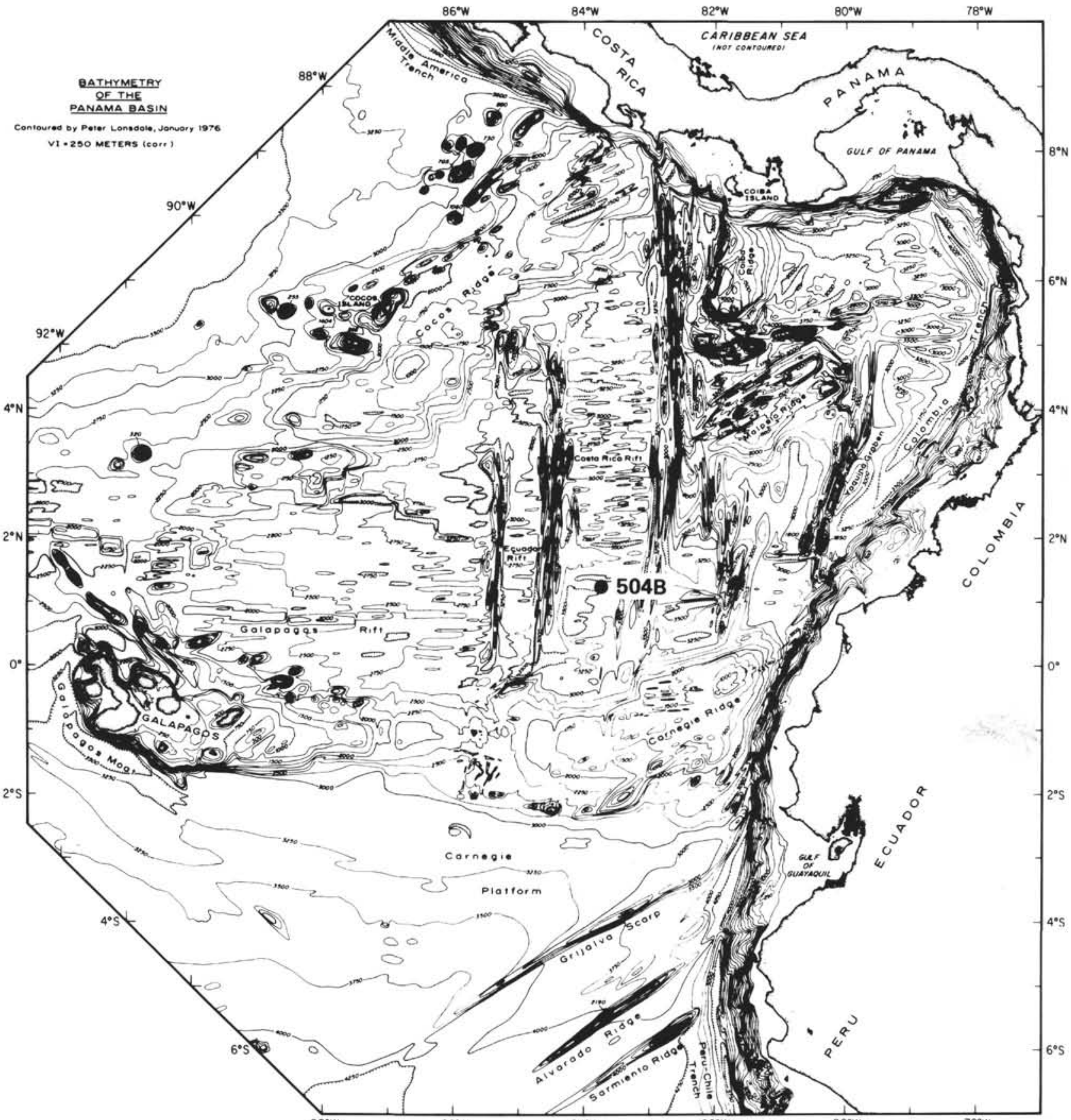

Figure 1. Location of Hole 504B south of the Costa Rica Rift in the eastern equatorial Pacific Ocean. From Lonsdale and Klitgord (1978).

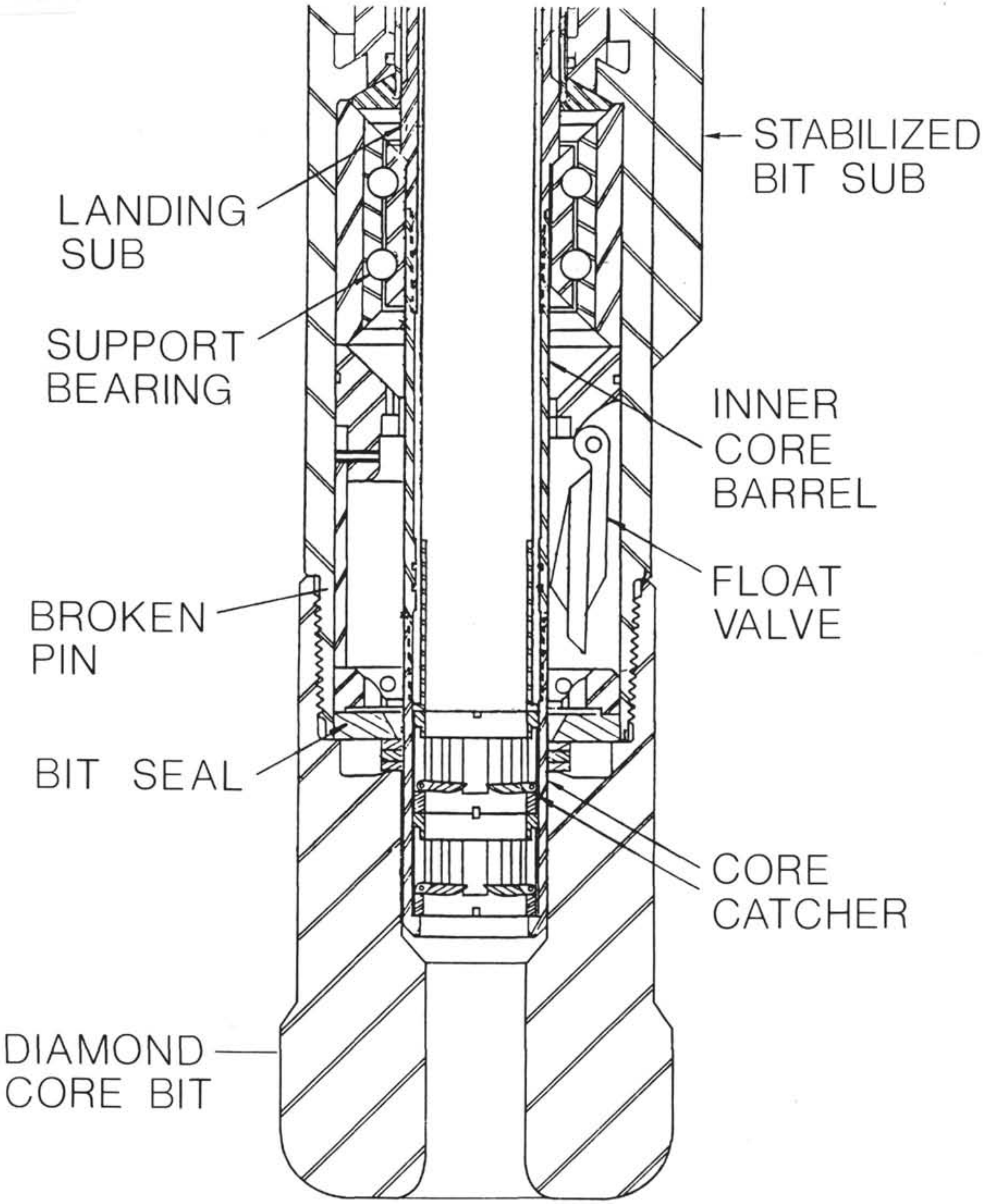

Figure 2. Schematic of the diamond coring assembly lost in Hole 504B at the end of Leg 111. The pin thread of the stabilized bit sub-assembly broke, leaving the core barrel, support bearing, float valve, and diamond core bit in the hole. The core barrel and outer race of the support bearing were recovered before Leg 111 ended. The remainder -- the inner race and ball bearings from the support bearing, the float valve, and the diamond core bit -- were successfully fished and milled from the hole during Leg 137.

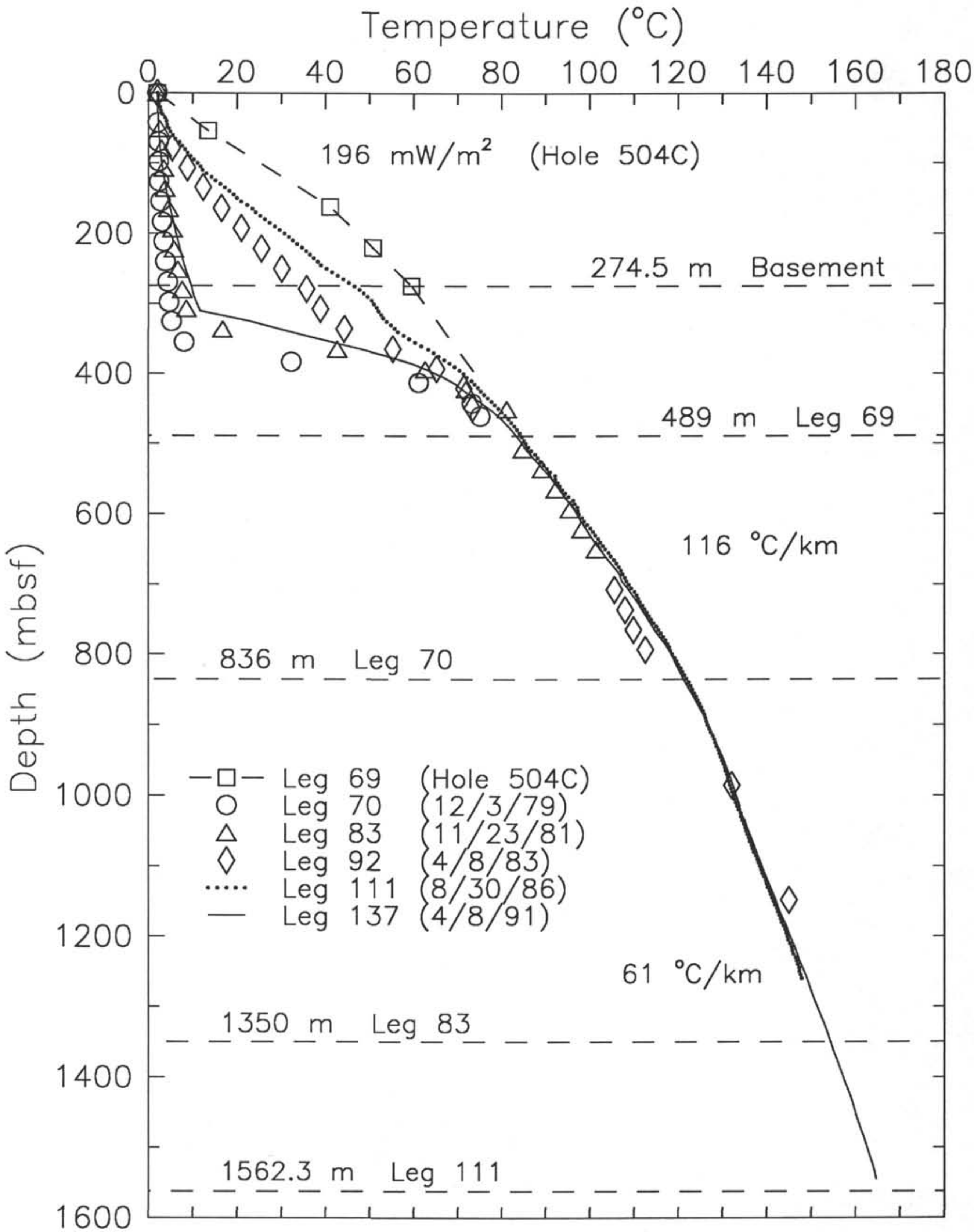

Figure 3. Composite of temperature logs obtained in Hole 504B during Legs 69, 70, 83, 92, 111, and 137.

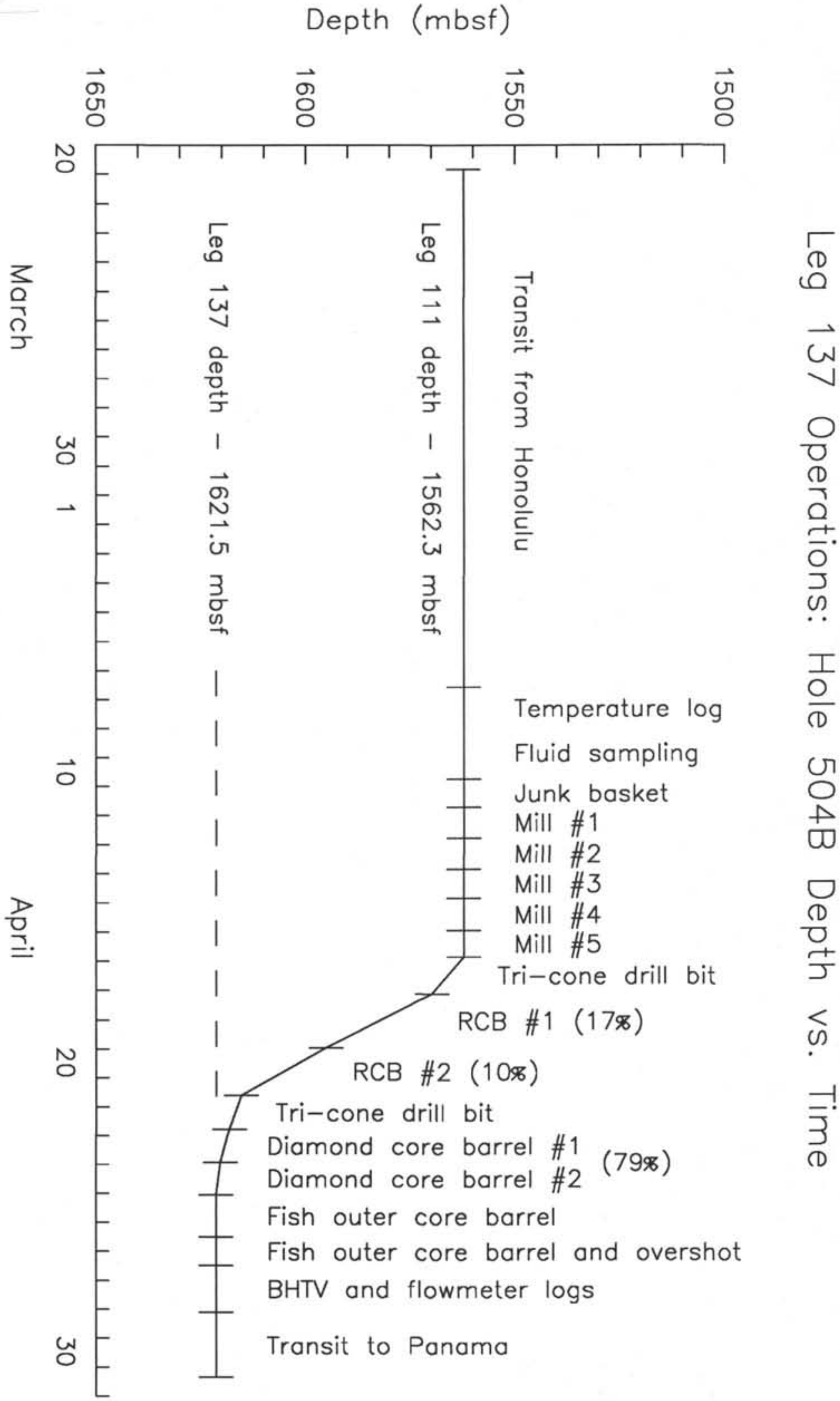

Figure 4. Summary of Leg 137 operations, showing depth of Hole 504B vs. time during the leg.

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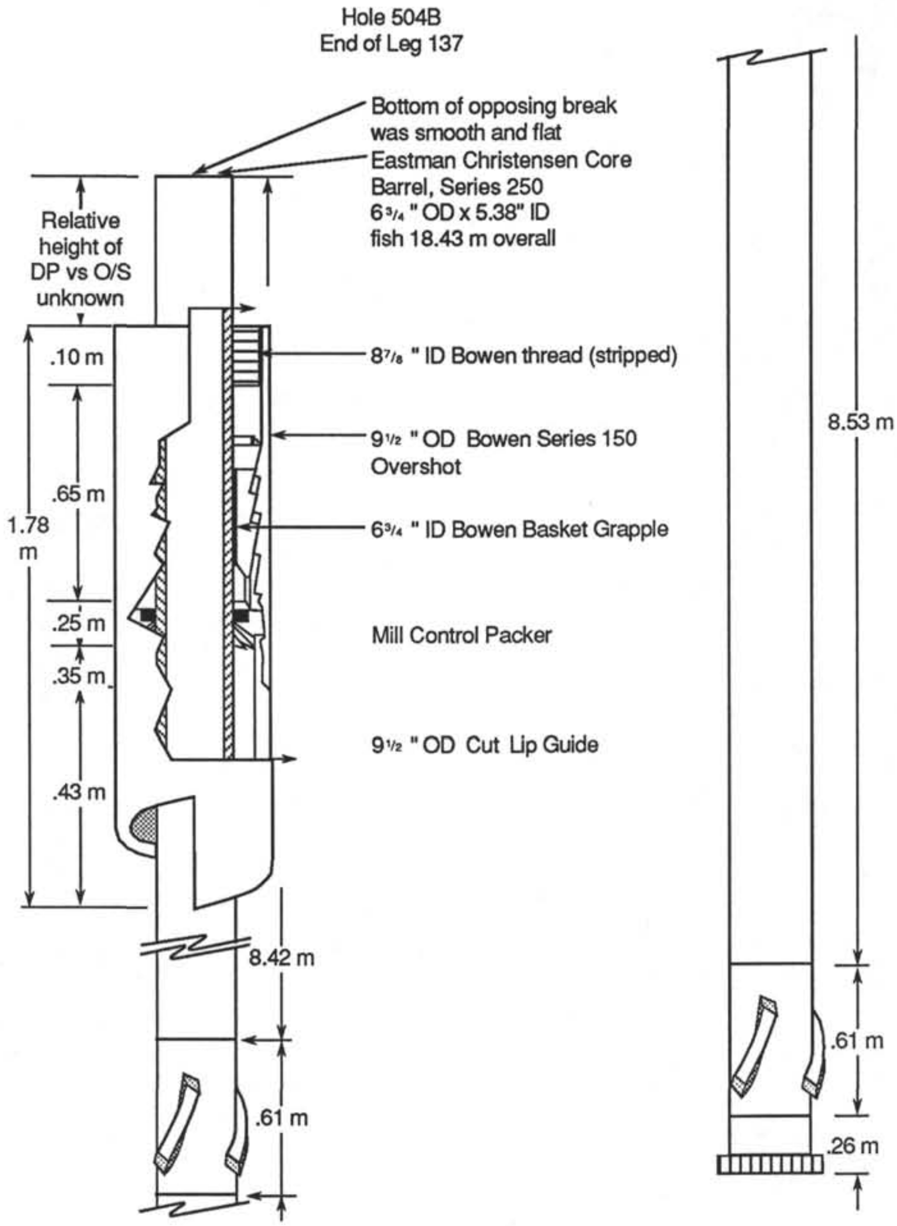

Figure 5a. Schematic diagram of the Christensen core barrel and Bowen overshot grapple, which comprise the "fish" left in the hole at the end of Leg 137. The grapple has probably slid down the outer surface of the core barrel some distance. It is impossible to tell for certain the position of the overshot grapple relative to the top of the core barrel, but ribs on the outside of the core barrel restrict the grapple's position to the top 8 m of the core barrel.

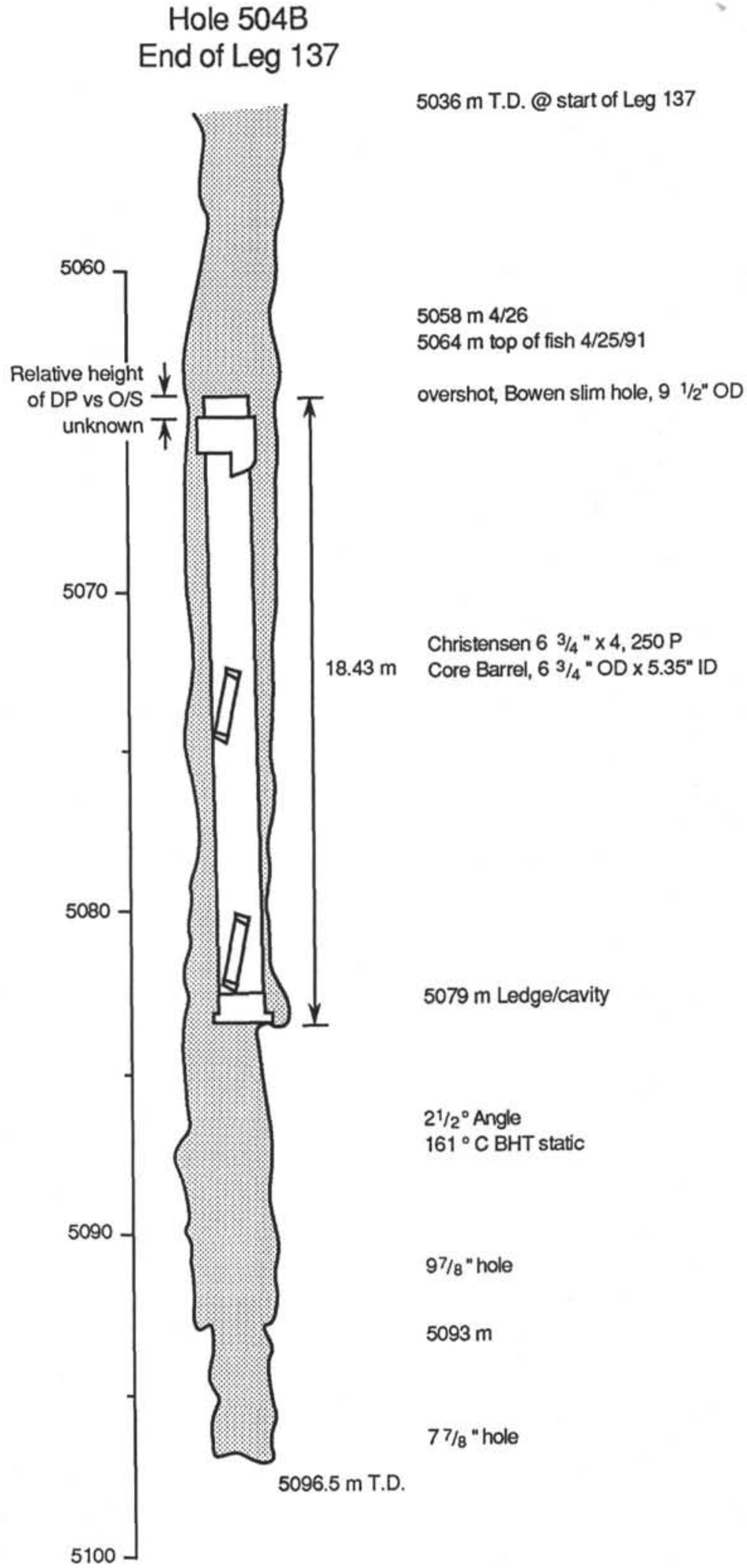

Figure 5b. The inferred position of the fish in Hole 504B. DP = drill pipe (Christensen core barrel); O/S = overshot.

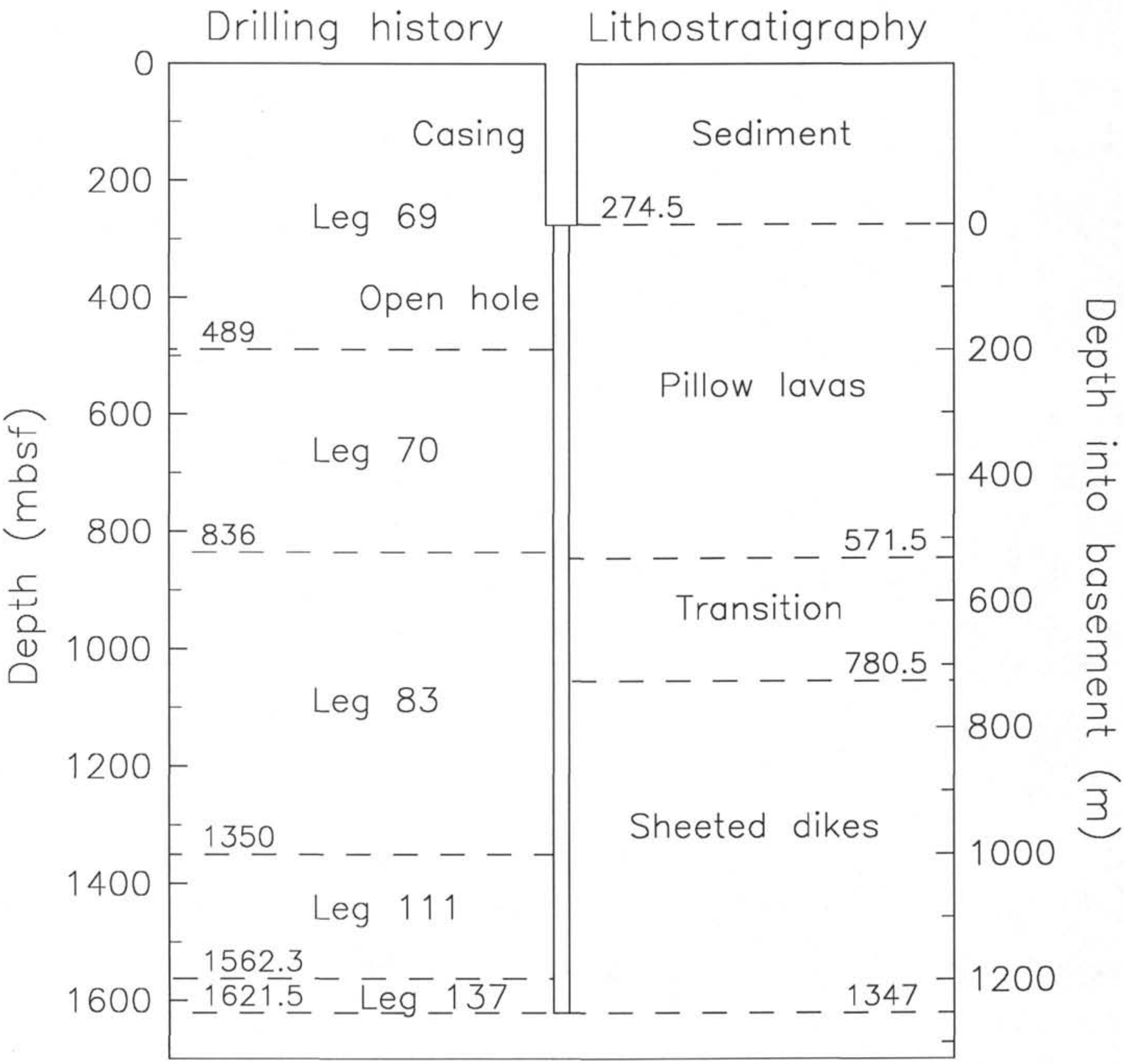

Figure 6. Schematic of drilling history and lithostratigraphy of Hole 504B as of the end of Leg 137.

OPERATIONS REPORT

The ODP Operations and Engineering personnel aboard *JOIDES Resolution* for Leg 137 were:

Senior Operations Superintendent: Glen Foss

Operations Superintendent: Gene Pollard

Schlumberger Engineer: Scott Shannon

OPERATIONS SYNOPSIS
Honolulu, Hawaii to Balboa, Panama
20 March 1991 to 1 May 1991

Overview

Leg 137 of the Ocean Drilling Program was dedicated to the salvaging of DSDP/ODP Hole 504B in the eastern equatorial Pacific. Due to lack of time and appropriate equipment, the hole had been abandoned with a substantial amount of "difficult" junk at total depth at the end of ODP Leg 111. The rescue expedition was scheduled to transit from Hawaii to Site 504 and to spend 22 days on the location. In addition to cleaning the junk from the hole, the leg was to evaluate alternative methods of coring in an effort to improve coring performance in anticipation of further deepening the hole.

Hole 504B represents the deepest offshore penetration of oceanic crustal rocks to date. It penetrates a portion of the seafloor that was formed 5.9 million years ago on the south flank of the Costa Rica Rift and is now blanketed by about 275 m of sediment. The reentry installation was set in 1979 in 3464 m of water on DSDP Leg 69 and had been revisited for deepening and/or downhole measurements on Legs 70, 83, 92, and 111 prior to the Leg 137 reoccupation. The sediment section was entirely cased off on Leg 69, and the basement hole had been deepened in stages to 1287 mbsf by the end of Leg 111. The hole is unique as the type model for oceanic crust formed at an open-ocean spreading center and also as a laboratory for hydrogeologic studies. (A flow of ocean-bottom water uses the borehole as a conduit and enters the volcanic basement rocks below the casing.)

Leg 137 began as an 18-day transit to the site from Honolulu. Hole 504B was reentered routinely and an initial suite of downhole measurements was undertaken prior to any disturbance of the water column. A temperature log determined that the hole was open to total depth and recorded the hole's temperature profile for comparison with those of earlier legs. A series of seven water samples also was collected, with each sample from progressively deeper in the borehole.

The cleanout phase of operations followed. Pipe trips were made to deploy a junk basket and five junk mills before the hole was considered to be clean enough for drilling. Removal of the junk was confirmed by drilling 9 m of new hole with a tri-cone drill bit.

Coring operations then proceeded, with two standard RCB bits dulled to provide a control for comparison with a conventional oilfield core barrel. Two core trips then were made with the diamond coring system for 4"-diameter cores. Core recovery was good, but both of the experimental diamond coreheads failed after penetration of less than 2 m. In addition, the core barrel parted near the top at the end of the second core run, returning the hole to a junked condition.

Fishing with a conventional overshot met with apparent success in engaging the fish, but failure of the overshot itself added to the fish already in the hole. One additional fishing attempt was made by improvising and modifying a taper tap in an attempt to engage the overshot bowl. After the unsuccessful fishing run, time remained for only a brief final phase of downhole measurements.

The digital borehole televiewer was used to make an inspection survey of the surface casing string, which was found to be damaged, apparently by excessive wear. An attempt to log open hole with the televiewer was successful in recording only about 90 m before failure of the downhole tool. The televiewer was followed by an experiment to estimate permeability by setting a packer in casing and measuring downhole flow with a wireline-deployed flowmeter. Two attempts were technically successful but were foiled short of actual measurements by the unseating of the packer.

Hole 504B was deepened by 59.2 m on Leg 137 and now awaits further deepening operations, but only after additional fishing to remove the core barrel/overshot assembly.

Operational highlights of the leg were the successful milling and removal of the junk in accordance with the operating plan, the recovery of core from a hole that had been considered by many to be hopelessly junked, and a series of 16 trouble-free reentries.

Honolulu Port Call

Leg 137 began officially when the first mooring line was put over at Pier 1, Port of Honolulu, at 1815 UTC 20 March 1991.

The brief port call was concerned primarily with scientific crew change and the loading and off-loading of limited freight shipments. Fresh water, helicopter fuel, and comestibles also were replenished. *JOIDES Resolution* departed Honolulu at 0045 UTC 21 March after only 6-1/2 hours in port.

Honolulu to Site 504

The vessel transited south of the islands of Molokai and Maui and passed through the Alenuihaha Channel between Maui and Hawaii. Once clear of the lee of the islands, the ship encountered headwinds of 25 to 30 knots. The opposing trade winds and North Equatorial Current held the average transit speed to just over 10 knots for the first nine days, to approximately the halfway point of the voyage. The winds then eased and became variable for the remainder of the transit. The final approach to Hole 504B was made on the basis of the Global Positioning System (GPS). At 1815 UTC 7 April, a positioning beacon was launched and assembly of the BHA began on the rig floor.

Average speed for the transit of 4533 nmi was 10.7 knots.

Hole 504B, Initial Downhole Measurements Phase

An abbreviated logging BHA of seven drill collars terminated by a 9" reentry/cleanout bit was made up and run to reentry depth. A routine reentry was made, and the end of the drill string was run to 3642 m, about 5 m past the obstruction or shoulder encountered by the fishing junk basket at the end of Leg 111. Nothing was "felt" by the rig weight indicator.

When the VIT reentry frame had been recovered, the French temperature logging tool was made up to the logging cable. Electrical problems in the cablehead "pigtail" and in the lowermost (high-temperature) section of the logging cable resulted in a misrun and caused a delay of about 4 hours.

While electrical troubleshooting was in progress, water samples were taken with the Los

Alamos National Laboratory (LANL) sampler (deployed on the coring wireline) from depths of 350 and 550 mbsf. Both runs were successful in recovering samples.

After the high-temperature cable had been removed, the temperature logging run proceeded without difficulty, and temperature was logged down from seafloor to 1520 mbsf. The measured temperature at that depth (about 17 m above total depth) was 161°C.

Upon completion of the temperature log, the water-sampling program resumed. The solenoid-operated Lawrence Berkeley Laboratory (LBL) sampler had to be run on the electric logging cable and was alternated with the LANL (Leutert) sampler, which was deployed on the coring wireline. Samples were collected from wireline depths of 800, 950, 1100, 1250, 1400, 1500, and 1519 mbsf. All attempts were successful except the one from 1250 mbsf, in which the sample was lost when the valve of the LANL instrument was prevented from closing by a piece of detritus (pipe rust?). Recovery of the final water sample concluded the initial phase of downhole measurements at 0800 UTC 10 April.

Remedial/Cleanout Operations

The reentry/cleanout bit was then run into the hole until resistance was met at about 5015 m by drill string measurement. The top drive was picked up and circulation was slowly increased to avoid thermal shock to the hole. The hole fill yielded to circulation and rotation, and the hole was cleaned to 5031 m (drill pipe measurement) before progress was halted by solid resistance. The depth was about 5 m short of the expected junk depth. No serious attempt was made to clean the hole deeper because the BHA was not suitable. The hole was flushed with high-viscosity drilling mud and the drill string was tripped at that point.

Upon recovery, the reentry/cleanout bit showed fairly clear indications of contact with junk in the hole. It was therefore concluded that there was a discrepancy between the current drill pipe depth and that of Leg 111 and that the junk would be accessible to a fishing junk basket. A BHA featuring the Bowen full-flow reverse-circulating junk basket was assembled and the drill string was tripped. After reentry, the junk basket was lowered to 4800 m (1325 mbsf) and circulated the remainder of the way to the fish with the top drive to cool the hole gradually. Reverse circulation was established by pumping a steel ball into place, and the junk basket was "worked" on the fish for about 30 minutes. When it was brought to the surface, the basket contained the inner race of the lower support bearing and a considerable quantity of basalt cobbles and pebbles.

The second remedial run was with a 9-5/8" ribbed "piranha" style junk mill as an attempt to machine the metal junk into flakes and cuttings that could be flushed from the hole with fluid circulation. Two "boot baskets" were located just above the mill to trap samples of the metal cuttings and also larger pieces of junk that were lifted into the annulus by circulation. The mill was rotated on the junk for 3 hours. When it was recovered, the boot baskets contained 40 of the 42 steel ball bearings from the lost lower support bearing as well as fragments representing about 10% of the float valve assembly.

Run number three was with a 9-5/8" concave junk mill. Only 2-3/4 hours was spent in milling, as the mill tended either to spin free without "biting" or to torque up and stall the top drive with the application of any weight. Upon recovery, the mill was found to be severely worn and reduced in diameter around its leading edge, indicating that either junk was lodged in the side of the hole or the hole was under-gauge. The contents of the boot baskets were somewhat disappointing in that the amount of metal was small and the few recognizable fragments were from the upper portion of the float valve assembly.

The mill was replaced with an identical concave junk mill and the trip/reentry was repeated. On the basis of the results of the previous run, more weight and higher rpm were used and the mill was "spudded" occasionally. Over 5 hours was spent on the fish before parameters indicated that the mill was probably worn out. The boot baskets produced a good assortment of metal fragments. Some were quite large and easily recognizable, while a considerable collection of thin flakes and shavings gave evidence of effective milling. Particularly significant were pieces of the float valve flapper (which had been expected to cause problems) and the 41st bearing ball, but the most exciting find was several pieces of matrix material from the diamond core bit, indicating that the final and largest part of the fish was at least beginning to break up.

The fifth run was with a 9-3/8" ribbed or "castle" junk mill. Attempts to mill met with little success for the first 3 hours, as severe torquing and sticking would occur whenever the mill was lowered into contact with the fish. With a reduction in circulation and rotary speed, more normal parameters were achieved for milling. After an additional 4 hours, a drop in torque indicated that the mill probably was worn down. The junk mill was recovered in a completely worn-out condition. The contents of the boot baskets were again encouraging, with a reduced amount of metal and smaller pieces than on previous runs. Again matrix material from the diamond bit was present, but in smaller chunks.

The final mill run was with a concave mill that had been redressed to full 9-7/8" diameter. After about 1 hour of fairly rough running, the milling parameters smoothed out with enough torque to indicate that progress was being made. The torque soon dropped further and indicated that the mill had worn down or that it was turning on solid rock at the bottom of the hole. The pipe was tripped after only 2-3/4 hours of milling. The mill was found to be worn smooth when recovered, but the lack of grooves or other junk marks on the steel surface of the mill's base was interpreted as a positive sign. The baskets yielded, in addition to the usual copious load of gravel-to-cobble-sized basalt, some disconcertingly large, flat steel pieces. The total load was again rather small, however, with very few mid-sized pieces and a fairly large proportion of fine and very fine shavings.

With the hole judged to be essentially clean, a hard-formation Smith F7 bit was selected for the task of proving that 504B had been salvaged. As drilling commenced, some minor roughness was noted, but it was more typical of rocks than of junk. Weight was applied cautiously, but all parameters indicated normal hard-rock drilling in new hole. The hole was deepened to 5045 m (1570 mbsf) and was swept with drilling mud. All indications were that it had been cleaned adequately for coring operations, and the round trip for a coring BHA began at 2300 UTC 17 April.

The bit was found to be in excellent condition when it was recovered, but there were several large pieces of steel junk (showing drilling marks) in the boot baskets. The condition of the bit and review of drilling parameters led to the conclusion that the junk had been collected early in the bit run and that little or none remained in the hole.

Coring Operations

The coring plan included a run with the conventional ODP wireline rotary coring (RCB) system before moving on to experiments with a standard oilfield-type diamond coring system. (The tungsten carbide roller-cone bits used with the RCB system are much less sensitive to the presence of junk in the hole than are the diamond coreheads of the oilfield system.)

The RCB core bit chosen was an RBI model C-7, which features short conical cutting inserts and is designed for hard-formation drilling. When coring was initiated, the bit bounced and "ran rough" for a few minutes, though there was no excessive torque. Drilling then "smoothed out" for the remainder of the first core interval and the two ensuing cores. The ROP varied between 1.5 and 2.0 m/hr, which was consistent with earlier Hole 504B drilling. Core recovery for the three cores ranged between 5% and 25%, which, unfortunately, also was consistent. In consideration of the Leg 111 history of short bit life and the possibility that some junk still remained in the hole, the bit was tripped after only three cores (25.3 m penetration) and 15-1/4 rotating hours.

Upon recovery of the BHA, the bit had surprisingly numerous broken inserts on three of the four cones. The bearings and seals were in good condition, and there were no junk marks or excessive wear on the bit body. As cutting-structure damage in hard-formation bits is virtually unknown in normal coring operations, it was suspected that some junk had remained in the hole, at least when coring had begun. The pockets of the boot basket/bit sub contained only a handful of thin flakes of steel in addition to the usual basalt pebbles and cuttings. There was no sign of anything that could damage a rugged C-7 bit.

Due to the possibility that steel junk still existed in the hole, the deployment of the oilfield coring system with its vulnerable and expensive diamond bit was postponed. A C-7 bit identical to the previous one was made up to the same BHA and sent back to the bottom of the hole.

Two full cores were cut with all parameters essentially the same as with the previous bit. Total core recovery was 1.9 m for 18.5 m cored. The ROP fell essentially to zero after 1.7 m had been penetrated, so coring was terminated, the core was recovered, and the drill string was tripped. Though it had only 11-1/2 rotating hours, the core bit was found have the drive rows totally destroyed on all cones--a more complete failure than on the previous bit. The pattern of failure was identical, however, and indicated bit failure as a result of interaction with very hard formation, not junk. As there were again no junk marks on the bit and the boot basket contained only a handful of small junk flakes and tungsten carbide fragments from the bit, the presence of harmful steel junk remaining in the hole was all but ruled out. Conditions were considered acceptable to maintain the schedule and initiate the next phase--diamond coring.

The 60-foot Eastman Christensen 250P core barrel assembly was picked up and predeployment checks began. It then was discovered that the required spacing between the lengths of the inner tube and outer barrel assemblies could not be achieved without a time-consuming modification of coring parts. The core barrel was laid down in favor of a quick "cleanup" run with a 9-7/8" tri-cone drill bit and boot baskets to crush and/or recover any tungsten carbide inserts remaining in the hole.

The bit was rotated on bottom for 2-1/4 hours with essentially the same drilling parameters as had been used with the two previous core bits. Penetration was only 2.9 m, confirming the extremely low drillability of the basalt. Upon recovery, the bit was found to be in essentially new condition with absolutely no cutting-structure damage after 11 rotating hours. Examination of the boot basket contents produced only a handful of steel and mill-matrix flakes, with no tungsten carbide fragments. All indications were that the hole was clean for diamond coring.

The spacing problem in the oilfield core barrel had been remedied, so the assembly was again made up and a 7-7/8" Hobic core bit was attached. The pipe trip and reentry were routine.

Coring began with very light weight and low rpm after the specified circulating rate had been established. The weight and rpm were increased slowly over the next 2 hours. During that period, the ROP was extremely low, but about 2 m of apparent penetration was made. No further progress was made during the next 4-1/2 hours, despite gradual increases in weight and rpm. Circulating pressure had increased to a value that indicated bit failure, so the first diamond bit run was terminated after a disappointing 6-1/2 rotating hours and 2 m of (tide-assisted) penetration.

The bit arrived at the rig floor in a severely worn condition. The diamond-bearing matrix on the cutting surface was reduced to the degree that the watercourses were completely worn away to smooth steel on the lower shoulder of the bit. The core barrel inner tube contained 1.1 m of 4"-diameter core.

Upon redressing the barrel assembly, it was found that the throat of the second core bit was slightly shorter than that of the preceding bit, so it was again necessary to shorten the core catcher assembly to achieve an acceptable space-out.

The second diamond coring run was identical to the first in most respects until near its end. About 1 m was penetrated within the first 30-40 minutes, but ROP dropped sharply after that. Circulating pressure remained unchanged for 3-1/2 hours, then began slowly to increase, indicating progressive bit failure. Before the coring attempt was terminated, however, circulating pressure dropped back to the original level. The reason for the drop in pressure was found as the core barrel assembly was hung off at the rig floor for the recovery of the core. The outer barrel had parted at the connection below the upper stabilizer. The inner tube assembly was intact, but the outer barrel assembly and the bit remained in the hole.

A 9-1/2" Series 150 Bowen slim hole overshot was dressed with a 6-3/4" basket grapple and mill control packer for an attempt to fish the core barrel from the hole. The trip and reentry were routine, and the top of the fish was contacted within 1 m of the anticipated depth. Only light weight and torque were applied to avoid damage to the grapple or fish. Because of its light weight and lack of internal restrictions, it was difficult to determine whether the fish had been engaged or not by the normal string-weight and circulating pressure criteria.

The long pipe trip through the open-hole interval then began. The VIT frame was run down the pipe so that the overshot could be viewed as it was pulled from the reentry cone. As the BHA was withdrawn into the upper cone section, the drill string deflected and it could be seen clearly that the overshot guide was sliding toward the rim of the cone with no fish attached. The drill string was kept within the cone, and the overshot was again lowered toward the fish.

On the second attempt to engage the core barrel, contact was made 15 m higher in the hole. The overshot was set down on the obstruction repeatedly with rotation, and some drag was noted each time the string was raised. It seemed likely that the fish had been engaged on the first try, raised an unknown distance, and then dropped. Again the string was raised and the VIT was deployed.

The lack of success with such a seemingly straightforward fishing job was puzzling. The most plausible explanations seemed to be that the steel of the core barrel was too hard and smooth for the grapple to maintain its grip or that the end of the fish had become belled or otherwise deformed, preventing it from entering the grapple fully. On the third attempt, more rotation and weight were used to "dress" the top of the fish and force it into the grapple. Again the fish was absent when the drill string cleared the cone. The pipe was tripped to the surface so that the overshot could be examined for signs of engagement with the fish, damage to the lip guide, or other indications.

The BHA arrived at the rig floor on the morning of 27 April. At that time it was found that the overshot assembly had separated at the connection between the top sub and the bowl. The threaded portion of the pin connection was intact. Marking on the lower surface of the top sub appeared to have been made by contact with the top of the fish, so it was concluded that the fish had been engaged on the first attempt and then dropped when the overshot separated during the open-hole trip.

Without additional commercial fishi [illegible] when the vessel departed for port at 0715 UTC 29 April.

Site 504 to Panama

Calm weather and a lack of anticipated opposing currents enabled *JOIDES Resolution* to log a speed of over 12 knots for the first half of the 2-day transit. As arrival time was to be governed primarily by the tide cycle (for clearance under the Bridge of the Americas), speed was reduced on the morning of 30 April to save fuel and to arrive at anchorage outside the bridge on schedule. Leg 137 came to its official end when the anchor was let go in the roadstead outside Balboa Harbor, Panama, at 1115 UTC 1 May 1991.

OCEAN DRILLING PROGRAM
OPERATIONS RESUME
LEG 137

Total Days (20 March - 1 May)..............................41.7
Total Days in Port... 0.3
Total Days Under Way.......................................19.9
Total Days on Site...21.5

Trip Time.................................5.44
Coring Time...............................2.26
Drilling Time.............................0.47
Logging/Downhole Science Time.............3.36
Reentry Time..............................0.61
Repair Time (Contractor)..................0.11
Fishing & Remedial Time...................8.64
Other.....................................0.61

Total Distance Traveled (nautical miles).................5072
Average Speed (knots)....................................10.6
Number of Sites..1
Number of Holes..1
Number of Reentries......................................16
Total Interval Cored (m).................................48.6
Total Core Recovery (m)..................................8.8
Percent Core Recovered...................................18.0
Total Interval Drilled (m)...............................11.6
Total Penetration (m)....................................60.2
Maximum Penetration (m)..................................60.2
Maximum Water Depth (m from drilling datum)..............3475.0
Minimum Water Depth (m from drilling datum)..............3475.0

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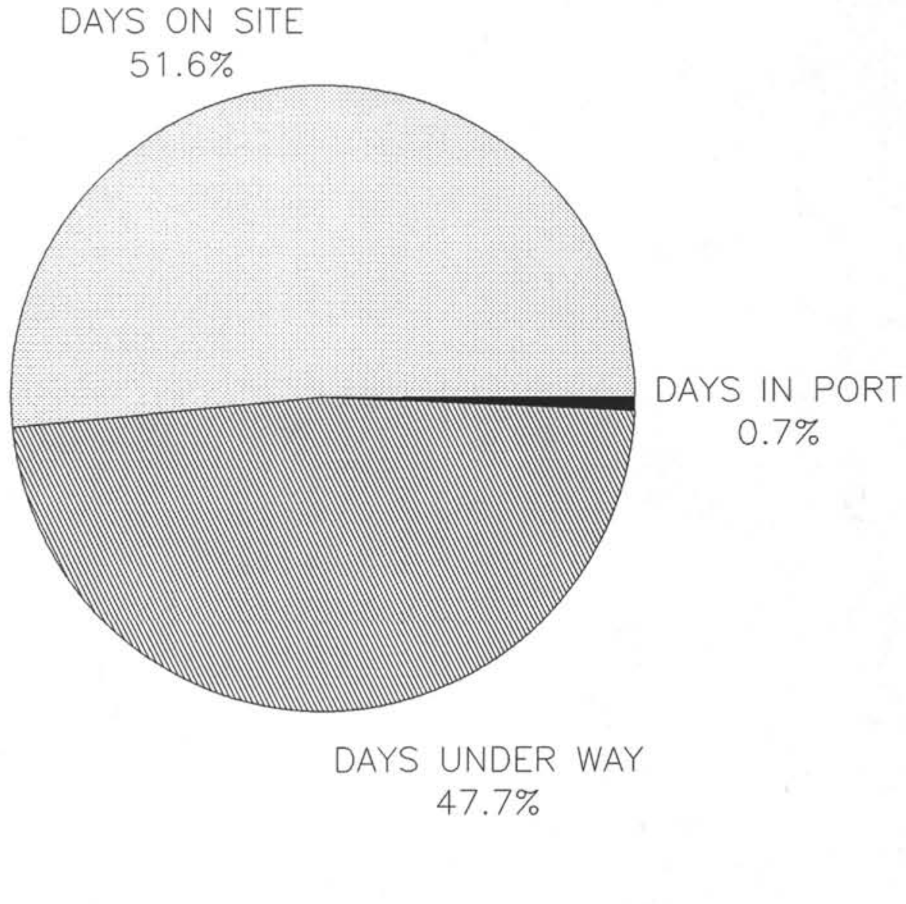
LEG 137
TOTAL TIME DISTRIBUTION



TOTAL DAYS OF LEG = 41.7

OCEAN DRILLING PROGRAM
SITE SUMMARY REPORT
LEG 137

HOLE	LATITUDE	LONGITUDE	SEA FLOOR DEPTH (M)	NUMBER OF CORES	INTERVAL CORED (M)	RECOVERED CORE (M)	PERCENT RECOVERED	INTERVAL DRILLED (M)	TOTAL PENETRATION (M)	TIME (HRS)
504B	01-13.61N	83-43.82W	3475.0	8	48.6	8.8	18.1	10.6	59.2	516.25
	SITE TOTALS:			8	48.6	8.8	18.1	10.6	59.2	516.25
	LEG TOTALS:			8	48.6	8.8	18.1	10.6	59.2	516.25

TECHNICAL REPORT

The ODP Technical and Logistics personnel aboard *JOIDES Resolution* for Leg 137 of the Ocean Drilling Program were:

Laboratory Officers:	Matt Mefferd
Bill Mills	
Yeoperson:	Michiko Hitchcox
Curatorial Representative:	Robert Kemp
Computer Systems Manager:	Edwin Garrett
Electronics Technicians:	Bill Stevens
Mark Watson	
Barry Weber	
Photographer:	Shan Pehlman
Chemistry Technicians:	Mary Ann Cusimano
Chieh Peng	
X-ray Technician:	Don Sims
Marine Technicians:	"Gus" Gustafson
Jeff Millard	
Ken McCormick	

TECHNICAL REPORT

The primary objective of Leg 137 was to salvage Hole 504B in preparation for future drilling. A diamond bit and some other parts of a coring assembly had broken off and remained in the hole at the end of Leg 111. With the three weeks allocated to the task of removing this junk, and the 17 day transit from Honolulu to Site 504B, not much core recovery was anticipated. However, Leg 137 provided an excellent opportunity to train two new technicians who joined this crew in Honolulu, as well as some of the veteran technicians who would be taking over responsibilities in other shipboard labs. Other activities included the installation of the new Subsea Shop, major computer hardware and software upgrades, and the reorganization of the library and storage areas.

Port Call

The Honolulu port call prior to Leg 137 was a very short one. Most of the technical staff had already settled in aboard the vessel as participants of Leg 136. Because of the short duration of Legs 136 and 137, many of the technicians sailed on both. However, since the primary objectives of Leg 137 were operational in nature, and we did not anticipate retrieving more than a few cores, eight technicians disembarked in Honolulu. Four technicians joined us for Leg 137, as well as a smaller than usual scientific party. The ship had arrived dockside in Honolulu at 0815 on 20 March, and departed 6-1/2 hours later at 1445 (local time), heading at full speed for Site 504. Our port call activities consisted of loading and off loading freight.

Under Way

During the 17 day transit to Site 504, we collected standard bathymetric, magnetic and navigational data. Since this was the fifth in a series of DSDP/ODP legs to occupy this site, we did not conduct a pre-site seismic survey. However, during the transit we tested the port streamer to determine the cause of ta 220 Hz noise noted on Leg 136. No noise was apparent during our tests. Several days into the transit the magnetometer (starboard) signal became quite noisy. Technicians replaced components in the deck electronics and the fluid in the sensor, and the signal was much improved. The sensor's fluid had been contaminated with both salt water and particulate matter from an unknown source, some of which was magnetic. The fluid was also changed in the port side sensor. The physical damage to the port magnetometer cable reported on Leg 135 was inspected and repaired with ScotchKote and electrical tape.

We developed a routine of launching 4 expendable bathythermographs (XBTs) per day while under way. The Captain balked at launching them on site for fear that the copper wire would become entangled on the main screws during DP operations. Although it was to have been the responsibility of SEDCO to launch XBT's, we found it more convenient to do this ourselves since SEDCO personnel are generally occupied with their duties on the bridge while under way, and there is always a technician on watch in the Underway Lab during these times. At the moment the procedure for transferring the data to the bridge computer for satellite transmission, along with the weather data, is rather clumsy, involving the intermediate step of copying the data from 5-1/4" diskettes to 3-1/2" diskettes. However, the SEAS operations manager at NOAA, intends to improve on this when the ship calls in San Diego after Leg 138.

As we approached the site using GPS the dynamic-positioning operator attempted to activate a commandable beacon that had been dropped on Leg 111, 4-1/2 years ago. When it did not respond, crew members deployed another beacon at the well known coordinates of Site 504, and the drill crew proceeded to reenter the hole as if we had never left.

We departed Site 504 in the early morning hours of 29 April, heading at full speed for Panama, thus ending Leg 137 with a 2-day transit. Again, we collected standard bathymetric, magnetic, and navigational data. Underway watches were stopped about 12 hours out of port to allow time to gather up all the data, make backup tapes, and prepare shipments.

Operations Support

The Eastman Whipstock Drop Multishot Camera was used once with a rotary core barrel as a test to see if photos taken of the compass rose while the drill string was rotating were readable. This test was undertaken as part of a plan to develop a system capable of recovering oriented hard rock cores. As expected, the photos were blurred and unreadable except those that were taken while rotation was stopped. ODP engineers believe that a more recently developed electronic compass may work while rotating. Testing one of these would be the next logical step in the development of this system.

Downhole Tools

A secondary objective of Leg 137 was to take undisturbed borehole fluid samples at intervals down the hole for chemical analysis. Two downhole water samplers that had been developed for hot holes, one from Lawrence Berkeley Lab (LBL), the other from Los Alamos National Labs (LANL), were brought out to take these samples. The Barnes *in-situ* water sampler and the Kuster sampler were made ready by our technicians as backups to these tools, but were not used. This sampling program was quite successful, resulting in the collection of 8 samples in 6 hours, 7 of which had characteristics that were in agreement with the results of previous sampling programs in this hole. The technicians from LBL and LANL trained three members of our technical staff to run these tools for proposed sampling of hot borehole fluids during Leg 139.

Electronics technicians also provided support as needed for a downhole flowmeter and a downhole temperature probe.

We brought two Adara heat flow recorders with us in the hope that we might find an opportunity to test them. Working with the Core Techs we improvised two ways to run the Adara heat flow shoe assembly on the sand line without impacting the sampling or drilling operations. One was on the overshot for one of the large volume water samplers and the other on the overshot for the rotary core barrel. A total of six runs were made. The first two runs were unsuccessful for different reasons. The first failure is attributed to a misunderstanding of the documentation, which resulted in draining the batteries before the tool was run. The second failed attempt is attributable to poor handling technique. The recording package was programmed outside the shoe. In the process of inserting the package into the shoe the batteries shifted slightly and apparently lost contact. Programming the recorder in the shoe prevented this from happening on subsequent runs. Runs three, four and five were all successful; run six stopped recording after 31 measurements for no apparent reason. These were the first successful runs of the Adara recorder and we are encouraged that this tool will be an important source of data at upcoming APC holes.

Curation

Core recovery and sampling were minimal during Leg 137, but the ambitious borehole fluid sampling program and unorthodox sample recovery (i.e., from fishing and milling tools) resulted in minor diversions from established curatorial policy. The two special water samplers that were sent out for this leg were used to take large volume (1-2 liter) borehole fluid samples. Since these were not cores and since there is no significant relationship between these samples and the cores that were taken at the same interval on previous legs, the data associated with these samples were kept in a separate database.

Rocks recovered during the milling operation in boot baskets and reverse circulating junk mills were considered of little scientific value since there was no way to determine where in the section they came from. However, the curator came up with an appropriate way to curate the rocks, since there was some scientific interest in them.

We recovered 2 cores with an off-the-shelf diamond coring system used on a trial basis to try to improve recovery. Since these cores had a 4" diameter they required special handling and curatorial supplies. This had all been anticipated and did not present any major problems. We used a special 12" diamond blade on one of the Felker saws to cut these cores.

Physical Properties Lab, Paleomagnetics Lab, Core Lab

A new physical properties technician spent most of this leg studying the documentation and training in the use of the equipment in the physical properties lab. Although few samples were taken, there were enough for him to gain a basic familiarity with the equipment in that lab. The multisensor track was used for 2-minute GRAPE and discrete magnetic susceptibility measurements.

We did not run any samples in the paleomagnetics lab on this leg. However, a considerable amount of time was spent training a technician in the use of its equipment.

The core lab was not heavily utilized, in keeping with the amount of material we recovered. As such the description table provided an ideal location to set up the various water samplers and prepare them for use, since the loggers required all the bench space in the downhole measurements lab for their experiments.

Chemistry Lab

The new chemistry technician continued training in the lab during this leg. The eight water samples collected with the LBL and LANL tools were analyzed for boron and hydrogen sulfide in addition to the standard suite of analyses.

X-ray Lab

One of the chemistry technicians was trained in the calibration procedures and operation of both the X-ray diffraction and X-ray fluorescence instruments. A few samples were taken from our Hole 504B cores and analyzed along with several samples that remained aboard to be analyzed at the request of one of the Leg 136 scientists. The problem with the autosampler on the XRD remains and samples must be loaded one at a time. We are awaiting the arrival of a new one that was ordered on Leg 136. The technicians also had problems with the optical sensors that read the XRF cassettes. New sensors were ordered.

For some time now we have been unable to run both X-ray machines at full power, simultaneously, as the Haskris heat exchanger was unable to keep them both properly cooled. In order to solve this problem we have installed 7/8" pipe to replace the 1/2" chill water supply and return lines on the Haskris. The installation will be completed upon the arrival of 7/8" valves at the upcoming Panama port call.

Thin Section Lab

Five polished basalt thin sections were requested to describe the hard rock cores we recovered. In addition, 8 polished thin sections were made from basalts collected on Leg 129, at the request of a shipboard petrologist .

Computers

This was an extremely busy leg in the area of computer systems management. Major software and/or hardware upgrades were implemented on almost all the computer systems aboard, requiring all of the systems manager's energy along with assistance from other members of the technical staff. The VAX clusters' operating system was upgraded from VMS4.7 to VMS5.3, the PC clones received new 386 motherboards and the WINDOWS operating system, the MACs were upgraded to version 6.0.7 of their system software, and 2 new laserwriters and 6 new MAC SIs were installed. In addition the system manager installed and tested the DI3000 postscript driver, which will allow all of the programs that use DI3000 routines or the PICSURE program to print to Apple laserwriters. This will allow us to remove the QMS laserprinters from the ship, which is desireable now that they have become unreliable and difficult to maintain. Many problems were encountered during these upgrades, mostly with the VAXes, but all of the major obstacles were overcome. The long transit and light use of the computers on this predominantly operational leg made it an ideal time for these upgrades, as their impact on science was minimal.

Storekeeper

The new storekeeper spent a considerable amount of time becoming familiar with ODP shipping and inventory programs, with guidance from previous storekeepers. He reorganized and performed physical counts in the hold stores, hold refrigerated storage, lower tween stores, ODP store, and upper tween stores. These areas look better than they have for a long time. This was an excellent opportunity for him to become familiar with most of our supplies and to get a feel for our inventory control system.

Subsea Shop

Shipboard laboratory space increased by 274 square feet with the initiation of Subsea Shop construction. The Subsea Shop is located on the port mezzanine deck (under the rig floor) with access from the starboard mezzanine deck and auxiliary warehouse. The shop will be a multi-use area providing:

1. Storage and repair space for reentry equipment.
2. Rigging repair and storage space for underway geophysics.
3. Additional work space for downhole tools.
4. Enclosed space for the reentry winch operator.

All initial construction goals for Leg 137 were achieved. These goals included the preparation of existing structures, installation of new decking and bulkheads, construction of a stairway into the auxiliary warehouse, and installation of electrical power and lighting. This represents about

70% of the construction. Work still pending includes the installation of doors, hatches, window, supply air ducting, A/C, ship's services, insulation and interior bulkhead finish.

Special Projects

The Yeoperson did a phenomenal job reorganizing the library. She reshelved all textbooks in the proper order, relocated all DSDP and ODP publications to the same general area, and labeled all shelves and cabinets with their contents. There are 71 volumes of DSDP bound reprints in the ship's library, containing over 1300 reprints. The Yeoperson has created a dataset containing information on all of these and a listing program to access it, making it much easier to locate or find information about a particular article.

Five of the new Macintosh SIs were installed in the paleontology lab and the microscopes were arranged to create five paleo workstations. A commercial Mac-compatible data entry program called BUGIN will soon be available on board that will enable the paleontologists to enter data while they are studying their samples.

LAB STATISTICS: LEG 137

General statistics:

Site	1
Hole	1
Interval cored (m)	48.6
Core recovered (m)	8.77
Number of sediment cores	0
Number of hard rock cores	11
Number of samples	223

Samples analyzed:

Inorganic carbon ($CaCO_3$)	0
Total carbon - CNS	0
Water chemistry	8
Thin sections	13
XRD	9
XRF	11
Cryomag runs	0
Phys props velocity	11
Index properties	11
Thermal conductivity	11
Vane shear	0
2 - min. GRAPE	15

Underway geophysics:

Total miles traveled (apx)	5059
Bathymetry, magnetic (apx)	4950
Seismic	0

Downhole tools:

Large volume water samplers	9
Multishot	1
Adara heat flow shoe	6