Report of the Offset Drilling Workshop

held at

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Technical Note 25

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EXECUTIVE SUMMARY

The Offset Drilling Workshop was convened by the Science Operator and took place at ODP-TAMU on 13-14 September 1994. The objective of the workshop was to bring together scientific, engineering and drilling operations participants of ODP Legs 147 and 153 and some members of relevant JOIDES panels in order to discuss the problems encountered on these two legs and to make suggestions for progress of PCOM's offset drilling strategy.

Legs 147 and 153 were ambitious legs in difficult-to-drill environments. Neither leg progressed as planned, although considerable quantities of core of great scientific interest were recovered. Major deficiencies were revealed in all stages of the execution of these legs: the site surveys did not adequately describe the sites to be drilled, many items of drilling equipment were unable to cope with the hostile conditions encountered, and there were communication problems between the scientific proponents and ODP-TAMU personnel. All aspects are discussed in detail in this report and, where possible, specific recommendations have been made.

To ensure the future progress of offset drilling, two strategies are proposed:

(1) **ODP needs to learn how to drill in difficult places.** The logical outcome of this strategy is that an engineering leg is needed to test new equipment and techniques for establishing re-entry holes and coring in environments such as those encountered on Legs 147 and 153. The objectives of the engineering leg are defined.

(2) **ODP needs to learn how to find easy places to drill.** This could be achieved in two different ways. A drilling leg of shallow single bit holes might find a "sweet spot" for deeper drilling, in the manner that Hole 735B was found and successfully drilled on Leg 118. The site selection process in hard rock areas is not yet so precise that serendipity does not play a part. Alternatively, on a longer timescale, near or on-bottom geophysical measurements might be used to define spots where the drilling is easier. The relationship of geophysical properties to drillability is discussed.

INTRODUCTION

At its April 1991 meeting, the JOIDES Planning Committee established the Offset Drilling Working Group (OD-WG), charging it with the tasks of prioritizing the scientific objectives and developing a strategy for a program of drilling offset sections of oceanic crust and upper mantle. In addition, the working group was asked to identify target areas, site survey and technological requirements for such a drilling program. The OD-WG report was presented to the Planning Committee in August 1992.

Concurrently with this study of the objectives and needs of offset drilling, the JOIDES structure was considering individual drilling proposals that formed a part of this larger strategy. At the December 1991 meeting of the Planning Committee, the proposal to drill lower crustal and mantle rocks in Hess Deep was scheduled as Leg 147. A year later, Leg 153 was earmarked for drilling in the MARK area of the Mid-Atlantic Ridge. Leg 147 took place between 25 November 1992 and 21 January 1993; Leg 153 was at sea from 27 November 1993 to 24 January 1994. The exigencies of ship scheduling rather than any expressed wish of the scientific participants led to both of these legs being at sea over the Christmas/New Year period.

Three drill sites were identified in the Scientific Prospectus for Leg 147. If operations went well, a single re-entry hole using a hard-rock guidebase (HRB) and multiple strings of casing would be established at the highest priority site (HD-3) and RCB coring would proceed to a depth of at least 500 m. In actuality, considerable difficulties were encountered in establishing guidebases and setting casing and, rather than a single cased deep hole, a dozen much shallower holes were cored at two sites. 123 m of core were recovered from a total interval cored of 487 m (Table 1). Substantial equipment losses were suffered, but the HRB, which toppled over at Hole 894C, was recovered at the end of the leg.

The objectives of Leg 153, as defined in its Scientific Prospectus, were similar to those of Leg 147. Two multiply-cased re-entry holes were to be established with HRBs, one at a gabbro site (MK-1) and the other at a serpentinized peridotite site (MK-2). It was hoped that each hole would be cored to between 200 and 400 m, and that both could be deepened on future legs to as much as 1000 mbsf. The reality of the leg was quite different. Use of the HRBs was quickly found to be impractical, and considerably more time was spent coring than on Leg 147 (Table 2). Fourteen shallow holes were cored rather than the two cased re-entry holes planned. A total of 261 m of core was recovered from a total interval cored of 798 m (Table 1).

In comparison with previous hard rock legs, Legs 147 and 153 were by no means unsuccessful. The rocks recovered on the two legs were remarkable in many ways and of great scientific interest. Core recovery of the gabbros and serpentinized peridotites encountered was substantially higher than that of the hard basalts during the deepening of Hole 504B on Leg 140 (Table 1). However, neither leg progressed anything like as planned and the maximum penetrations achieved (154 m at Hole 894G on Leg 147, 201 m at Hole 920D on Leg 153) fell short of what had been hoped. Both legs ended up drilling a large number of unsupported, single-bit holes, and operations with the hard-rock guidebases were repeatedly frustrated. Neither leg left behind a cased re-entry hole that could be deepened on a subsequent leg (such as Hole 735B). Furthermore, considerably greater expenditure was incurred by ODP in preparing for these two legs than for a "typical" ODP leg. As a rule of thumb, the drilling operations budget for a "typical" leg at this time was about $250K. The budget for 147 and 153 was about $500K for each leg.

The Offset Drilling Workshop, which took place on 13-14 September 1994, was convened by ODP-TAMU to discuss the problems encountered on Legs 147 and 153 and how the objectives of the Offset Drilling strategy might be better achieved in the future. The participants (Appendix 1) consisted predominantly of scientific and ODP-TAMU participants on the two legs together with a lesser number of representatives of relevant JOIDES panels and ODP-TAMU. Travel and subsistence costs for participants from outside College Station were paid with commingled funds from the ODP-TAMU budget. The costs of the workshop were minimized by holding it in College Station, since that limited the number of outside participants to 10. Furthermore, that also allowed other ODP-TAMU personnel to attend on an occasional basis.

Over the last few years the proportion of ODP legs that are technologically complex and operationally difficult has been increasing. The sequence of difficult legs over the past five years includes 132, 142, 147, 153, 156, 158. These legs can be regarded as high risk in the sense that the chance of failure to meet the objectives set out in the Scientific Prospectus is greater than for "typical" legs. The cost of preparing for such legs and the risk of losing equipment on them is also greater. It is likely, therefore, that similar gatherings of ODP-TAMU personnel and scientific participants will be needed in the future to review the progress of the increasingly high risk operations that ODP is being asked to undertake.

TABLE 1: Comparison of Core Recovery, Legs 118, 140, 147, 153

	Interval Cored	Core Recovered	Percent Recovery
Hole 735B (Leg 118)	501 m	435 m	87%
Total (Leg 140) (Hole 504B)	379 m	48 m	13%
Total (Leg 147) (12 Cored Holes)	487 m	123 m	25%
3 Serpentinite Holes (Site 920)	341 m	144 m	42%
11 Gabbro Holes (Sites 921,922,923,924)	457 m	117 m	26%
Total (Leg 153)	798 m	261 m	33%

TABLE 2: Coring Rates on Legs 147 and 153.

Leg	Time Spent Coring	Interval Cored	Coring Penetration Rate	Core Recovery	Core Recovery Rate
147	11.1 days	487 m	43.9 m/day	123 m	11.1 m/day
153	26.9 days	798 m	29.7 m/day	261 m	9.7 m/day

OPERATIONS SUPERINTENDENT'S PERCEPTION OF LEG 147

Leg 147 was the first of several legs planned to explore the concept of offset drilling on high angle, hard rock sites exposing lower crust and mantle rocks. The drilling sites were expected to be on bare rock exposures with up to 25° slopes and shallow sediment covers. An intensive operations and engineering effort at ODP led to the development of new or modified tools to accommodate the new operating requirements. The three-legged Hard Rock Base (HRB), capable of handling up to 25° slopes, was mated with a new Dril-Quip dual-casing hanger system. A Cam Actuated Drill Ahead (CADA) feature was added to the running tool to permit spudding the hole after the HRB was set without tripping the pipe. New Rotary Core Barrel (RCB) core bits were developed for very hard rock, and close catch core catchers were developed to try to improve recovery in highly fractured rock.

Hole 894A (Site HD-3)

On arrival at Hess Deep, a TV survey on the summit of the intra-rift ridge found gabbro outcrops with 0.5 to 6.5 m of soft sediment, scattered patches of small cobbles 5 to 20 cm in diameter, and isolated massive outcrops and large blocks up to 2 m diameter. Hole 894A was spudded-in on the ridge summit. Core 1R (0-6.0 mbsf) was interpreted as regolith; therefore, coring was terminated.

Hole 894B (Site HD-3)

Hole 894B was located above a steep 15-m-high scarp of massive gabbros on a 35-m-wide sedimented bench with a slope of up to 20° in 3031.0 m water depth. Core 1R (0 to 7.0 mbsf) consisted of two fragments of metagabbro. Coring was terminated, but surface conditions appeared to be adequate for an HRB site.

Hole 894C (Site HD-3)

Hole 894C was positioned on the crest of the ridge, and the HRB was deployed near Hole B. The running tool with the CADA drill-ahead feature was used for the first time. It was not possible to see around the HRB with the TV camera, and the running tool (with the CADA feature engaged) did not permit unlatching for surveys and then moving the base; however, the HRB location was believed to be correct based on the angle, water depth and beacon coordinates. A brief stability test was performed.

The CADA tool was unjayed, and Hole 894C was spudded in 3044 m water depth. The 14-3/4 in. hole was drilled to 31 m. During a wiper trip, the BHA parted. The HRB had been set by mistake on a steep sediment slope about 60 m east and downslope from the intended hard rock ledge. The most probable cause of the positioning error was that the HRB swung out of position in the process of moving the vessel and resetting the legs three times. The sediment slope was destabilized by circulation while drilling, causing the sediment to slump and undermine the HRB leg on the downslope side. The HRB tilted further, and the zip lift groove on the second drill collar was cut by the CADA tool neck. When the bit was pulled to the seafloor, the HRB tilted, bowed, and broke the BHA, allowing the HRB to topple over downslope.

Hole 894D (Site HD-3)

Hole 894D was spudded on a flat sedimented area on the west side of the ridge summit in 3024.0 m water depth. Core 1R to 2R (0-19.5 mbsf) recovered 1.52 m of granular sediment and basalt fragments. The hole was terminated because of the very unstable upper hole, which ruled out the possibility of using a reentry cone.

Hole 894E (Site HD-3)

Hole 894E was spudded on flat sedimented terrain at the ridge summit in 3024.6 m water depth. Cores 1R to 3R (0-28.7 mbsf) recovered 3.03 m of foram ooze, gabbroic sand, gabbro, and basalt. The hole was terminated because of the very unstable upper hole, which ruled out the possibility of using a reentry cone.

Hole 894F (Site HD-3)

An area was found southwest of the ridge summit with flat-lying blocky outcrops covered by 1 m of sediment. Hole 894F was spudded just north and upslope of Hole B. Cores 1R to 3R (0-25.7 mbsf) recovered 1.80 m of gabbro and basalt. Hole and surface conditions were good for HRB deployment; therefore, the precise spot was marked with a beacon released by the VIT beacon (an ODP first).

Hole 894G (Site HD-3)

The only remaining HRB was set 10 m north of Hole 894F as a retrievable installation (i.e., without cementing the casing) because of the persistent hole problems, which may have exacerbated subsequent hole cleaning problems. The running tool was released (CADA was locked out), and a TV survey verified the location (with the option to move the base) before the decision to drill was made. The legs had a uniform 1 m of penetration into the soft sediment cover, and the tilt beacon read 11° by 20°.

Hole 849G was spudded and a 14-3/4 in. hole was drilled to 18.6 mbsf. The hole condition appeared to be good, and 17.68 m of 13-3/8 in. casing (with flush joint connections) was run. The casing stopped on the lip of the hole, and offsetting the ship to change the ship-to-hole alignment was not successful; therefore, the casing was pulled. A 14-3/4 in bit would not reenter the old hole. The top hole drilled very slowly with high torque and overpull, indicating that the holes were misaligned. Below 4 mbsf, the bit intercepted the old hole and was run to 18.6 mbsf TD. A 16.67 m section of 13-3/8 in. casing stopped 1.25 m below the surface. Subsequent information from logging, core examination and marks on the equipment confirmed that there was a combination of problems:

a) Ship offset when spudding started the hole with a 4° to 5° angle.
b) No centering bushing was used; therefore, a non-concentric hole was drilled.
c) The hole deflected downslope, and angle increased rapidly below 65.6 mbsf.
d) The HRB was tilting as sediments were washed out from under the legs. (Figure 1)

The hole was cleaned out to TD, and Cores 1R to 3R (18.6-39.6 mbsf) recovered 3.85 m of olivine gabbro and basalt. Except for slab boulders on the surface, conditions were good in gabbro to 20 mbsf; however, the fractured gabbro started falling into the hole (Core 3R contained a piece of the hole wall). A 14-3/4 in. hole had to be drilled out twice to TD. A 31.0 m section of 13-3/8 in casing was run with a 12-1/4 in. pilot bit, but it could not be worked below 4.6 mbsf and was pulled. A 5.88 m section of 13-3/8 in. casing was set to attempt to pin the HRB, and the hole was deepened from 39.6 to 45.0 mbsf. A 41.56 m section of 10-3/4 in. casing with a 12-1/4 in. pilot bit could not be run; however, it was shortened to 35.56 m and set at 33.0 mbsf.

RCB Cores 4R to 14R (45.0-118.8 mbsf) recovered 32.32 m of gabbronorite. The hole could not be cleaned out, and the pipe stuck briefly despite repeated reaming and two wiper trips. At 118.8 mbsf the bit was pulled as a precaution. The stabilizer pads were worn away, and the body was worn down 1/4 in.

The hole was cleaned out with a 9-7/8 in. RCB core bit to 118.8 mbsf. After Core 15R (118.8-122.8 mbsf), the hole could not be reamed back to TD because of high torque, and the bit was pulled. The wear pads and body were worn down 1/2 in. A 9-7/8 in. drill bit was run to wipe out ledges and doglegs in the hole and drilled 3.0 m to 125.8 m. The bit sub and stabilizer blades had heavy wear from abrasion, but the bit showed no wear, indicating that ledges were the problem.

A 9-7/8 in. CC-9 RCB bit with integral spiral stabilizer blades and close catch design was then run in an effort to clean out the hole to TD and core ahead with lower torque. The hole was reamed to 125.8 m TD, and RCB Cores 17R to 19R (125.8-145.6 mbsf) recovered 5.75 m of gabbronorite and basalt. The hole was packing off and could not be reamed back to bottom. The bit had vertical abrasion marks on top of the stabilizer blades. Ledges, deviation and inability to clean the hole continued to frustrate attempts to core; therefore, a BHA with two stabilizers was run in an attempt to straighten the hole and wipe out the ledges. The hole was reamed to 145.6 m TD with high stabilizer torque. Core 20R (145.6-154.5 mbsf) recovered 1.37 m of gabbronorite and basalt. The drill pipe subsequently plugged and was cleared again four times.

The ledges in the hole could not be removed with a stabilized BHA despite repeated reaming, and the hole could not be cleaned out by circulating mud sweeps. High torque stalled the top drive, and circulating pressures increased. The pipe stuck while reaming to bottom with the bit at 146.6 m, but the pipe was freed and pulled out. The top stabilizer had severe blade wear, indicating it had been reaming on ledges. Another CC-9 bit was unsuccessful in a final attempt to clean out the hole. The pipe stuck briefly, and coring was terminated. A TV survey found a new washout in the sediment downslope from the HRB. The HLDT (one arm caliper) indicated alternating cavities to 18 in. diameter and ledges to 10.2 in. diameter. A multishot survey instrument read a 5° angle at 56 mbsf.

HD-3 Coring Problems

Hole 894G was probably started on an angle because of the hole-to-ship misalignment in strong surface currents, which compromised subsequent drilling/coring/casing operations. The hole was spudded without a centering bushing; therefore, it may have been non-concentric with the reentry cone throat. Many hard basalt dikes intruded into the softer fractured gabbro, leaving ledges and cavities that contributed to hole cleaning, deviation and rotating problems. Highly fractured gabbros were loosely cemented with soft alteration products and became unstable after a few days. Hole conditions were too unstable to risk leaving the pipe hanging for a survey, and attempts to straighten the hole with stabilization were unsuccessful. The caliper log showed a steady decrease in hole diameter through successive ledges culminating in a 10.2 in. diameter hole through the ledge at 74 mbsf. Heavy reaming with stabilizers was required below 74 mbsf, which indicates that the hole angle probably continued to build by about 1°/10 m to 12° to 15° at 154.5 mbsf TD. Recovery was poorest (with high rop) in the fractured gabbros and best in the harder basalt dikes (with low rop).

Hole 895A (Site HD-4)

Hole 895A was spudded in 3832 m water depth in the southeast quadrant of the ridge. Core 1R to 2R (0-17.2 mbsf), recovered 2.38 m of serpentinized breccia, harzburgite, clay, and basalt. Loose surface rubble resulted in heavy fill and high torque. A 3-m heave in long period swells reduced heave compensator control of weight-on-bit. The DC pin parted at the top of the second drill collar 5.5 m below the mud line.

Hole 895B (Site HD-4)

Hole 895B was spudded in 3832.0 m water depth. Core 1R (0-10.3 mbsf) recovered 1.02 m of serpentinized harzburgite and dunite. The hole was unstable with high erratic torque and heavy fill and could not be cleaned out.

Hole 895C (Site HD-4)

Hole 895C was spudded in 3831.0 m water depth. Core 1R to 4R (0-37.6 mbsf), recovered 5.79 m. Hole conditions were good (the best of the leg). While cutting Core 5R, the BHA parted 0.55 m down on the fourth drill collar at the top of the zip lift groove. An unsuccessful attempt was made to fish the BHA in open hole. Three cracked pins were found in the BHA.

Hole 895D (Site HD-4)

Hole 895D was spudded near Hole C in 3832.0 m water depth. Cores 1R to 9R (0-93.7 mbsf) recovered 19.99 m of serpentinized harzburgite and dunite, basalt, and troctolite despite unstable hole conditions (some 0.5 in. rock fragments were recovered). The bit was pulled because high torque was stalling the rotary near bottom suggesting a possible undergauge bit problem. Another CC-9 bit was run, and the hole was reamed from 23 to 90 mbsf; however, the crossover between the DC's parted in the box threads. An unsuccessful attempt was made to recover the BHA.

Hole 895E, (Site HD-4)

Hole 895E was spudded in 3764 mbsf water depth about 270 m north of Hole D. Cores 1R to 8R (0-87.6 mbsf) recovered 32.93 m of spinel bearing olivine gabbro, serpentinized dunite and harzburgite, and troctolite (37.6% recovery). The harzburgites and dunites were impregnated with gabbroic melt, which strongly suggests that this section is the "crust/mantle transition" or "Moho". Hole conditions started deteriorating after Core 5R, and torque and overpull increased from unstable rock falling into the hole. The pipe stuck and could not be freed; therefore, it was severed.

Hole 895F, (Site HD-4)

Hole 895F was spudded in 3704.0 mbrf water depth on a sediment slope with small boulders and cobbles 200 m north of Hole E. The bit encountered 4 m of very soft sediment. Cores 1R to 2R (0-26.2 mbsf) recovered 1.98 m of serpentinized harzburgite and dunite. Hole conditions were very unstable, and coring was terminated.

Hole 894G, (Site HD-3) Logging & HRB Recovery

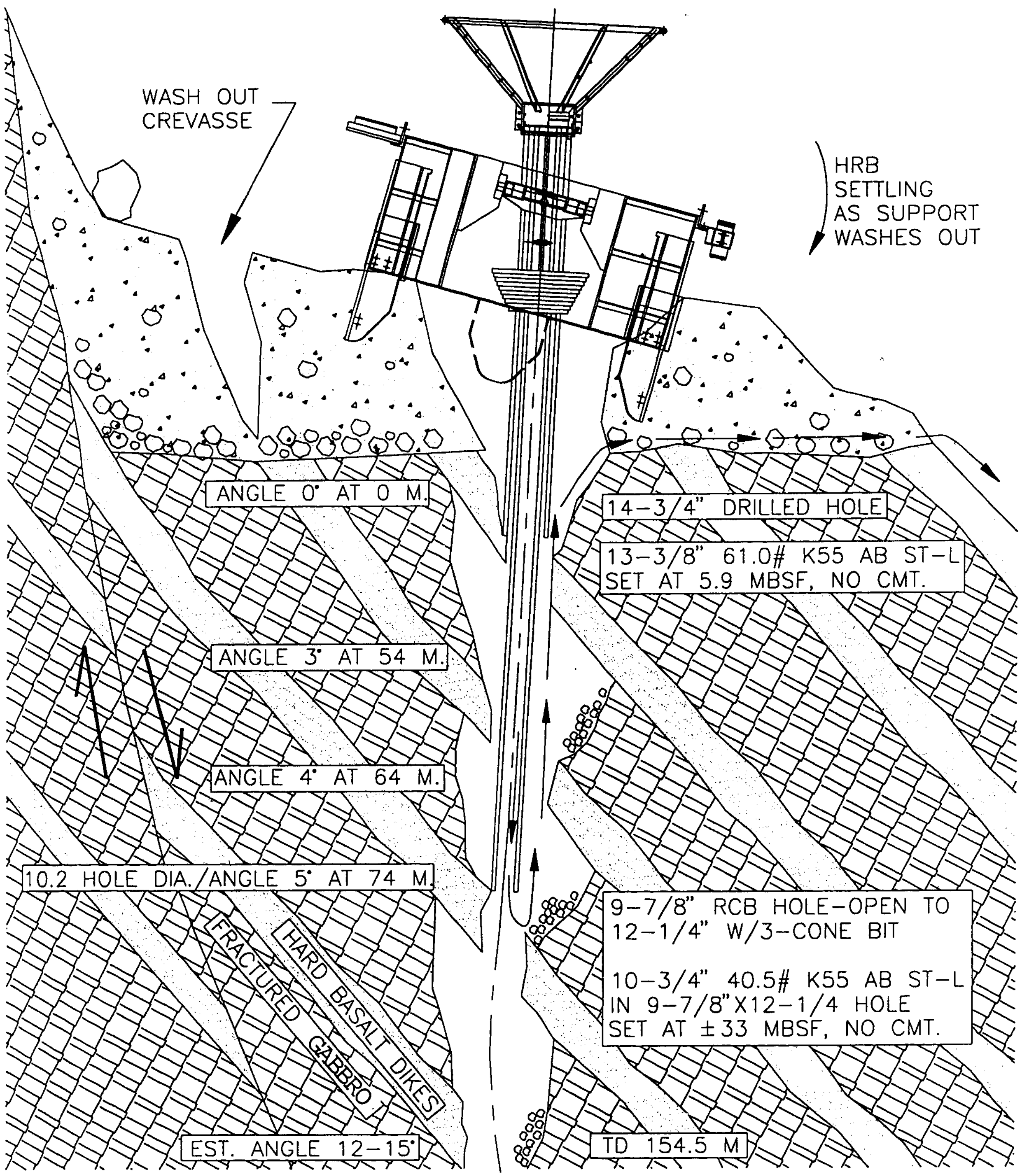
The HRB at Hole 894G was reentered for logging. The FMS tool could not be worked past a ledge at 71.6 m. The tool indicated a fairly constant hole angle of 4° at 240° azimuth, but it stuck while being pulled into the pipe. The 10-3/4 in. casing and hanger were pulled out with the FMS tool, which was jammed in the bit by a broken sensor pad. The HRB was recovered.

HD-4 Coring Problems

A total of 272.9 m (23.7% recovery) of serpentinized peridotites impregnated or crosscut by gabbros was cored at Site HD-4. Each cored section had to be rereamed, apparently because the rock was relieving internal stresses by closing-in the well bore, and there was heavy pad wear on bits and stabilizers. Unstable hole conditions were encountered with constant high torque stalling the top drive, high overpull and the annulus packing-off at circulation rates above 150 gpm. Large rock chips accumulated above the bit. Viscous gel sweeps and/or increasing the pump rate caused the debris to pack-off above the bit; therefore, it was not possible to clean most holes. Tandem 20 bbl mud sweeps were fairly effective in cleaning the more stable holes such as 895B/C. Many core sections exhibit a pronounced curvature, and broke-off in roughly 0.2 m disks after contacting the inner core barrel wall.

Future Offset Drilling

Future offset drilling programs in unstable formations might be more productive if precise drill sites were marked with beacons or floats on dives. A bare rock pilot hole should first be cored as deep as possible to confirm the lithology, determine rock stability, and obtain logs. A reentry cone with a short surface casing should be drilled-in (using an underreamer) and cemented to anchor the base. Drilling should be done with stabilized BHAs to wipe out the ledges, and deviation should be controlled. Multiple casing strings would be run as required (probably about every 70 to 100 m) for deep penetrations in unstable formations.



DRIL-QUIP DUAL
LEG 147-HESS DEEP SITE 894G(HD-3)

Figure 1

Leg 147 - Operational Problems and Suggested Solutions

1. Site survey data were not adequate:
   a) Better maps are needed.
   b) Proposed Drill Sites should be marked with location beacons or floats placed by submersibles.

2. More time is needed to core multiple Pilot Holes to evaluate sediment cover and rock consolidation near the surface (but more risk to drill string), in order to identify Deep Hole location.

3. TV/Sonar/Drill String difficult to control accurately.
   a) Need Steering Sub to force bit movement and counter pendulum.
   b) Need TV Pan, Tilt, and Zoom to improve visual search.

4. BHA failures when spudding on hard, sloping, bare rock.
   a) Replace weak connection on 7” DC with a Tapered Drill Collar.
   b) Need Heave Compensator in top condition for accurate WOB.

5. The HRB is unstable on sedimented slopes and falls over as circulation washes sediment from under the legs.
   a) Abandon the use of HRBs for offset drilling.
   b) Need a Reentry Base for sedimented/rubble slopes compatible with the Casing/Underreamer system used on Leg 158.

6. Hole 894G started at 4°-5° angle because ship was offset to counter strong, shifting surface-currents. This caused alignment problems when attempting to reenter with bits and casing.
   a) Need BHA Angle surveys at the seafloor before spudding, and to use ship offset to spud Vertical Hole.

7. Non-concentric hole was drilled because HRB tilted, and drill string fell to low side of HRB casing throat.
   a) Use Centering Bushings to centralize drill string in casing throat (upper holes).
   b) Core small 9-7/8” hole to improve hole stability (but requires hole opening or underreaming).
   c) Use Drilling Stabilizers when enlarging core holes.

8. Cam-Actuated-Dril-Ahead (CADA) running tool did not permit disengaging from base to verify position (without tripping) before spudding.
   a) Modify CADA tool to permit disengaging from base and verifying the position before drilling ahead (without tripping).

9. Alternating cavities and hard ledges caused problems with hole angle, torque, drag, hole cleaning, clearance, and running casing. Also prevented effective concentric hole enlargement with pilot bit and stabilizers and caused stuck pipe problems.

   a) Need Armored Bit Stabilizers with edge buttons and upreaming buttons on top to wipe hole, drill keyseats, and crush ledges.
   b) May need up to 4 Casing Strings in unstable formations.

10. Rubble continued to fall in the hole and fluid circulation occurred around the casing (making hole cleaning impossible) because the surface casing was not cemented (to allow remaining HRB to be moved if required).

   a) Surface casing should be cemented to secure the unstable seafloor rubble and control seafloor washout.
   b) Use casing Underreamer system to case through unstable sediments and prevent hole cleaning problems.

11. Hole enlargement from unstable formations led to hole cleaning problems.

   a) Use Sepiolite Sea Water Mud to provide additional lifting capacity (also used for high temperature drilling and to reduce clay swelling from fresh water clay hydration).
   b) Load open holes with sepiolite mud to keep hole open prior to logging and running casing.
   c) Use Silicate Mud Viscosifier to remove large fill from the hole at lower circulation rates.

12. Difficulty running casing in unstable holes with Cavity/ Ledge / Alignment problems.

   a) Underreamers and Mud Motors inside a casing string were used on Leg 158 to drill casing into place in unstable moderately hard rock; however, the Dril-Quip running tool will have to be modified for underreaming.
   b) Use guide or tapered casing shoes to start casing in the hole and work past ledges.

OPERATIONS SUPERINTENDENT'S PERCEPTION OF LEG 153

920A (Site MK-2) Water depth: 3339 m; Total penetration: 14.0 m

Hole 920A was initially overcored to 14 mbsf without any significant hole problems. While retrieving the first core barrel, the bit became plugged and the hole began packing off. The core barrel and wireline became stuck inside the bottom hole assembly. The wireline had to be severed to be recovered. The drill string then had to be recovered to remove the stuck core barrel, thus ending Hole 920A.

920B Water depth: 3339 m; Total penetration: 126.4 m

Hole 920B produced high, erratic torque throughout the coring operation. No other significant hole problems occurred. While pulling out of the hole to replace the bit (43-3/4 rotating hours on the bit) the bottom hole assembly became stuck at 112 mbsf. The drill string was worked 6 hrs before it came free. After reentering via a modified free fall funnel, the hole was reamed to 26 mbsf. It was determined that a new hole was being made and the hole was abandoned.

920C Water depth: 3343 m; Total penetration: 16.0 m

The hard rock base was deployed 10 m south of Hole 920A. The initial slope, as indicated by a tilt beacon attached to the base, was 16°. The base was moved 5 m east where the indicated slope was 10°. During the round trip for the drilling assembly, the base settled, tilting over 2.6°. While drilling a 17-1/2 in. hole to 16 mbsf, the base settled an additional 1.3°. While conditioning the hole in preparation for casing, the base settled 1.9° more. The base was now leaning against the bottom hole assembly, preventing the bit from being worked to the bottom of the hole. During the round trip for the running tool, the base settled an additional 2.6° for a total of 8.4° (Figure 2). While attempting reentry, the base reentry cone toppled over and would not right itself. Finally, with the use of a "rig fabricated" stabilizer, the base reentry cone was righted, reentered and latched into. The base was then successfully recovered for repairs, ending Hole 920C.

920D Water depth: 3338 m; Total penetration: 200.8 m

Hole 920D produced high, erratic torque below 125 mbsf. Constant hole reaming was required below 175 mbsf. The drill string became stuck at 182 mbsf and subsequently freed. At 200 mbsf the hole began packing off faster than it could be cleaned. As the bottom hole assembly was being pulled from the hole, it became stuck at 190 mbsf. The drill string eventually had to be severed, ending Hole 920D.

921A (Site MK-1) Water depth: 2488 m; Total penetration: 17.1 m

Hole 921A was cored once to 17.1 mbsf with persistent high erratic torque throughout the coring operation. The hole was abandoned due to the high torque and hole fill.

921B Water depth: 2490 m; Total penetration: 44.1 m

Hole 921B produced high, erratic torque with continuous hole fill. Excessive reaming was required to keep the hole open. The hole was abandoned due to deteriorating hole conditions.

921C Water depth: 2495 m; Total penetration: 53.4 m

Hole 921C produced high, erratic torque while coring. No recovery was achieved in an apparent fault zone from 39 to 53.4 mbsf. This zone also appeared to be taking fluid. The hole was abandoned due to deteriorating hole conditions below the fault zone.

921D Water depth: 2514 m; Total penetration: 48.6 m

Hole 921D produced high, erratic torque with hole fill. Apparently, the same fault zone as encountered in Hole 921C was penetrated. The hole was abandoned due to deteriorating hole conditions below the fault zone.

921E Water depth: 2456 m; Total penetration: 76.8 m

Hole 921E produced high erratic torque and continuous hole fill. Excessive reaming was required. Frequent mud sweeps were used with only marginal success. The hole was abandoned due to deteriorating hole conditions.

922A Water depth: 2612 m; Total penetration: 14.6 m

Hole 922A produced high erratic torque with low penetration rate (0.3 m/hr). The hole was abandoned in preparation for a second attempt to deploy a hard rock base.

Second Hard Rock Base Deployment Attempt

The hard rock base was tripped to the seafloor without incident (Figure 3). The base was set down 13 times without finding a slope angle less than 20°. The effort was finally abandoned and the base was recovered.

922B Water depth: 2612 m; Total penetration: 37.4 m

Hole 922B produced high erratic torque with low penetration rate (0.3 m/hr). With 75 rotating hrs on the bit, the drill string was recovered to replace the bit. The hole was reentered and reamed to 12 mbsf when the bottom hole assembly, top sub box, failed, leaving the outer core barrel assembly in the hole.

923A Water depth: 2440 m; Total penetration: 70 m

Hole 923A produced high erratic torque with low penetration rate (0.3 m/hr). Good core recovery was achieved in the upper 50 m. Excessive reaming was required in the lower 20 m. Hole fill on connections increased near the bottom. At 70 mbsf, the hole packed off and had to be abandoned.

924A Water depth: 3170 m; Total penetration: 10 m

Hole 924A produced high erratic torque from the outset. With the bit at 10 mbsf, the first drill collar above the outer core barrel failed through the zip lift groove. The failure occurred 12 m above the seafloor, resulting in loss of Hole 924A.

924B Water depth: 3176 m; Total penetration: 30.8 m

Hole 924B produced high erratic torque from the outset. At 30.8 mbsf, 40,000 lbs overpull was required to free the bottom hole assembly and the hole was abandoned.

924C Water depth: 3177 m; Total penetration: 48.5 m

Hole 924C was cored at a low penetration rate (0.3 m/hr) to a depth of 48.5 mbsf with no significant hole problems. The hole was abandoned when the allotted coring time expired.

Leg 153 Operations Generalizations

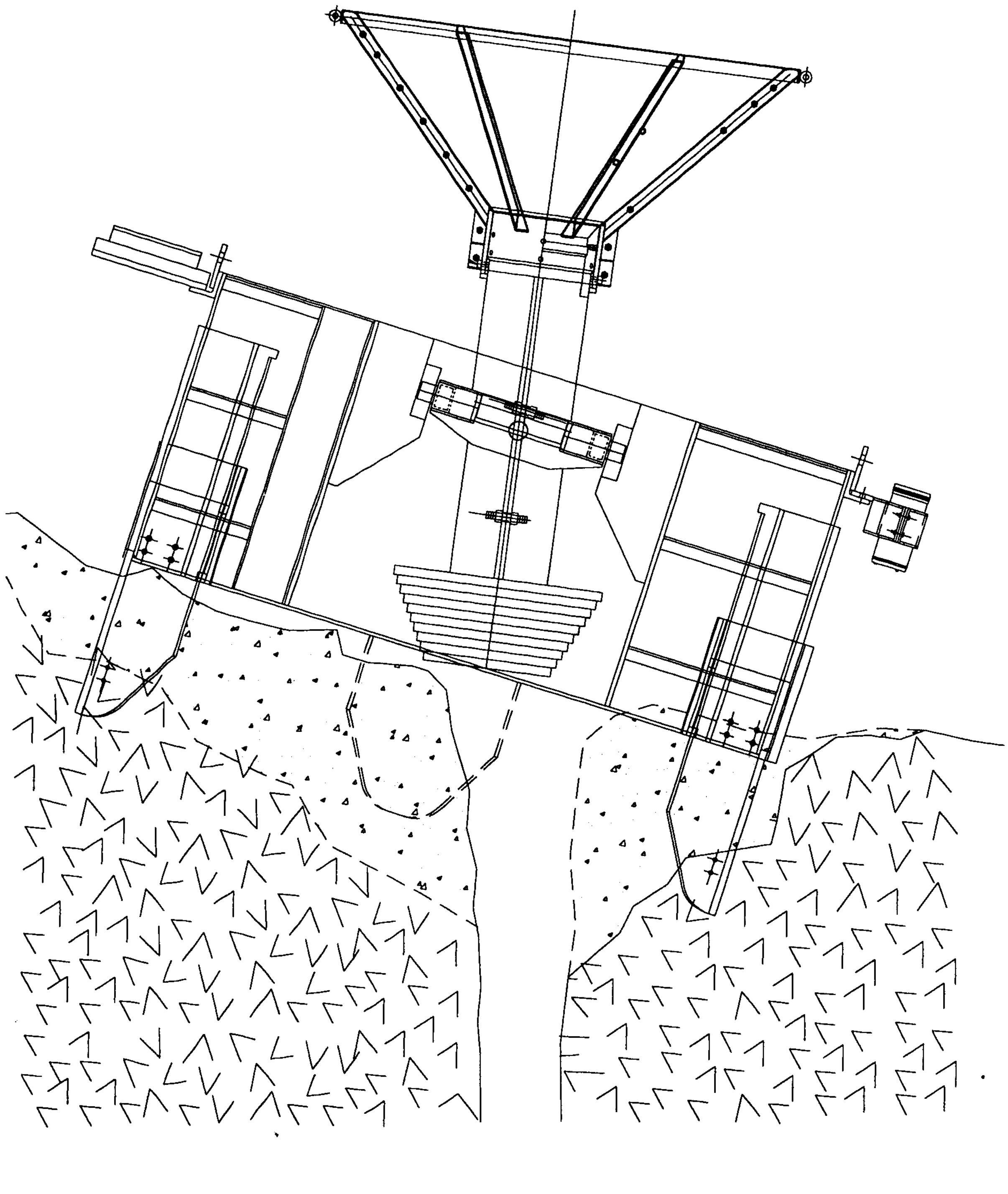
The following operational generalization are made from a "rig floor" point of view.

1. Peridotite (Site 920) appears to produce crooked holes with high erratic torque from top to bottom, excessive fill problems, moderate penetration rates (2 - 3 m/hr), and extreme difficulty in removing cuttings (Figure 4).
2. Gabbro (Sites 921, 922, 923 and 924) appears to produce straight holes with intersecting fractured zones, "ratchet" rocks, high erratic torque below the fractured zones, low penetration rates (0.3 - 1 m/hr) and extreme difficulty in removing cuttings (Figure 4).

End of Leg 153 - Operational Thoughts and Suggestions

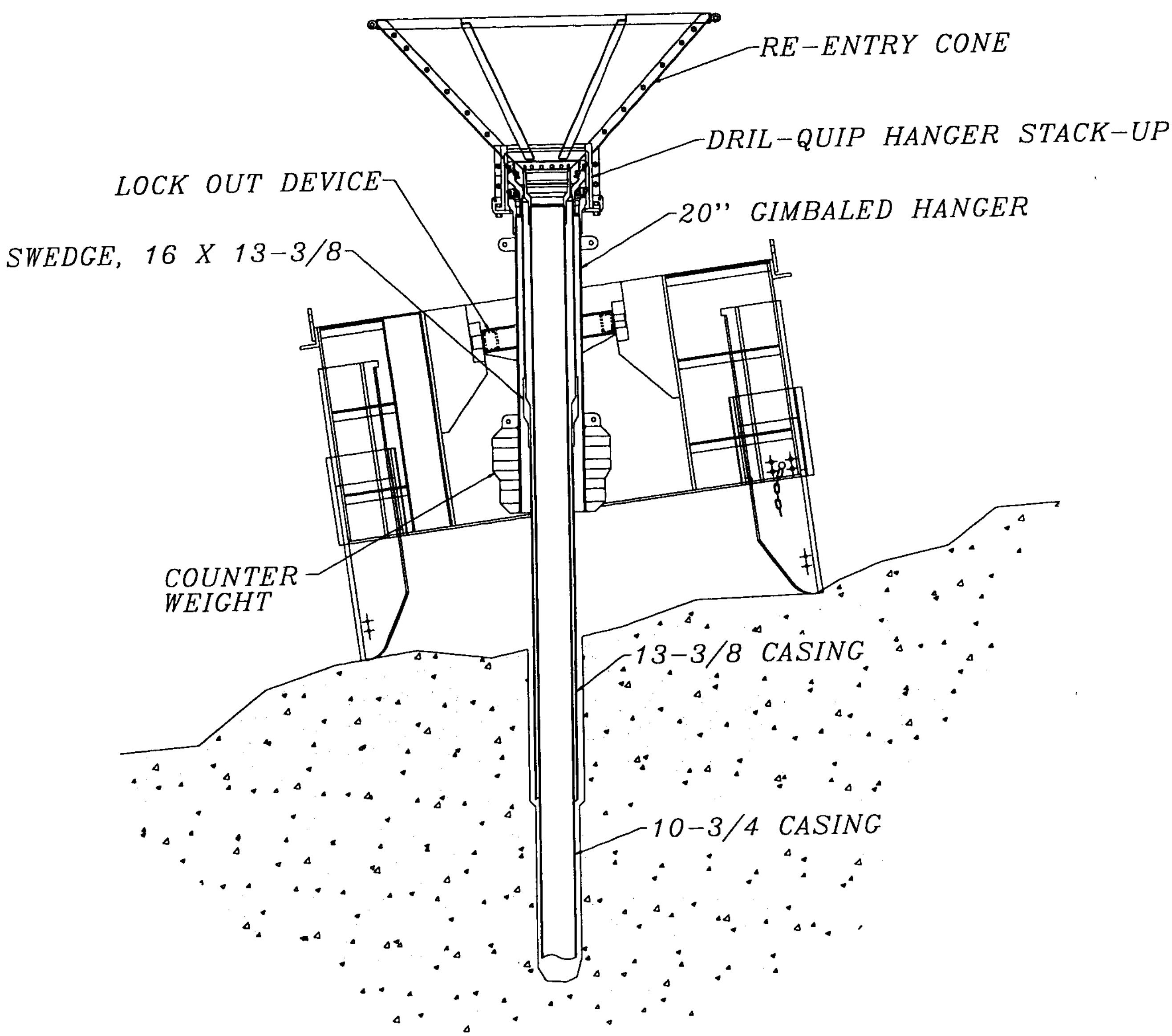
The following are "thoughts and suggestions" for improvements to the current plan of attack for coring areas such as MARK in the future.

1. If the hard rock guide base is to be used, better site surveys are required to locate multiple sites suitable for setting down the hard rock guide base.
2. The ship should be better equipped to do seafloor surveys in a MARK type area.
3. Seafloor slope angle cannot be adequately determined from the drill ship as it is now equipped.
4. The current limitations of the drill ship require a large (100 m diameter) target area for expeditious setting of hard rock guide bases.
5. Jet tests for determining sediment thickness are only partially useful due to apparent overlying gravel and loose rock.
6. The feasibility of a "drill-in casing" system for hard rock should be explored.
7. A "seafloor template" should be designed to replace the existing hard rock base.
8. Better hole cleaning techniques need to be developed.



HARD ROCK BASE CONFIGURATION
AFTER CONTINUED SETTLING AT HOLE 920C

Figure 2



PLANNED HARD ROCK BASE
INSTALLATION FOR MARK (LEG 153)

Figure 3

"RIG FLOOR PERCEPTION" OF GENERIC BOREHOLES DRILLED DURING LEG 153

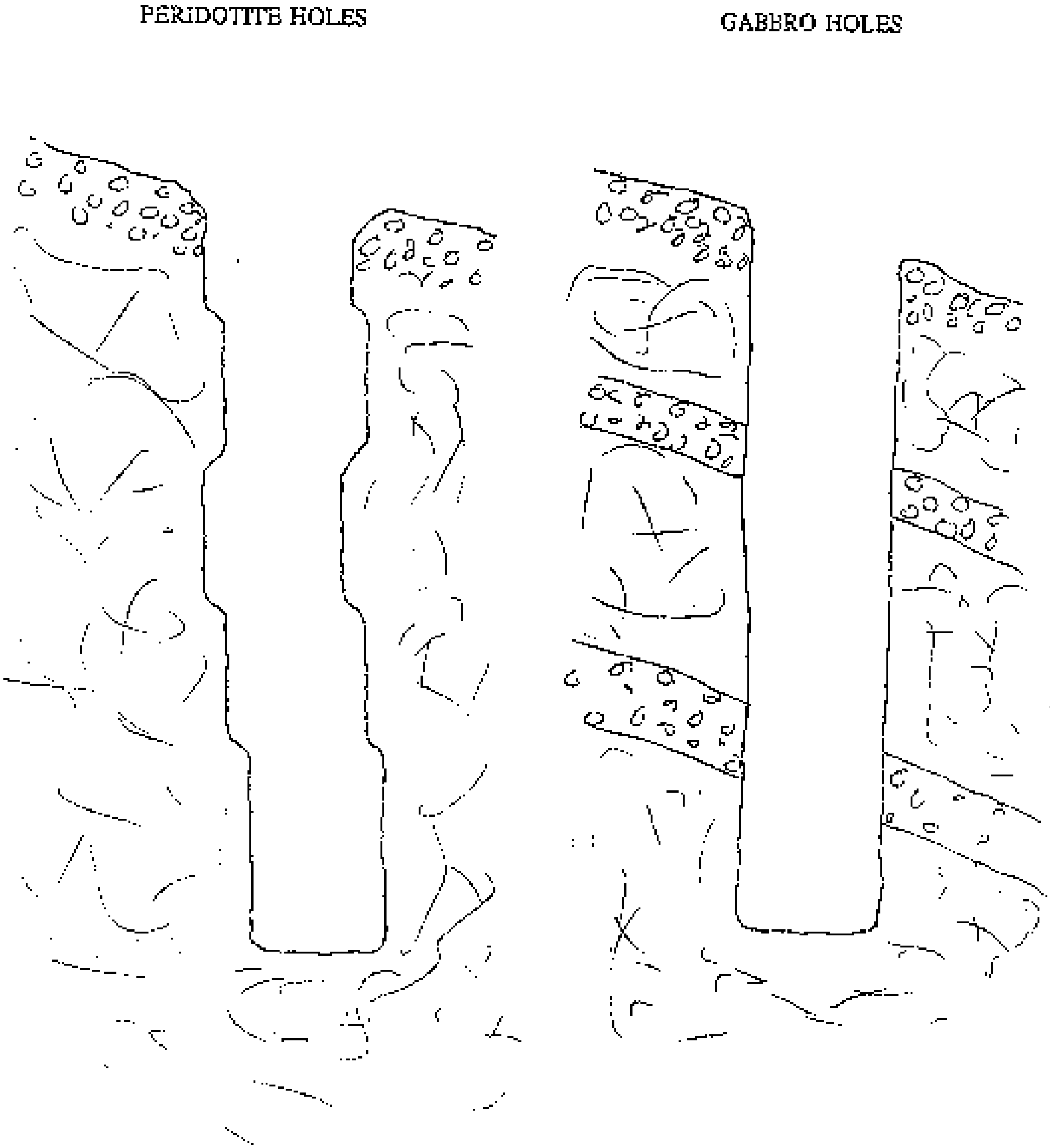


Figure 4

SCIENTISTS' PERCEPTION OF LEG 147 OPERATIONS

Leg 147 was the first drilling leg that specifically followed the offset drilling strategy to test models for magmatic accretion at the fast-spreading East Pacific Rise. At Site 894, a sequence of gabbroic rocks was recovered from a tectonic exposure of the lower crust and provided critical new data to characterize the nature of the upper part of axial magma chambers and the processes that shape them. Within 9 km of Site 894, a sequence of harzburgite, dunite, and gabbros representative of the shallow mantle was recovered at Site 895. This unique suite of cores demonstrated spatial heterogeneity of melt percolation in the upper mantle.

Site 894

The drilling strategy for Site 894 was based on the success of Hole 735B, where gabbroic rocks were successfully drilled with high recovery. We anticipated that, once a hole was initiated, drilling would proceed smoothly and that hole conditions would be stable. We did not anticipate the degree to which the intra-rift ridge would be brittlely fractured and the difficulties that this would present for drilling. In addition, the predrilling survey with the *JOIDES Resolution* showed that the intra-rift ridge was covered with a more continuous and thick sediment cover than expected and that in many locations the sediments were underlain by talus. Both of these factors posed significant challenges for drilling. This was primarily a consequence of the fact that the submersible survey observations on which the sites were selected were not made with the intent of selecting drilling targets. A more appropriate submersible survey may not have prepared us for the degree of fracturing but would have provided information about sediment thickness and the slope of outcrops, which would have modified our operational plans.

Six pilot holes were drilled to test the drillability and determine the rock types. These holes provided important information concerning the neotectonics of Hess Deep, as well as the representativeness of the hole we committed for deep drilling. At Hole 894G, we deployed a hard-rock guide base and despite guide base and hole instabilities, a 154-m-deep hole was drilled. Drilling problems resulted from: the guide base slipping due to placement on a steep sedimented slope; considerable hole instability due to brittlely fractured rocks cemented with soft minerals; difficulty in deploying casing; and the decision not to cement, which caused circulation problems. We decided not to cement so that the HRB could be moved if we lost the hole.

At 894C, the first attempt to deploy a guide base failed because we were unable to accurately place the guide base on the basis of the X-Y map and we were unable to look around the site to confirm the location with the camera before we started drilling. The accuracy of the X-Y map was insufficient for deploying the guide base on a very small target area. The result was that the HRB flipped over during drilling due to slope failure after misplacement on a talus slope. On the basis of our pre-cruise meeting, we were led to believe that it would be possible to confirm the site location prior to drilling. We were surprised to learn that this would not be possible as the HRB was being lowered to the seafloor. This experience demonstrates the importance of continuous communication between the co-chiefs, staff scientist, and engineers. The operational process was modified before deployment of the second HRB so that the site could be marked and viewed prior to setting down the guide base.

Site 895

At Site 895, our strategy was to drill a series of unsupported holes to bit destruction as we no longer had a HRB to deploy. We drilled seven holes along a N-S transect. Although drilling conditions were quite variable, holes became unstable within 30-90 mbsf. Drilling at several holes was terminated due to the loss of the BHA rather than hole conditions. Although on-bottom observations suggested that we had selected outcrop to drill, paleomagnetic data from most holes indicated that we had drilled large blocks that may have contributed to hole problems. This array of holes, however, emphasized the feasibility of unsupported spud in to drill holes with a very high scientific return.

SCIENTISTS' PERCEPTION OF LEG 153 OPERATIONS

Despite not meeting the deep drilling objective set forth in the scientific prospectus for Leg 153, the lateral and potential temporal variability preserved in the cores recovered during this leg represent a major contribution to our understanding of ocean crust and upper mantle processes. Extensive documentation of this variability is presented in the Preliminary Report and the Initial Report volumes for this leg. The following represents the perceptions of the scientific party regarding the operational aspects of drilling on Leg 153.

Given what we understood to be the operational limits of the guide base (30°-35° slope), the precruise submersible surveys identified several potential sites within these limits. We considered the precruise surveys to be adequate in light of these operational limits. Our experience with attempts at guide base deployment, however, demonstrated that the limits of operation we envisioned were theoretical limits, and not true operational reality. Obviously, this misconception may have been prevented with more thorough communication between the scientists planning the cruise and the engineers charged with development of operational techniques. One ancillary benefit of this publication is to ensure that communication at this level is more common in planning future legs.

Once we understood the true operational limits of the guide base (≤20°), the precruise site survey data were no longer adequate for establishing a guide base location. Necessarily, we were forced to reevaluate our drilling strategy, and undertake extensive video surveys to find appropriate sites. As a consequence of the amount of time dedicated to seafloor surveys designed to locate drill sites within the true operational limits of the guide base, drilling time was significantly reduced. Had these surveys been designed with the intention of locating sites for single bit holes, several more sites could have been drilled, since the precruise site survey data were adequate for this type of operation.

Sites within the operational limits of the guide base are well below the angle of repose for talus and pelagic sediments. Bare rock outcrops are, therefore, very difficult to identify, particularly given the low resolution of the current shipboard video survey system. Additionally, the hard rock guide base was not designed to be emplaced on sediment, which is a general characteristic of areas on the seafloor with such gentle slopes. However, during the course of our surveys we successfully located outcrops within these operational limits. Pilot holes at these sites demonstrated that downhole instability precluded establishing a multiple reentry hole with the available drilling and casing tools and techniques.

Operations on Leg 153 proved invaluable in two principal aspects. We now recognize that to establish a multiple reentry site, many potential sites must be surveyed because downhole conditions are not predictable at this stage. Even if a survey identifies a site with all the criteria necessary to allow establishing a hole, downhole formation characteristics not perceptible to current survey methods may prohibit deep penetration. Second, we recognize that existing drilling, casing, and surveying tools need to be improved, and new methods and tools must be investigated and developed if we are to meet the deep penetration objectives of offset drilling.

SITE SURVEY ISSUES

Where we are now:

The current ODP site survey data guidelines (approved by PCOM in August 1994) require swath-mapped bathymetry, photographic or video data, a regional magnetic anomaly survey and rock sampling for tectonic window drill sites. In addition, the current site survey data guidelines recommend, under certain circumstances, several additional data types: gravity, OBS microseismicity, side-looking sonar, high resolution seismic reflection or 3.5 kHz, and deep penetration or surface ship refraction. Proponents are expected to submit "recommended" data types to the ODP Data Bank if such data already exists, but they are not expected to acquire such data if it does not. The seismic data are intended as regional rather than site-specific data types, and, in fact, need not cross the site at all. The high resolution seismic reflection or 3.5 kHz data are intended for use in the selection of backup sites in sediment ponds in the event of failure of the bare rock drilling equipment. Deep penetration seismic reflection or surface-source refraction data are recommended in cases where it is possible to identify and survey an adjacent or conjugate piece of undismembered crust that is expected to have nearly the same crustal structure as that possessed by the targeted crust prior to tectonic disruption.

Each of the "required" data types for tectonic window drilling was available for the Hess and MARK drill sites. In each case the visual data came from submersible dives, typically with one dive actually crossing the drill site. The visual data were presented as interpretive sketches with structures and lithologies indicated as symbols along a profile or map-view track line. The Hess data package included two additional "recommended" data sets: gravity and deep penetration seismic reflection. The MARK data package included the following "recommended" data types: gravity, deep penetration seismic reflection and side-looking sonar (nearby but not over the sites). In the case of MARK, only two potential drill sites were documented with site-specific data.

In general, data of the sort submitted for Hess and MARK, in combination with a modest amount of Resolution VIT surveying, proved to be sufficient for finding drillable sites of high scientific interest for single-bit shallow (<200m) penetration sites with unsupported spud-in. No substantive adjustments of existing site survey procedures would be needed to drill more holes of this sort, although it would be prudent to document a larger number of potential drill sites than was done for MARK or Hess.

However, both Hess and MARK experienced great difficulty and limited success at finding spots in which to place a guide base and drill a deep hole. It would appear that successful a *priori* identification of deeply drillable sites in tectonically dismembered terrains involves three-dimensional characterization of surface and subsurface microenvironments around candidate drill sites of a better quality than the community has yet accomplished. The engineers at this workshop have described their problems at MARK and Hess in two categories: (1) to put down the guide base, (2) to "dig the hole." The remainder of this section discusses ways in which better site characterization might help with these two types of problems. Pre-drilling techniques for seafloor characterization can help find the right place to put down the guide base. Pre-drilling techniques for subsurface characterization can help find the right place to "dig the hole." An iterative process, involving close coordination between the drilling and surveying communities, will be needed to find the most useful combination of data acquisition, processing, display and interpretation strategies to reliably find deeply drillable sites.

The remainder of this section deals only with site-specific data, with the expectation that the regional geological and geophysical setting is already well-characterized by broader scale surveys.

Seafloor site characterization:

Visual data (typically from a submersible) and high quality swath-mapped bathymetry (typically from a hull-mounted multibeam echosounder) are recognized as absolute prerequisites for siting any borehole in a tectonically dismembered terrain. In addition, the Hess and MARK experiences have shown the importance of detailed pre-drilling characterization of the local seafloor slope and sediment cover around prospective hard-rock guide base sites.

At this workshop, the engineers asked the surveying community to find and document hard-rock guide base targets 100 m in diameter, throughout which the seafloor slope is less than 20° and the sediment cover is less than 1 m. It is clear that such sites are uncommon in areas like Hess or MARK. But it is also clear that we have not come close to exhausting every available strategy for finding and documenting such sites.

Seafloor Slope: In typical oceanic water depths, the footprint of a single beam of a hull-mounted multibeam echosounder is more than an order of magnitude larger than ODP's bare rock guide base. Thus multibeam bathymetric maps are not an adequate database on which to identify locations where the seafloor slope will be flatter than the ~20° maximum slope on which a guide base can be placed. Better slope information can be obtained through a combination of several techniques:

* **nearbottom-towed bathymetric mapping sonars:** Higher resolution bathymetric maps can be produced with a near-bottom towed multibeam echosounder (such as that under development for the MPL/SIO Deep Tow) or near-bottom towed interferometric swath-mapping sonar (such as that on SeaMARC CL). Such data will

not single-handedly document an appropriately flat area, but it could be used to rule out large areas that are not worth consideration as prospective guide base sites.

*** quantitative stereo photogrammetry:** It is possible to produce extremely fine-scale (decimeter vertical) resolution microtopographic data from digital stereo pairs of vertically incident photographs shot from a near-bottom towed vehicle. To complete such an analysis for a 100-m-diameter photomosaic would be labor intensive, but the resulting map would certainly provide the desired documentation of seafloor slope.

*** submersible water depth measurements:** Submersibles typically measure their depth with a pressure sensor, and their altitude above the seafloor with a high-frequency echosounder. These two measurements can be summed to produce a high-resolution bathymetric profile along the submersible track. If a potential drill site were criss-crossed with a network of well-navigated submersible dives, a high-quality bathymetric or slope map could be produced. Even in the case of a single dive traverse, accurate seafloor slopes can be calculated for those portions of the dive where the submersible is driving directly upslope (typically a large fraction of the time for most dives), provided that the submersible navigation is of high quality.
The submersible data for MARK and Hess, as submitted to the ODP Data Bank, were not presented in such a way that seafloor slopes could be accurately or precisely computed.

*** Geocompass:** The Geocompass, developed by Jeff Karson and associates, is a kind of underwater Brunton compass. When held in the submersible's claw, and placed against a seafloor surface, it can measure the dip and strike of the surface. Whereas the techniques described above have the problem of integrating seafloor slope over a larger area than the guide base footprint, the Geocompass has the opposite problem: it measures slope over a tiny area compared to the guide base footprint. In the site characterization context, Geocompass measurements can be useful as spot checks or ground truth for the broader-scale slope-measuring techniques. Geocompass measurements could also be very valuable in calibrating engineers' eyes for the interpretation of submersible videos: "that's what a 17° slope looks like."

Sediment Cover: A fundamental problem is that a site can exhibit absolutely no penetration on a hull-mounted 3.5 kHz subbottom profiler, and yet have too much sediment to emplace a hard-rock guide base. Improved knowledge of the distribution of sediment cover could be obtained through several existing or viable techniques:

*** photomosaicking** from a towed vehicle or ROV: A reasonably large area can be photographed with vertically incident cameras mounted on a towed vehicle or remotely operated vehicle. If these data are photomosaicked, an accurate map of outcrop locations can be produced. A photography campaign with towed vehicle or

ROV produces many times more areal coverage of outcrop location map than does the same amount of shiptime devoted to submersible diving.

*** quantitative photoanalysis of visual data:** On the typical interpretive sketch of dive observations, with lithologies and structures represented as symbols along a profile or track chart, the importance of outcrop is quantitatively over-represented. This is partly an unintended side effect of trying to represent all important observations, and partly a reflection of the observer's visceral sense of a dive in which the pilot probably sped over sediment ponds and lingered over outcrops. If, instead, the percent sediment cover is estimated from the still photographs every 15 or 30 seconds, and then graphed as percent sediment cover versus distance along track, it becomes more obvious just how little outcrop there is in a specific area.

*** sediment measuring rod:** Using its claw, a submersible could stick a calibrated rod into the sediment and measure sediment thicknesses up to about a meter. Areas with more than a meter of sediment are not interesting anyway. This method is primitive, and time consuming, but cheap and effective.

*** subbottom profiler on towed vehicle or ROV:** A typical subbottom profiler on a near-bottom towed vehicle would be a wide-beam 3.5 kHz or 4.5 kHz downward-looking sonar. It's not clear whether such a sonar, which might have a 50-100 m footprint on the seafloor, could help much amid the complex microtopography and depositional microenvironments of a tectonically dismembered terrain. Certainly, such a tool could be used to eliminate some areas that clearly have too much sediment. New developments in near-bottom towed subbottom-profiling sonars, including parametric sonars and swept-frequency sonars, may be able to produce the requisite combination of narrow beam width and fine resolution.

*** subbottom profiler on submersible:** Although we are not aware of any examples where this has been done, we think it should be possible to mount a subbottom profiler on a submersible. One could envision a frequency-agile, downward-looking sonar with a choice of frequencies between 1 and 10 kHz, so that the diving scientists could choose what trade-off to make between resolution and penetration. The advantages of such a system are: (1) it would produce profiles of use for science, as well as for ODP site-characterizaton; (2) it would not require additional expertise on the part of the scientific party, as would, for example, the percussive or pinger-type refraction experiments described below; (3) it would not require special dives or a modification of the dive track. Disadvantages are: (1) the extra sonar would consume battery power and thus shorten the dive; (2) the system would probably not penetrate very well if the sediment were a rubbly mixture containing a substantial fraction of coarse clasts.

Predrilling Subsurface Site Characterization

Marine seismic experiments that use bottom sources and receivers to investigate the oceanic crust to shallow depths (a few meters to 100s of meters) provide the ocean drilling community with a promising new technology for evaluating the drillability and structural context of a hard rock/offset drilling site. Unfractured volcanics are known to have a seismic velocity of 4-5 km/s; velocities as low as 2-3 km/s are a direct result of increased porosity resulting from voids, cracks and fractures. This suggests that a relationship may be inferred between the drillability of a formation and its bulk seismic velocity (as opposed to that measured in hand specimens). On-bottom seismics might also help determine the structural context of a drill site. For example, consider the two alternative hypotheses for the emplacement of peridotite in the western wall of the MARK area proposed by Karson and Cannat (see Fig. 6 of Leg 153 Scientific Prospectus.) If the seismic velocity of the serpentinized harzburgite differs from that of the surrounding rocks, it might be possible to determine whether the peridotite is an isolated body (has a bottom).

On-bottom seismic refraction and reflection experiments have the potential for addressing the following issues: (1) the thickness of sediment and/or talus overlying hard rock to an accuracy of meters and (2) lateral and vertical variations in seismic velocity resulting from changes in lithology and/or bulk porosity, the latter being affected by the distribution and density of cracks, fractures, and faults. Shallow geophysical experiments conducted on land over the past several decades have proven that high-frequency (>100 Hz) refraction and reflection experiments are a cost-effective and reliable method for measuring the thickness of overburden and the geometry of the interface between bedrock and overburden. The principal advantages of a bottom-source, bottom-receiver experiment are (1) the higher frequency content of the refracted energy permits the resolution of smaller-scale features, (2) the ability to observe crustal refraction at near-zero offset, allowing the imaging of near seafloor structures and (3) a modest but significant improvement in the accuracy of the travel time data.

On-bottom percussive or pinger-type sources. To image structure on a scale of meters, land-based experiments often utilize a sledgehammer (or shotgun-type) source and a receiving array of 12-24 geophones deployed at intervals of meters (maximum source-receiver offset of 100-300 m). The dominant frequency of such a source may vary between 100 and 1000 Hz. Typical objectives include the thickness and composition of overburden (e.g., sediment or talus) and the topography of the contact between overburden and bedrock. The thickness of overburden can be measured to within 1-3 m and the dip of the contact can be constrained to within a few degrees. The depth of penetration of these techniques is limited to <100 m. The technology for conducting such experiments on the seafloor is not currently available; however, Macdonald conducted a similar type of experiment more than a decade ago on the East Pacific Rise at 21 N. It is anticipated that a well-navigated submersible would be required to position the sources and receivers. Receivers may include existing ocean-bottom hydrophones or scaled down receivers deployed for short intervals from a submersible; the latter would require design and manufacturing. Refraction experiments using a pinger source and hydrophone streamer draped on the seafloor have also been used to characterize the uppermost sediments in deep-ocean settings, suggesting that a similar experiment may be feasible at a bare rock site.

On-bottom explosive sources. To image structure on a scale of tens of meters over distances of hundreds of meters to kilometers, one can use on-bottom explosive sources and receivers (ocean bottom seismographs). This technology already exists within the marine seismology community and it has been used successfully to image the shallowmost crust of the East Pacific Rise [Christeson et al., 1992]. The depth of penetration of these techniques is 1-2 km. Experiments in one, two, and three dimensions are possible and would be conducted from a typical research vessel.

Reconnaissance experiments around already-drilled sites would be useful to determine: (1) which seismic methods may be used to assess drillability, and (2) whether there is a resolvable seismic signature to crustal structures such as fractured versus unfractured gabbro and peridotite, hydrothermal mineralization zones, and serpentinized regions.

Navigation and Site Marking

Drillable targets in tectonically dismembered terrains may be very small (<50 m diameter). To maximize the chances that the *JOIDES Resolution* will be able to re-occupy the exact spot identified during pre-drilling site characterization surveys, the best possible navigational techniques must be routinely used, and a range of site-marking techniques should be implemented.

All high resolution, near bottom data should be transponder navigated, and transponder nets should be tied to GPS. In areas where repeated survey and drilling cruises are anticipated, a long-life transponder network should be established and maintained. All surface ship data should be GPS navigated.

Long-term coordination between site survey proponents and ODP/TAMU should be encouraged. In particular, site survey investigators should be provided with advice and materials with which to mark candidate drill sites.
Appropriate markers could include passive sonar reflectors, passive visual markers or acoustic beacons, depending on the terrain, the anticipated time before possible drilling, the numbers of anticipated sites, etc.

Drillship procedures

ODP/TAMU needs to acquire the equipment and expertise to navigate the *JOIDES Resolution* and the VIT-camera relative to the same long-baseline acoustic navigation networks used for site survey navigation.

VIT video data is useful for geological mapping, as well as for operations. The utility of VIT data could be maximized by improving the quality of VIT navigation and image quality. The navigation system for the VIT camera system should provide (a) realtime display of camera and ship position as track charts on an X-Y or lat/long grid, (b) logging of camera navigation data, (c) software to acquire and integrate short-baseline navigation, long-baseline navigation, and GPS navigation, (d) software to post-process DP data to provide the best possible post-facto camera track chart.

Image quality of the video could be improved with a more modern video camera, better lights and better lighting/camera geometry. A pan, tilt and zoom option is desirable.

Some aspects of these recommendations will be addressed by a scheduled, funded upgrade of the *JOIDES Resolution* navigation system.

Site Survey Funding

The site-specific survey data required to reliably identify deeply drillable sites in tectonically dismembered terrains will seldom be produced as a by-product of independent science-driven survey cruises. Dedicated submersible dives and perhaps dedicated cruises may be required to produce the requisite density of near-bottom observations, measurements and samples to adequately characterize the surface and subsurface microenvironments of candidate sites.

Such dives and such surveys may not be able to compete successfully for funding as world-class science in their own right. We feel that the funding structures of ODP member nations should include mechanisms to support site-specific surveys whose main contribution is to prepare the ground for drilling, rather than to directly reveal primary truths about earth processes.

NEED FOR AN ENGINEERING LEG

One of the important conclusions of the workshop was that the drilling equipment used on Legs 147 and 153, while adequate for coring shallow single-bit holes, was not up to the task of establishing deep re-entry holes. Furthermore, the need of the scientific party for core to study militated against operational time being spent on overcoming the difficulties associated with setting guide bases and casing. But although the inadequacies of some existing equipment were brutally exposed on these two legs, the consensus of drilling engineering opinion at the meeting was that 500+ m holes could be achieved, using drilling technologies that have yet to be tested in these harsh seafloor environments and strengthened versions of existing equipment. A clear case can therefore be made for an engineering leg to test this hardware in an offset drilling location before another science leg is scheduled with the aim of achieving a deep hole.

The overall objectives of an engineering leg would be to concentrate on establishing a re-entry structure with casing down to 100-200 m. Work would be restricted to one or two sites and only a skeletal scientific party (maximum 10 scientists) carried. Some coring would be conducted mainly to confirm rock type or to test particular coring systems, but maximizing core recovery would not be an objective of the leg. Indeed, the opportunity to core in the top 100-200 m would be sacrificed if that improves the chances of setting casing.

Specific objectives of the leg would probably include:

1. <u>Testing new hardware for initiating the hole</u>
   - (a) Modified hard-rock guide base or template.
   - (b) Drill-in Casing System (DIC). The existing DIC in ODP is designed for sediments. With a re-entry funnel on the top end, it was used on Legs 139 and 150. A more robust DIC would be needed for offset drilling.
   - (c) Drill-in BHA with Tricone Retractable Bit (TRB). This system was developed for initiating a DCS hole. With the TRB it might be possible to drill in a few joints of 10 3/4" casing. Coring would then have to rely on the 7 1/8" Diamond Core Barrel (DCB)

2. <u>Testing Coring Systems</u>
   - (a) DCB in gabbro and peridotite
   - (b) Motor Division Core Barrel (MDCB) in gabbro and periodotite

3. Testing equipment for drilling and hole stabilization
   (a) Under reamers
   (b) Hole openers
   (c) Roller reamers
   (d) Bits
   (e) Stabilizers

4. Testing improved methods of hole cleaning

5. VIT Camera system
   Improved operation and navigation

The location of an offset drilling engineering leg would be based on the following criteria:

(1) It should be in an area already characterized by drilling, e.g. MARK or Hess Deep.
(2) It must be in a place where both gabbro and periodolite can be drilled.
(3) The area should have a range of slopes, e.g. 10°-30°.
(4) Sites with and without sediment/rubble cover should be available.

REALISTIC STRATEGIES FOR OFFSET DRILLING

With Legs 153, 147 and 118, scientific ocean drilling has tested drilling conditions in each of the three principal tectonic environments where windows into the lower ocean crust and mantle exist. These are, respectively, rift valley walls, the amagmatic tips of propagating rifts and the crests of transverse ridges flanking fracture zones. Each of these environments is crucial to a successful offset drilling strategy as they provide unique opportunities to study different aspects and features of the ocean crust. Propagating rifts provide the only logistically realistic opportunity to drill the lower ocean crust and mantle created at fast spreading ridges; rift valley walls provide our best opportunity to directly study the tectonic processes creating seafloor topography at slow spreading ocean ridges and to explore the isochronal structure and heterogeneity of the lower crust and mantle along individual spreading segments. In contrast, the crests of transverse ridges provide an opportunity to study the temporal variability of the lower ocean crust and mantle along lithospheric flow lines, as well as sampling the fabric and composition of the ocean crust where it is least influenced by the tectonic processes creating the rift mountains. Thus, all of these environments are important potential targets for offset-section drilling.

Whereas drilling on Leg 118 demonstrated that the crests of transverse ridges can be easily drilled to depths of 500 m, drilling on the rift valley wall at the MARK area of the Mid-Atlantic Ridge during Leg 153 and on the intra-rift high at Hess Deep in a tectonic block of old EPR lower crust and mantle during Leg 147 was much more difficult. These legs, however, did demonstrate the utility of properly located and spaced holes of 30 to 200 m in characterizing portions of the lower crust and mantle. Thus, despite not having drilled 500-m holes, these legs provided a high scientific return. Nonetheless, the objective of directly characterizing the ocean crust on a seismically meaningful scale remains a principal objective of offset drilling. A revised offset-drilling strategy, based on what we now know we can do, should also be designed to lead to accomplishing this objective even in relatively hostile environments.

Recognizing the high priority of long vertical sections to the lithosphere community, any strategy for offset drilling is likely to include proceeding at the first opportunity to deepen Hole 735B. We must recognize, however, that such an opportunity is not known to exist at fast spreading ridges, and that rift valley walls offer other first order scientific opportunities that the community wants to pursue. Thus, we offer several parallel strategies that can lead to successfully reaching our objectives in this environment. The first strategy is to learn to drill in hard places. The second is to learn how to find easy places to drill. The latter includes locating "sweet" spots in otherwise hostile environments. This might be accomplished either serendipitously during drilling a suite of single bit holes designed to explore the lateral variability of the crust, or might use geophysical techniques, such as on-bottom seismology, as described elsewhere in this report.

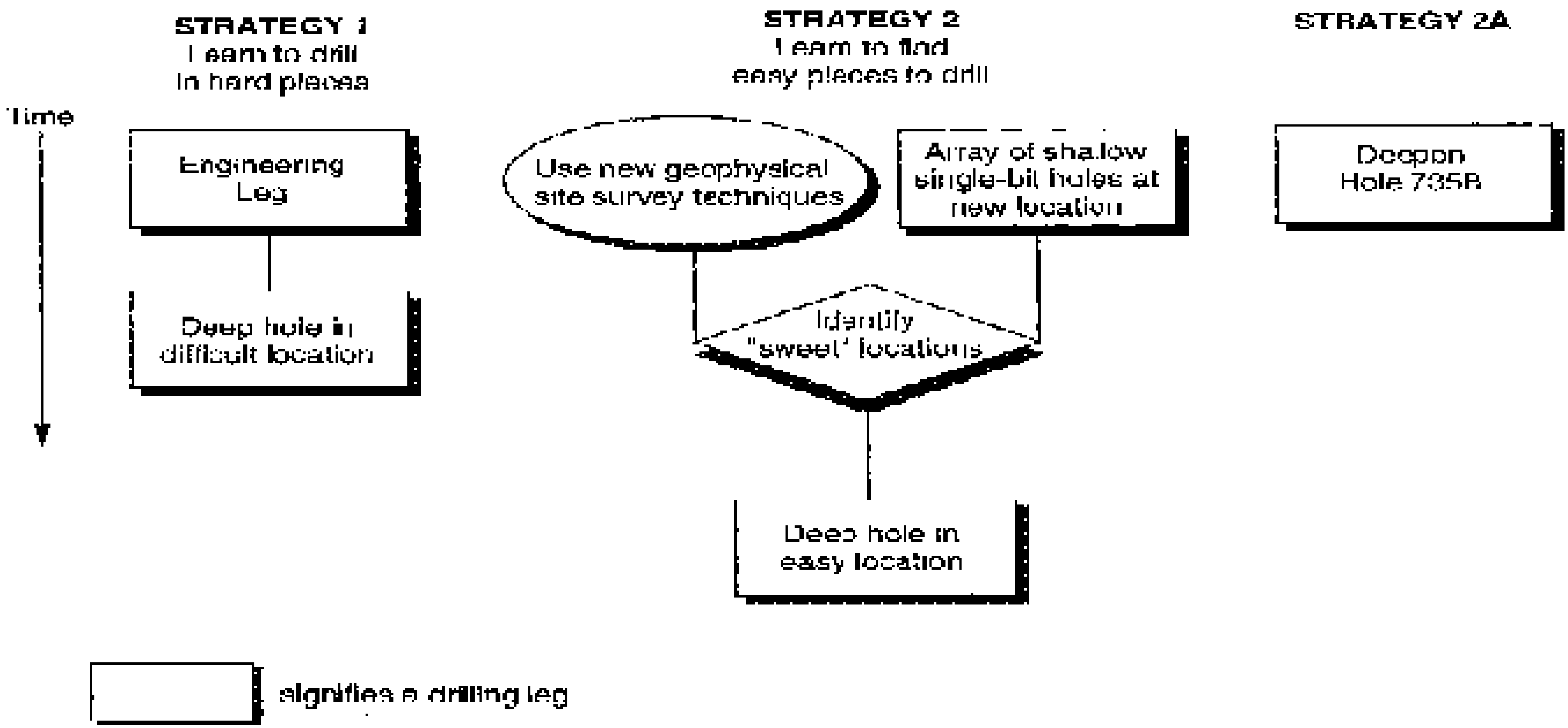
We take the point of view here that there are logistical and technological strategies that ultimately will improve our ability to find and drill sections of lower crust and mantle to depths of 500 m or more in places like Hess Deep and MARK. A necessary first step in developing these strategies is an engineering leg, as discussed elsewhere in this report in detail. The combination of existing drilling technologies, which have not been tested in these harsh seafloor environments, together with incremental improvements to previously used equipment are likely to significantly improve the ability to drill gabbro and peridotite in tectonically stressed environments. An engineering leg should proceed in a region where drilling conditions have previously been characterized, and are representative of those we wish to overcome. The location should also be in a region that has the best available site survey information. For the immediate future, offset drilling in the more hostile environments of rift valley walls and propagating rifts should proceed with the understanding that we are more likely to drill arrays of numerous shallow holes. This will allow characterization of the lateral variability of the crust and shallow mantle in these environments, lead to the improvement of drilling techniques in serpentinite and gabbro, and at the same time may lead to the discovery of suitable locations for siting deep holes.

As our ability to drill in more hostile environments improves, we also recognize that a deep hole at any given location must not only be based on site-specific survey information and the existence of a favorable location for guide base placement, but must include demonstration that the formation itself can be drilled. Although remote sensing techniques may enhance our ability to locate such a spot, they also require a successful pilot hole in a matrix of holes documenting the local lateral variability of the crust. These pilot holes should be as deep as possible using a single bit (to bit destruction).

The different strategies discussed above are shown diagrammatically in Figure 5. If this revised approach to offset drilling is adopted by the JOIDES community, it would be possible to insert any of the three legs in the top row into the 1997 schedule. The engineering leg would be an expensive one, comparable in cost to Leg 147 or 153, but the other two would not. A leg planned as an array of shallow single-bit holes would be similar to what actually happened on Leg 153, but no money would need to be spent on guide bases and casing systems. Offset drilling proposals that might be pursued by this strategy, exist in the JOIDES system, but may need revision with this particular approach in mind. The timescale of progressing to deeper holes at either hard or easy locations cannot be predicted, because these drilling legs would not be scheduled until the outcome of the earlier cruises was known.

Finally, it is important to stress that the prime objective of the lithosphere community in its offset drilling strategy is to obtain long vertical sections of the total column of the oceanic crust down to the mantle. Understanding lateral heterogeneity is a secondary priority. Thus, while a drilling leg consisting of an array of shallow holes is inherently of scientific interest, its most important function may be to pave the way toward one of the deeper holes to which the lithosphere community has consistently aspired.

FIGURE 5. NEW OFFSET DRILLING STRATEGIES



APPENDIX 1. WORKSHOP PARTICIPANTS

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Mathilde Cannat	(Université Pierre et Marie Curie)	Leg 153 Co-Chief Scientist
Henry Dick	(WHOI)	Leg 147 participant, JOIDES PCOM member
Glen Foss	(ODP-TAMU)	ODP Operations Superintendent
Timothy Francis	(ODP-TAMU)	Workshop Chair
Kathryn Gillis	(University of Victoria)	Leg 147 Co-Chief Scientist
Leon Holloway	(ODP-TAMU)	Leg 153 Development Engineer
Jeffrey Karson	(Duke University)	Leg 153 Co-Chief Scientist
Kim Kastens	(LDEO)	Chair, JOIDES SSP
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PCOM = Planning Committee
LITHP= Lithosphere Panel
SSP = Site Survey Panel
TEDCOM = Technology and Engineering Development Committee
LDEO = Lamont-Doherty Earth Observatory
WHOI = Woods Hole Oceanographic Institution