Storms, M. A., Natland, J. H., et al., 1991
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9. DIAMOND CORING SYSTEM—MODIFIED CORE BARREL ASSEMBLY[1]

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EXECUTIVE SUMMARY

A modified coring system was developed for use with the Diamond Coring System (DCS) drilling equipment. This system integrated both mining and oilfield technology to produce a coring system that would withstand the rigors of offshore drilling. The coring string was run through the conventional API drill string used aboard the *JOIDES Resolution* and could be deployed with either type of seafloor template (mini-hard rock guidebase (HRB) or reentry cone) designed for the DCS. The bit cut a 100.58 mm (3.96 in.) hole while producing a 55.88 mm (2.20 in.) core. Both 1.5 and 3 m (5 and 10 ft) core barrels were available to be run. The inner core barrel was deployed by free falling it inside the tubing string and retrieving it on a wireline after the interval was drilled.

The core barrel hardware performed almost flawlessly through the entire program even though low core recovery was achieved. Drilling parameters were adjusted in attempts to increase core recovery. However, due to a highly fractured volcanic tuff encountered at the Bonin location, recovery remained low. This was primarily due to the lack of proper core catchers for these formations. Cores taken where fractured or vesicular basalt was actually encountered were cut to gauge and produced recovery of over 60%. Over 79 m (260 ft) was drilled and cored with the new core barrel system. This amounted to 20 hr of actual coring time for the 33 times it was deployed in 1,800 m (5900 ft) of water. Total recovery for the hole amounted to slightly over 11 m of core with final recovery near 19%. Even though this percentage is lower than desired, it is probably realistic when the amount of voids and type of material are taken into account. A latch-in center bit was also used on several occasions to drill ahead and clean out the bottom of the hole. A total of three 10 ft core barrels were used throughout the drilling program. These barrels were run both with and without core liners.

The core barrel retrieval system was also upgraded over that used during Leg 124. The latching mechanism provided positive trouble-free operation throughout the leg. A bit deplugger was used on several occasions to clear the throat of the diamond bit when a core jam prevented the inner barrels from latching in.

Several upgrades to the coring equipment to increase its flexibility in different soil/formation types are under consideration based on experience from the leg. These include additional types of core catchers, introduction of a piston sampler for soft formations, and possibly adding a float valve to eliminate swabbing of the tubing during core barrel retrieval.

INTRODUCTION

The Ocean Drilling Program in conjunction with the Longyear Company has developed a slimhole core barrel for use with DCS drilling equipment. The outer core barrel was a modified version of a coring system that the Oil and Gas Division of Longyear and AMOCO research developed for AMOCO's Stratigraphic High-speed Advanced Drilling System (SHADS) onshore drilling program several years ago. Much of what was learned from that project has been used in designing the outer core barrel components for the DCS. The inner barrel used a smaller wireline version of Longyear's conventional HQ-3 type system along with changes initiated from ODP so it could be deployed through the DCS tubing string.

The DCS concept developed for the *JOIDES Resolution* uses a small-diameter tubing string inside the larger 5 and 5-1/2 in. API drill pipe. This smaller tubing is rotated while the larger drill string is held in tension to provide lateral support. Thus, the API drill pipe essentially serves as a mini-riser. A schematic of the two types of seafloor systems (mini-HRB and reentry cone) used to provide tension when operating the DCS is given in Figure 1. Additional detail pertaining to the seafloor hardware is presented in another report and will not be discussed here.

The outer core barrel assembly is made-up onto the bottom of the tubing string prior to running it to the seafloor. The assembly consists of a thin-kerf diamond bit, reamer shell, outer barrel, adapter coupling, and cross-over sub. An assembly drawing of the outer barrel is given in Figure 2. The kerf on the diamond bit cuts a 100.58 mm O.D. × 55.8 mm I.D. (3.96 in. O.D. × 2.20 in. I.D.) core.

The inner barrel is deployed by free falling it inside the tubing string. It consists of a core lifter case, inner barrel, and shut-off valve/latch assembly. The inner barrel allows a 55.8 mm × 3 m (2.20 in. O.D. × 10 ft) long core to be cut. The barrel can be run with two types of liners or without any at all. An exploded view of the complete core barrel is presented in Figure 3 with the inner barrel itself presented in Figure 4.

The tubing string is rotated with an open swivel, electric top drive that is mounted in line with the main top drive on the rig. It can operate at speeds between 20 and 540 rpm. The new DCS system designed for Phase II is capable of producing higher torque and has larger load-carrying capacity than the previous model used during Phase I (Leg 124E). The top drive is rated at 800 horsepower with the capability of producing a maximum torque of 8,000 ft-lb. The open top swivel will allow the core barrel to be retrieved without having to disconnect from the tubing string.

In order to core successfully with the DCS it is imperative that weight on bit be controlled with precision. This is accomplished by the introduction of a secondary heave compensator. This secondary system removes the inefficiencies of the primary 400 ton passive heave compensator permanently installed aboard the *JOIDES Resolution*. The compensator along with the entire DCS platform is arranged in series beneath the larger compensator. Figure 5 presents an illustration of the DCS drilling platform. Stack-up height of the system for the *JOIDES Resolution* is presented in Figure 6. It should be noted that the DCS platform is elevated over 13.91 m (45 ft) above the rig floor. The secondary compensator system is intended to provide control for weight on bit fluctuations of ± 227 kg (500 lb) and to compensate for drill

[1] Storms, M. A., Natland, J. H., et al., 1991. *Proc. ODP, Init. Repts.,* 132: College Station, TX (Ocean Drilling Program).

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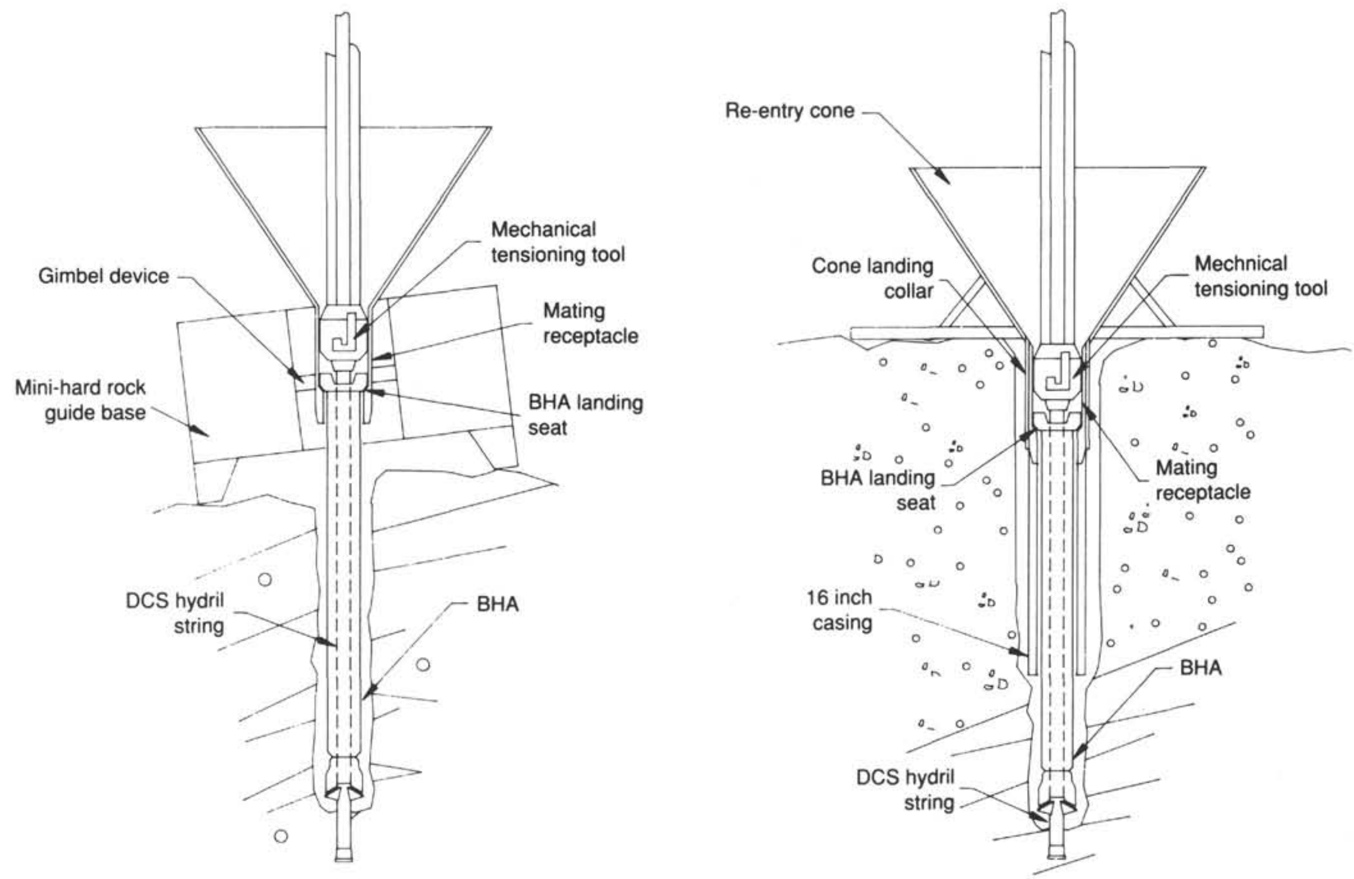


Figure 1. Comparisons of seafloor deployment systems.

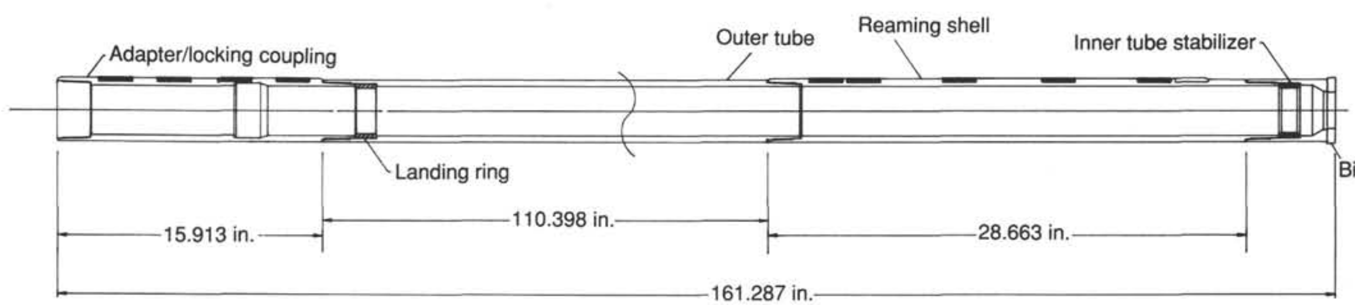


Figure 2. Outer core barrel assembly.

ship motion resulting in total heave of ± 300 mm (12 in.) at the DCS platform. This secondary system is rated for 68 metric tons (15,000 lb) of working tubing string weight.

CORE BARREL DESIGN FEATURES

Outer Barrel

The outer core barrel system was adapted from much of the work that Longyear performed in developing Amoco's SHADS. This system was designed for the more rugged use typically found in the oilfield. It is much more robust than conventional mining type coring systems, but it was able to retain many of the features that have allowed high recovery rates noted in the diamond coring industry. Several of the design features incorporated into ODP's system include:

1. In-hole stabilization with extended-length reaming shells and adapter couplings,
2. Minimum restriction of fluid passageways on the reamers/adapter couplings,
3. Stabilizers with both surface-set diamond and tungsten carbide pads,
4. Proven Longyear CHD 101 thread connections,
5. Adaptation of the locking coupling and adapter coupling into one piece, and
6. Ability to run conventional HQ-3 size inner barrels by changing the landing ring, inner tube stabilizer, and bit.

Reaming shells manufactured for Leg 132 consisted of two types of pads placed on the exterior surface of the shells. Pads consisted of both surface-set diamonds and tungsten carbide in-

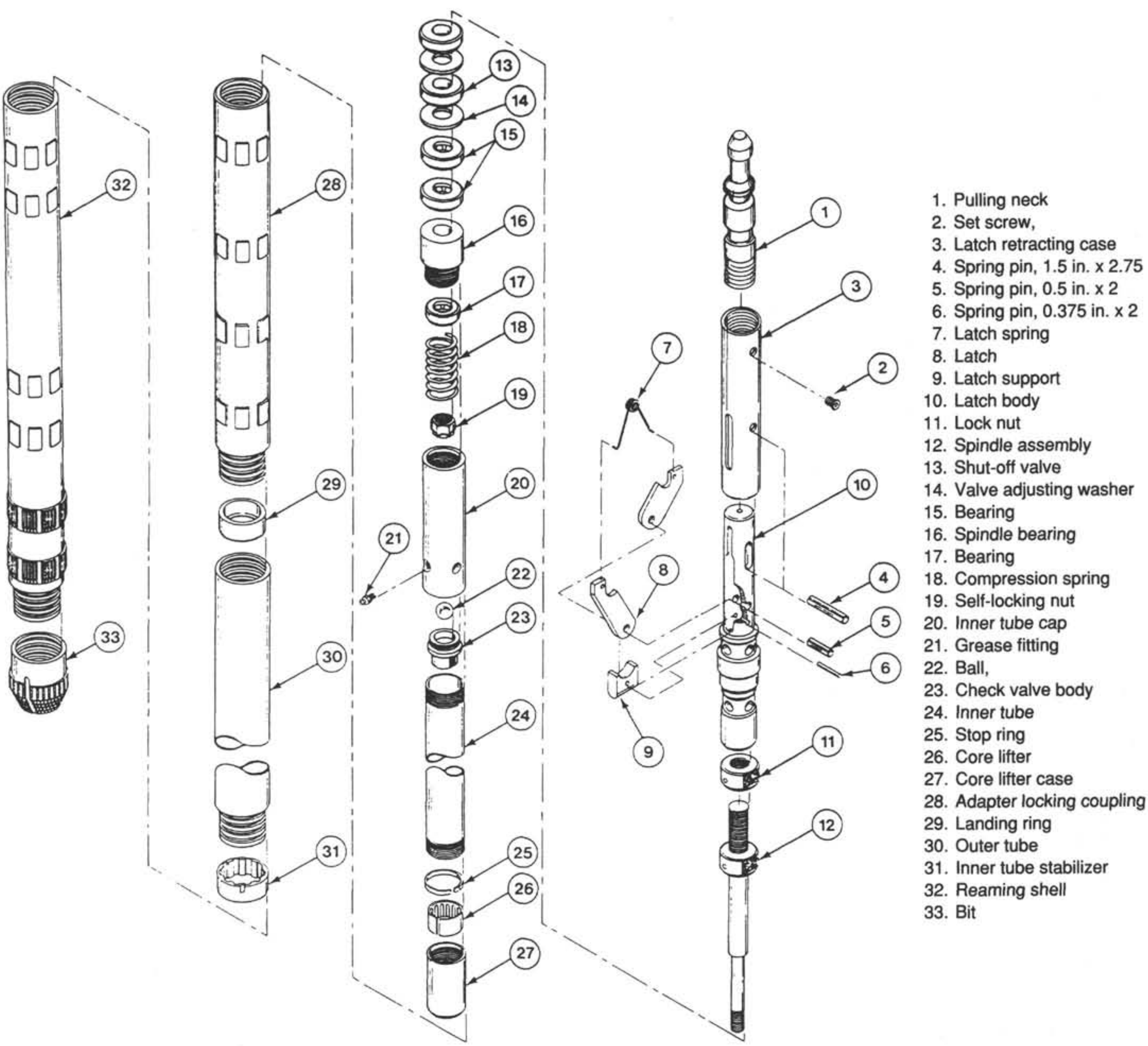


Figure 3. DCS core barrel assembly.

serts. Six sets of five pads each were provided on the rounded pentagonal-shaped reaming shells at approximately 72° apart. Typical pad width was 16 mm (0.625 in.). There were two different types of reamers made. These consisted of both single and double rows of diamonds pads on the first two sets of the six rows of pads.

Locking adapters were designed with four rows of five pads each using the same rounded pentagonal shape as the reaming shells. The locking adapters were designed incorporating both the locking couplings and the adapters couplings into one piece. This strengthened the core barrel by eliminating one connection in the downhole assembly. As the name implies, the locking adapter houses the receptacle where the inner core barrel latch locks into the outer core barrel. Another design feature built into the locking adapter was rotation tabs. These tabs were used to lock the center bit driver rod assembly so it will rotate with the outer barrel if a drill-ahead mode is desired.

Two lengths of core barrels were made so that both 1.5 and 3 m (5 and 10 ft) cores could be cut. This was primarily done since space-out dimensions of the DCS mast were not finalized before placing the order for the core barrel. The barrel itself is basically a transition section of pipe to attach the reamer and adapter coupling together. The only difference is a recessed lip inside the box end where the landing ring is situated.

Inner Barrel

A conventional Longyear HQ-3 barrel was the starting point for modifications to the inner barrel. The general design of the barrel was left unchanged, however, the overall size had to be reduced so that it would pass the internal diameter of the tubing

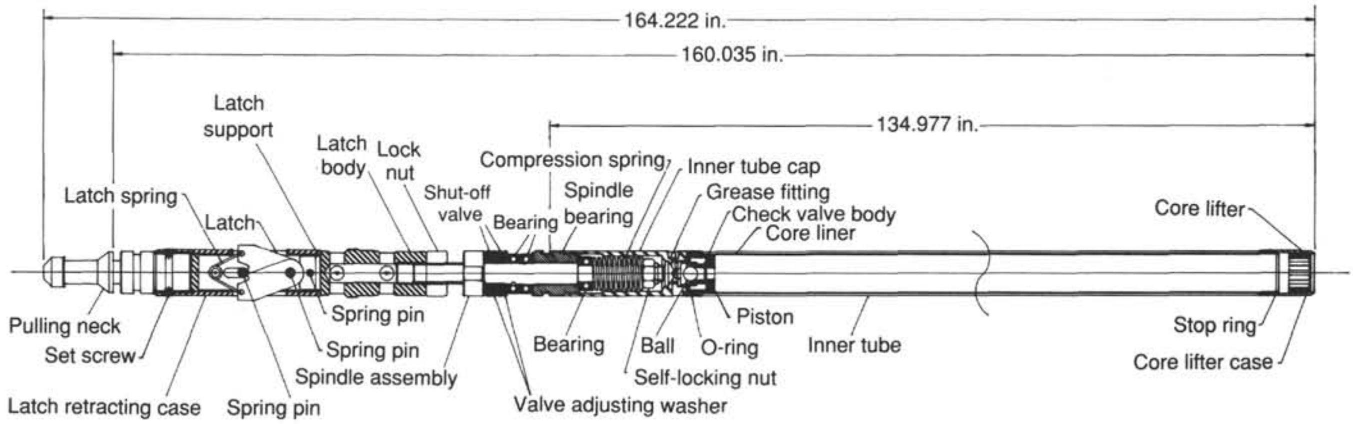


Figure 4. Inner core barrel assembly.

string. The smallest restriction of the tubing is 74.73 mm (2.942 in.) at the tool joint. Therefore, the largest outside diameter of the inner barrel which could be effectively run was 73 mm (2.875 in.). This dimension was at the landing shoulder. The annular clearance between the inner barrel landing shoulder and the tool joint I.D. was 0.851 mm (0.0335 in.). With the landing shoulder O.D. limited, the largest inner tube diameter that could be run became 66.675 mm (2.625 in.). Allowing for clearances and wall thickness of the tubes, the largest core that then could be taken was set at 55.80 mm (2.200 in.). All the dimensions of both the inner and outer barrels are presented in Table 1.

Several modifications were made to the inner barrel in addition to reduced dimensions to adapt it to the more rugged environment of oilfield use. Some of these changes include:

1. An Otis pulling neck incorporated into the retrieval system,
2. Landing shoulder contact width increased to 2.819 mm (0.111 in.),
3. Core lifter case modified to allow liner to be held at the entry end of inner barrel,
4. Spindle assembly slotted with wear groves to allow visual observation of landing seat contact area wear,
5. Larger ball check valve added to improve flow in and around the latch body,
6. Dual shut-off valves to signal core blockage,
7. Inner barrel adaptable to both split steel and tenite butyrate core liners, and
8. Increased spindle assembly arm to allow a fuller range of gauge adjustments.

Diamond Core Bits

Background

Several manufacturers of diamond core products were contacted concerning supplying the diamond core bits for the DCS core barrels. The primary vendors who showed an interest and responded to ODP's request for quotation included: (1) Longyear Company, (2) Huddy International, and (3) Diamatec Incorporated. Since the formation/material type at each location was reasonably well known, the bit selection was tailored for each site. Each manufacturer was requested to recommend three types/series of bits for each location that would cover the range of drilling parameters expected. Since each location presented different types of formations to be cored, bits from each of the three different categories of diamond bits were selected. These categories included: (1) natural diamonds, (2) synthetic grit, and (3) polycrystalline diamonds (PCD).

Natural diamonds are used in all surface-set bits. These bits are selected based on the number of stones per carat (SPC) along with the quality of diamonds used. Typically, the greater the SPC (smaller diamonds), the harder the formation the bit will effectively cut. Another important feature found in these types of bits is the bit profile. Selection of the profile is based on the individual characteristics of the formation to be cored. Figure 7 presents the typical profiles available for surface set bits with the appropriate identifying letter and a brief description of the intended use.

Synthetic grit is the medium normally used for the cutting structure in the impregnated type of bit. The quantity of diamonds in an impregnated bit is defined as concentration. It is usually expressed as the volume of diamonds per unit volume of the impregnated matrix. Various thickness of matrix can be specified along with the number of threads per inch on the face (V-grooves), face discharge ports and the length of the threads (i.e., distance the particle has to travel before entering the waterway). Some manufacturers (Huddy and Diamatec) also use a notched thread design (turbo design) to further shorten the distance that cuttings must travel before entering the watercourse. The diamonds used in impregnated bits are mainly cubo-octahedral in shape.

The polycrystalline diamond consists of many small diamond crystals bonded tightly together. These bits are ideal for drilling in sedimentary-type formations. PCD bits are still fairly new in the mining industry even though they are widely used in the oilfield at the present time.

Diamond Bits Selected for Leg 132

Impregnated bits were the main choice of all three manufacturers for two of the locations (Bonin and MIT Guyot), and surface-set diamond bits were recommended only for Shatsky Rise. An impregnated bit comparison chart is presented in Table 2. This chart is arranged by manufacturer for the full range of bit matrix and rock type recommended for impregnated bits.

Based on the response from the bit manufacturers, the following impregnated bits were selected for evaluation on Leg 132.

1. Longyear: Series 6
2. Longyear: Series 2
3. Huddy: Silver Blue
4. Huddy: Yellow
5. Huddy: Gold
6. Diamatec: M6
7. Diamatec: M4

Two profile types of surface set bits were selected for the Shatsky Rise location. These included a X profile and a modified

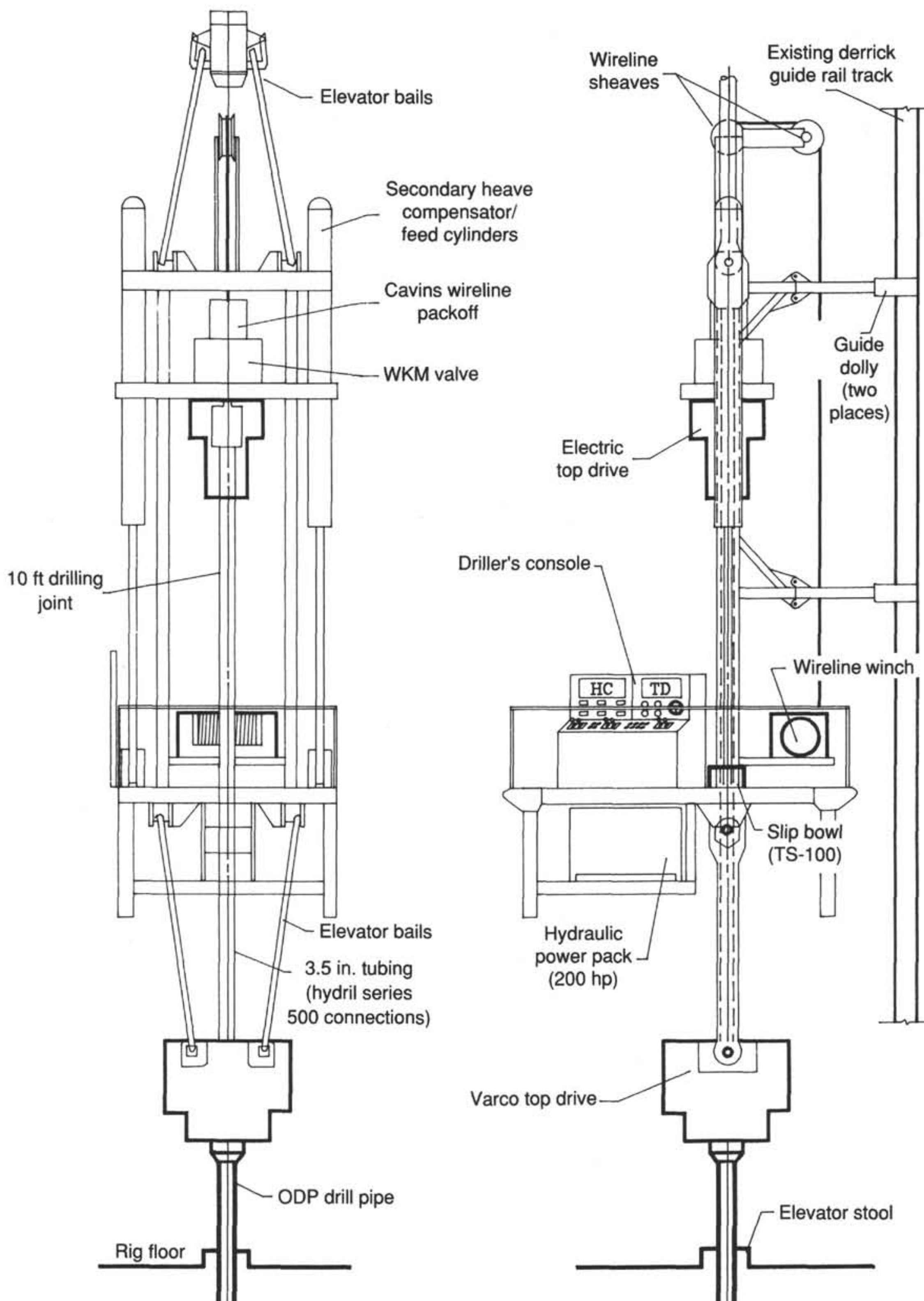


Figure 5. Diamond coring system platform configuration (Phase II, 4,500 m depth capacity).

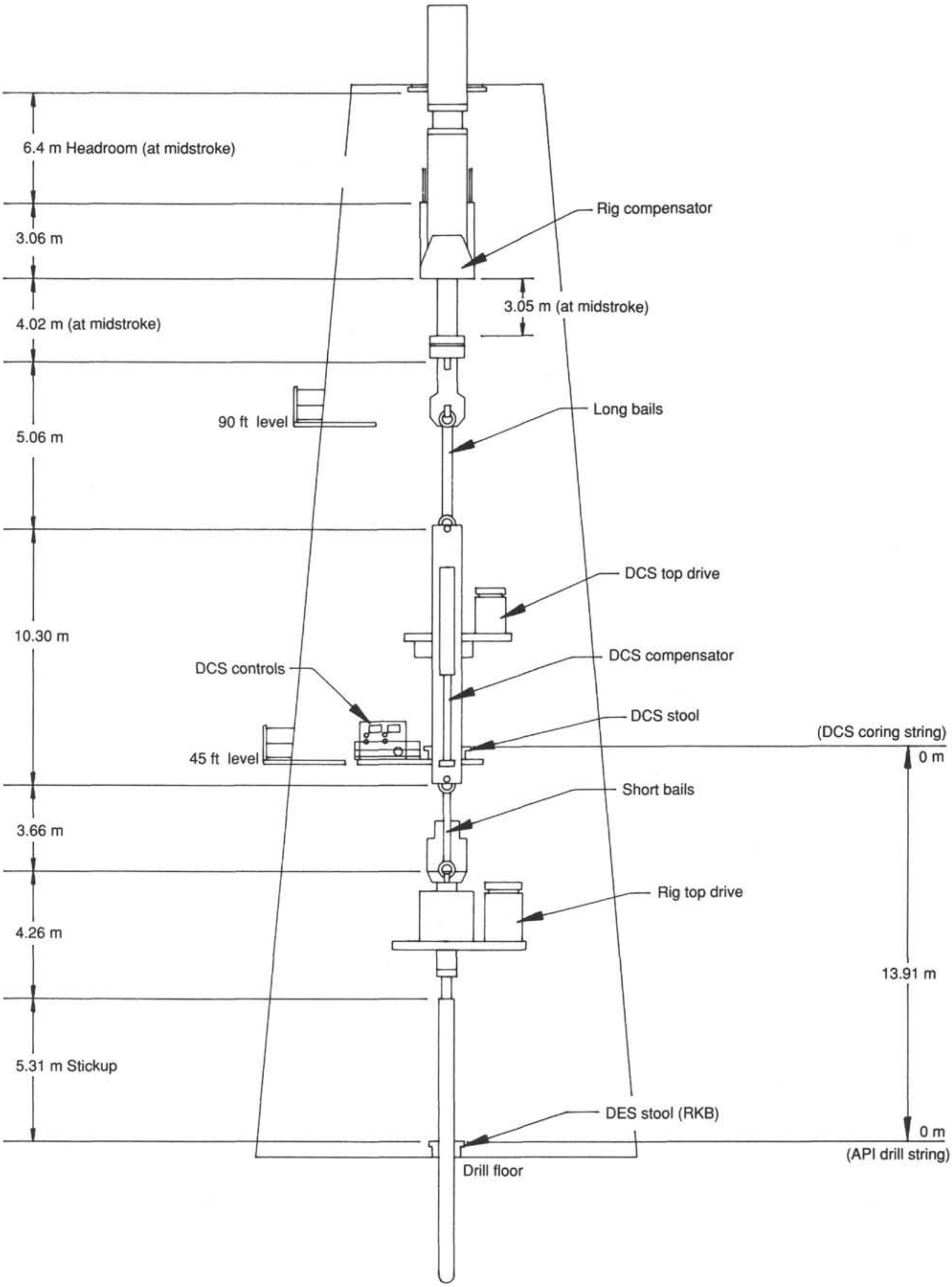


Figure 6. DCS derrick stack-up.

Table 1. DCS core barrel dimensions (in inches except barrel length in feet) for Longyear modified HQ-3.

Hole size	3.960
Core size	2.200
Outer tube, O.D.	3.625
Outer tube, I.D.	3.063
Outer tube wall thickness	0.281
Inner tube O.D.	2.625
Inner tube I.D.	2.375
Inner tube wall thickness	0.150
Liner O.D.	2.343
Liner I.D.	2.243
Liner wall thickness	0.048
Barrel length(s)	5 and 10
Landing shoulder width	0.111
Landing shoulder impact area	0.871
Radius (Hole O.D./Core O.D.)	1.80
Bit kerf width	0.88

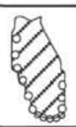
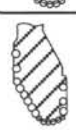
Profile	Letter	Description
	A	Fully round (standardized by DCDMA). Strong setting at gauges.
	B	Semiround (standardized by DCDMA). Standard for majority of non-step core bits. Exceptional strength of very hard broken ground. Requires high bit loads.
	No	Step (standardized by DCDMA). Standard bit for wireline drilling; good penetration and stability in all but very broken formations.
	M	Tapered pilot. Good in most formations. Stable with strong I.D. and O.D.
	W	Part-round profile: very strong O.D. gauge, good for rough drilling and collaring.
	X	Narrow pilot. Particularly good core recovery in soft, friable formation, especially when used with face discharge waterways. Good stabilization. Low vibrations.

Figure 7. Surface-set diamond bit profiles.

X profile. The modified version having a slightly thicker pilot tip than a conventional X profile. A list of the surface-set bits brought for Leg 132 include:

1. Longyear: 35/45 SPC, X profile
2. Longyear: 25/35 SPC, X profile
3. Longyear: 15/25 SPC, X profile
4. Huddy: 25/40 SPC, modified X profile
5. Huddy: 18/20 SPC, modified X profile

Due the cost of PCD bits and because there are not as many data to support their performance as the more conventional-type diamond bits (surface-set and impregnated), only one PCD bit was purchased. This bit was manufactured by Hobic, a Huddy-affiliated company. It has a partly round profile (W) with 130 medium geoset PCD inserts. It is designated as a Syndax 3 bit by Hobic.

Tables for each site were prepared with the types of bits suggested in descending order of preference. In addition, recommended drilling parameters, including weight on bit, flow rate, and rpm, are included (Tables 3–5).

Drilling Mud Products

Drilling fluids used in diamond coring are as important as the coring equipment itself. Their effectiveness in coring a particular formation is related to the physical properties that the drilling mud exhibits. Drilling fluids must be selected depending on the formation type and material being cored. Several benefits that drilling fluids exhibit when coring are:

1. Clear cuttings from the bit and the bottom of the borehole,
2. Wall off permeable formations,
3. Control formation pressures,
4. Prevent washouts and hole stability problems, and
5. Cool and lubricate the bit.

Typical drilling and coring operations aboard the *JOIDES Resolution* use seawater as the drilling medium. Drilling fluids are used sparingly to sweep/clean the hole if the annulus begins to fill with cuttings or when hole problems develop. Drilling fluids used for this purpose are normally based on bentonite and/or barite.

Several drilling fluid companies and diamond bit manufacturers were approached for recommendations of drilling fluids for the three types of formations that were expected to be encountered on Leg 132. Space/storage limitations aboard the vessel were also considered as pertaining to what product or products would be most beneficial. The consensus from the companies was that a polymer-based drilling fluid should be used. Several reasons were given why a polymer should be used. These include:

1. Soluble in either salt water or drill water,
2. A small amount goes a long way,
3. Provides high carrying capacity to keep the hole clean,
4. Maintained similar weight properties to that of seawater or fresh water,
5. Viscosity could be increased quickly if required,and
6. Could be added to regular weighted drilling fluids if situation/formation required heavier mud.

After reviewing the different products offered, Barvis was the product selected based on the reasons given above and on the fact that it was not feasible to purchase three different products for each site planned. Barvis is distributed by N L Baroid, Inc.

Another concern centered around drilling fluids was what product to use, if any, to serve as a friction reducer or lubricator in the annulus between the API drill string and the DCS tubing. Excessive torque build-up in the tubing string with the added need for high rotational speed with the DCS top drive were two of the primary reasons why a further product was located. The drilling fluid companies were again approached for recommendations on this type of product. The product recommended was EP Mudlube. It is also a N L Baroid product.

CORE RUNS

Clearfield, Utah

The core barrel system was initially broken-in while the DCS was set up in Clearfield, Utah, during March 1990. Over 160 ft of

Table 2. Impregnated diamond bit comparison chart.

Rock type	Rock condition	Longyear	Christensen	Huddy	Diamatec	Sprague & Henwood	Hoffman	Acker	J. K. Smit	Minex
Ultrahard Jasperite	Competant	10 10D	Purple	H14 Super H	M8	Blue	Copper	Yellow	White	Black
Quartz Taconite	Nonabrasive	9	Black #2	H10			Bronze			
Very hard Quartzite Granite Diorite	Competent Nonabrasive	8D	Black #1	H8 Gold	M7	Tan Gold	Red	Gold	Orange Yellow	Gold
Gneiss Rhyolite Gabbro	Competent or broken abrasive	6	Tan	H6 Yellow Orange	M6	Silver	Gray	Silver	Gold Red	Silver
Hard to medium hard	Economy bit	4		Red	M5	Yellow	Blue	Orange	Green	Blue
Andesite Peridotite Gabbro	General drilling	2/3	Gray	Green Silver Blue	M4	Green	Green	Blue	Green	Green
Schist Pegmatite	Broken abrasive	1	Green	Blue		Red	Super Green	Green	Blue	Red
Weathered granite	Extremely broken, fractured	1D		Black		Brown		Black		

Note: Exact determination by series or colors selection is not always possible for certain geological conditions.

Table 3. Suggested diamond coring bits–Bonin back-arc.

Bit	Type	Description	Profile	SPC	Quality	Weight on bit (kip)	Flow rate (gpm)	RPM	Optimum drilling conditions
1	Longyear	Series 2–Ahozud/1	Impregnated	NA	NA	4–8	15–40	150–250[a]	General drilling
2	Huddy	Silver-blue	Impregnated	NA	NA	5–9	20–35	500–1000[b]	Abrasive, solid to moderately hard
3	Longyear	Series 6–Ahozum/2	Impregnated	NA	NA	4–8	15–40	150–250[a]	Competent or broken abrasive
4	Huddy	Yellow	Impregnated	NA	NA	5–9	20–35	500–1000[b]	Hard to very hard, medium to fine grained, solid, slightly abrasive
5	Longyear	Surface-set–Ahob61	X	25/35		4–8	15–40	150–250[a]	
6	Huddy	Surface-set	Modified X	25/40	AA-37 cts	5–7	20–35	500–1000[b]	
7	Diamatec	M4	Impregnated	NA	NA				General drilling

Notes: Make-up torque should not exceed 5000 ft/lb. Flows rates are not to fall below 10 gpm. Techniques to sharpen while drilling include: reduce rpm, increase weight on bit, reduce fluid flow; add silica sand/carbide grit. Sharpen techniques while on surface by sand blasting. Use bit with a break-in period, start with 25% bit weight for 30 min, then 50% bit weight for next 30 min, then increase weight on bit to achieve optimum penetration rate.
[a] Times bit diameter in inches.
[b] Maximum achievable without vibration.

Table 4. Suggested diamond coring bits–Shatsky Rise.

Bit	Type	Description	Profile	SPC	Quality	Weight on bit (kip)	Flow rate (gpm)	RPM	Optimum drilling conditions
1	Longyear	Series 6–Ahozum/2	Impregnated[a]	NA	NA	4–8	15–40	150–250[b]	Competent or broken abrasive
2	Longyear	Surface-set–Ahob61	X	35/45	35 cts	4–8	15–40	150–250[b]	
3	Huddy	Surface-set	Modified X	25/40	AA-37 cts	5–7	20–30	500–1000[c]	
4	Huddy	Surface-set	Modified X	18/20	AA-43 cts	5–7	20–30	500–1000[c]	
5	Huddy	Yellow	Impregnated	NA	NA	5–9	20–35	500–1000[c]	Hard to very hard, medium to fine grained, solid, slightly abrasive
6	Huddy	Gold	Impregnated	NA	NA	5–9	20–35	500–1000[c]	Extremely hard, fine grained, solid nonabrasive
7	Diamatec	M6	Impregnated	NA	NA				Competent or broken abrasive

Notes: Make-up torque should not exceed 5000 ft/lb. Flows rates are not to fall below 10 gpm. Techniques to sharpen while drilling include: reduce rpm, increase weight on bit, reduce fluid flow; add silica sand/carbide grit. Sharpen techniques while on surface by sand blasting. Use bit with a break-in period, start with 25% bit weight for 30 min, then 50% bit weight for next 30 min, then increase weight on bit to achieve optimum penetration rate.
[a] Depends on degree/thickness of chalk and chert interbeddding.
[b] Times bit diameter in inches.
[c] Maximum achievable without vibration.

Table 5. Suggested diamond coring bits–MIT Guyot.

Bit	Type	Description	Profile	SPC	Quality	Weight on bit (kip)	Flow rate (gpm)	RPM	Optimum drilling conditions
1	Longyear	Series 2–Ahozud/1	Impregnated	NA	NA	4–8	15–40	150–250[a]	General drilling
2	Huddy	Silver blue	Impregnated	NA	NA	5–9	20–35	500–1000[b]	Abrasive, solid to moderately broken
3	Longyear	Surface-set–Ahob8	X	15/25	40 cts	4–8	15–40	150–250	
4	Huddy	Surface-set	Modified X	18/20	AA–43 cts	5–7	20–30	400–10006[b]	
5	Huddy	Surface-set	Modified X	25/35	AA–37 cts	5–7	20–30	500–1000[b]	
6	Hoble	Syndax 3—medium geoset	W	NA	130 Geoset	10–15[c]		250	Competent formation
7	Diamatec	M4	Impregnated	NA	NA				General drilling

Notes: Make-up torque should not exceed 5000 ft/lb. Flows rates are not to fall below 10 gpm. Techniques to sharpen while drilling include: reduce rpm, increase weight on bit, reduce fluid flow; add silica sand/carbide grit. Sharpen techniques while on surface by sand blasting.
[a] Times bit diameter in inches.
[b] Maximum achievable without vibration.
[c] Use bit with a break-in period, start with 25% bit weight for 30 min, then 50% bit weight for next 30 min, then increase weight on bit to achieve optimum penetration rate.

cement was effectively cored with both 5 and 10 ft core barrels. Recovery was close to 100% on every run. The complete core barrel system was checked including the new mini-jar and overshot/retrieval hardware. There were only two minor machining errors on the core barrels themselves that had to be changed during the testing/evaluation period. All parts fit as they should and were interchangeable throughout; the only exception being the split steel liners.

Bonin Back-Arc

The first location (Bonin) that was to be cored during Leg 132 was expected to be the most difficult in terms of hole stability and hardness of formation. This proved true during the drilling operations for the two test holes (809A and 809B) as well as during the drilling-in of the bottom-hole assembly (BHA) with the back-off sub on Holes 809C through 809F. The first 6 m (20 ft) of penetration were relatively easy drilling. This was confirmed in all the holes (A–F) in the general area. However, beyond 6 m (20 ft), hole stability problems were experienced but not immediately recognized as the problem. The drilling difficulties were partly masked by the fact that the guidebase and/or casing hanger had exceeded its designed tilt limitation and/or shifted putting the drill string in a bind. Therefore, the problems experienced in drilling the holes down were thought at the time to be caused totally by the inclination problem and not borehole stability.

Borehole 809C was abandoned when the BHA was backed off prior to reaching the desired penetration depth, requiring the mini-HRB to be moved to begin another hole. Hole 809D was established but abandoned due to a latch dog on the jay-tool breaking off and becoming lodged in the BHA. Excessive tilt caused by the guidebase shifting and by hole problems forced the guidebase to again be moved from Hole 809E. Hole 809F was finally established with the BHA set only 6 m (20 ft) below the seafloor. Elevations of the hard rock guidebase for the Bonin site are presented in Figure 8. A summary of the attempts to drill-in and back off the BHA is presented on Table 6.

Diamond Bit Run 1

With a cased hole finally established for coring, the core barrel was run on the tubing to just inside the bit of the BHA string. Prior to actually beginning coring, some trial touch-downs were performed to test the secondary heave compensator. After these tests were run, the inner barrel was pulled because of an excessive amount of pressure registering on the gauge. It was found that several pieces of fractured basalt had jammed into the throat of the barrel. Another barrel was then sent down and the first core run was made. The average penetration rate was 2.1 m/hr (7 ft/hr). This was with a rotation of 80 rpm, approximately 682 kg (1500 lb) weight on bit, and with a flow rate of 20 gpm. However, after the first few centimeters the penetration rate increased dramatically. The run was finally stopped after the computer retracted the bit off the bottom the third time during the run. This occurred when the bit weight exceeded the lower limit (–455 kg/–1,000 lb)

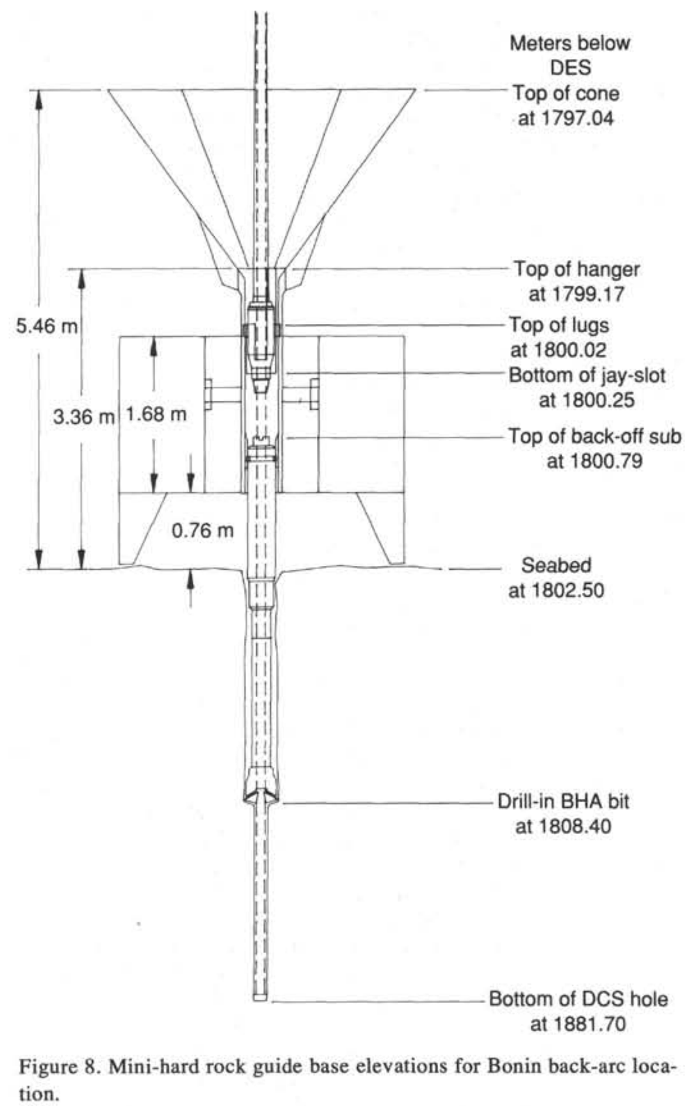


Figure 8. Mini-hard rock guide base elevations for Bonin back-arc location.

Table 6. Boreholes drilled at Bonin back-arc.

Description	809A	809B	809C	809D	809E	809F
Depth of penetration (m)	8.3	13.4	4.1	6.3	8.0	5.9
Supported spud-in	no	no	yes	yes	yes	yes
Bit size (in.)	11-7/8	9-7/8	11-7/8	11-7/8	11-7/8	11-7/8
Center bit (in.)	4.0	4.0	4.0	4.0	4.0	4.0
Center bit position	1.75 ahead	1.75 ahead	1.5 behind	1.5 behind	1.5 behind	1.5 behind
Type of hole	test	test	DCS	DCS	DCS	DCS
Hours of rotation	7	9	1.75	0.8	14	0.5
Reason for abandoning hole	completed	completed	excessive tilt of HRB	latch dog in BHA	HRB shifted, excessive tilt	completed
Hours on site	30.25	21.0	209.75	82.75	33.25	471
DCS run	no	no	no	no	no	yes
DCS bit run 1	n/a	n/a	n/a	n/a	n/a	8.4
DCS bit run 2	n/a	n/a	n/a	n/a	n/a	64.9
Total recovery	n/a	n/a	n/a	n/a	n/a	15.18%
Total hours coring	n/a	n/a	n/a	n/a	n/a	19.92

of the preset weight on bit programmed into the computer. The penetration was so fast at this point that the computer could not keep up with initial settings. Core recovery reveled that the bit had cut a clean hole but that some core was missing from the end of the run confirming that some voids and loose material were being encountered. Two more runs were then made without any successful recovery. Penetration rates were much faster than the previous two runs with average rates of 9.7 and 24 m/hr (32 and 79 ft/hr). Drilling parameters were held constant with the exception of an increase in rotation to 100 rpm.

At this point it was suspected that something might be wrong with the core barrels (i.e., not latching-in or the core catcher not working properly). Several attempts were made with a bit deplugger to remove any core that may have blocked the core bit and prevented the barrel from latching-in. A center bit assembly was also run and the barrel drilled back to the bottom of the hole. Upon recovery it was observed that it had not latched-in but rather rotated inside the barrel while drilling down. The center bit was run two more times with similar results. Excessive pump pressures also indicated that something was causing a restriction in the throat of the bit and/or core barrel. The barrel was then raised up inside the stress joint where pump tests indicated that it was clear after another deplugger was run. The barrel was again dropped and washed back down to the bottom of the hole. Approximately 3 m (10 ft) of fill were detected each time the bit was washed back down to the bottom of the hole. It was discovered through the final pump tests that the core barrels themselves were causing the higher pressures and not any obstructions in the bit. At this point it was thought that the problem may be due to too tight a gauge for the formation, but it was later confirmed that the bit matrix had eroded away to such an extent that the flow path was almost nonexistent when placed on the bottom of the hole. This was demonstrated by opening the gap setting an additional 16 mm (5/8 in.) and rerunning the flow tests. This adjustment increased the flow considerably and pressures were again noted close to where they had originally been measured prior to coring. The bit was well off the bottom of the hole during these tests. With these changes made, the core barrel was again washed down to the bottom of the hole. Penetration through the rubble zone was slow and required the bit to be rotated. Four attempts to core were made with limited success. Penetration rates for these four runs ranged between 0.1 and 0.4 m/hr (0.3–1.3 ft/hr) with pressures higher than should be expected. Some pieces of the rubble were brought up in one of the barrels confirming that a breccia layer was indeed present between the depths of 6.6 and 13.4 mbsf (21.7–44 feet). It was finally decided that the bit had most likely been damaged due to the repeated drilling it had done through the rubble zone, evidenced by the higher pressures experienced as soon as the bit touched bottom. Furthermore, any additional attempts at coring with it could leave the bit matrix in the hole and require the hole to be abandoned. At this point, it was decided to pull the tubing string, change the bit, and inspect the core barrel to answer some questions raised during the initial core runs.

Diamond Bit Run 2

The core barrel came out in nearly pristine condition with the exception of the bit. Almost all the impregnated matrix face was worn away. Flow ports were less than 1.5 mm (1/16 in.) from being altogether worn away, confirming the suspicions behind high pump pressures. Both the internal and exterior gauge of the bit were completely gone. Inspection of the core barrel's landing ring showed no signs of wear. There were, however, two small holes on the reamer shell about 1.5 mm (1/16 in.) in diameter and depth where filler material holding the surface-set diamond pads had worn away. The inner barrels were all regauged after changing the core bit. Due to the abrasive nature of the basalt, it was also decided to change the reamer shell as an added measure against any further deterioration of the small holes found in the material holding the pads in. The core barrel was reattached to the tubing and run back in the hole. The center bit was left in so that the core barrel could be drilled down to the bottom of the hole without taking the chance of plugging off the core bit.

The borehole was cleaned out with the center bit in what appeared from the way it drilled to be competent solid material. Three short cores were then cut, but excessive pressure and/or core blockage prevented penetrating more that a few inches each time. Weight on bit had to be gradually reduced to 500 lb in order just to maintain some flow and keep the barrel from immediately jamming. Flow rates associated at this weight on bit were running 50–60 gpm and 200 rpm.

All three the drilling parameters at this point in the program were different from when coring was initiated and different from those recommended by the diamond bit manufacturer. Something downhole was not allowing the core to drill as it should. The bits being used were ruled out as the problem since they were designed to take weights between 1,818 and 3,636 kg (4,000–8,000 lb). Bit speed also had to be ruled out as suspect since bits were designed to run at rpm's of 800–1,000. Therefore, the problems being experienced with the high pressure could only be caused by flow being shut off to the bit. Further investigation revealed that higher-than-recommended flow rates were probably the reason for the drilling difficulties. This was caused by the inner barrel's core lifting case being forced into the throat of the bit and consequently shutting off flow. This engagement would normally occur when the bit is picked up off the bottom of the hole to break the core. The barrel is designed so that the force required to break a core is carried in the bit and not through the core barrel's bearing assembly. The internal spring used to engage the shut-off valves serves a dual function in that it also allows the barrel to move down to protect the upper assembly when the core is broken. To ensure that this would not be recurring at the higher flow rates that were felt needed, the gap setting was also brought back another 6.35 mm (0.25 in.). This appeared to solve the immediate problem and allow coring to proceed.

These diamond bits were designed for flow rates between 10 and 40 gpm. Reducing the flow rates to the designed level and using the correct gap setting probably would accomplished the same results, if not better, instead of using the high rates and a larger gap setting. High flow rates have always been normal in the oilfield to remove the large cuttings caused by the type of bits traditionally run. However, cuttings from mining-type diamond bits tend to be more much fine. This is further confirmed by the size of annulus in which the cuttings can escape. Extensive testing on flow rate has been done on this type and size of bits so that a fairly narrow range exists for maximum performance. However, it was felt that higher flow rates might be needed so as not to damage another bit and because this application might be out of the normal operating limits suggested by the bit manufacturers.

It was pointed out that the larger gap setting and the higher flow rates might be two reasons core jams were continually occurring in the fractured basalt. The effect of running too high a flow may have forced fractures in the rock to open slightly. This, combined with too large a gap setting by not allowing the core to be immediately captured, may have lead to the barrels plugging off prematurely. The core barrels and drilling parameters were gradually brought back to where they were originally set and to the manufacturers recommended guidelines. However, the problem seemed to be more an matter of holding the material inside the barrel than effectively cutting a core.

Below 35 mbsf the recovery went to zero. The driller couldn't keep any weight on bit between 35 and 42 mbsf (115–138 ft) as the core barrel drilled/fell through 3 m (10 ft) intervals in less than 10 min each. Voids were suspected as the main reason for the fast penetration rates since the weight on bit was minimal. Some different drilling parameters were again initiated but recovery remained at zero. Eventually some weight was reestablished on the bit below 42 mbsf (138 ft) but recovery still remained at zero. The material drilled/acted like fine sand/breccia observed earlier in the borehole. It was felt that it may be so friable that it was washing away before entering the core barrel. This was observed when the center bit was run and it was retrieved from being drilled 6 m (20 ft) without the paint even being scratched from its face.

A number of different core catching schemes were tried along with reducing the flow rates almost to zero, increasing the mud viscosity, cutting flapper valves into the liner, introduction of socks into the liner, greasing the liner, and using a floating check valve. However, none of the techniques yielded enough material to really provide the scientist with any concrete clues other than the material composition had changed along with color and density. The boring was finally terminated at 79.2 mbsf (260 ft) when the penetration rate again fell to almost zero indicating probable bit failure. It was also felt that the formation was atypical of what would be found at future sites (East Pacific Rise, in particular) where DCS coring was planned. Therefore, in an attempt to save time on the remaining portion of the leg, it was decided to abandon further drilling and to move onto Shatsky Rise to test the DCS in a different formation.

SHATSKY RISE

Shatsky Rise was selected as one of the sites because of the extremely low percentage of recovery reported in past attempts to core the interbedded Mesozoic sequences of layered chert-porcellanite and chalk with alternating hard and soft characteristics. Past experience with conventional rotary coring techniques in this area have shown that the chalks were being washed away prior to encountering the chert layer, then when reached, the chert would usually cause a core jam when the drill bit broke through the chert after coring partially into the layer. This washing/jamming sequence was mainly caused by inadequate bit design, too high flow rates, and excess weight exerted on the bit.

To correct the problem when breaking through, specially designed surface-set diamond bits were manufactured with a pilot-type crown. This design allows a narrow pilot to be cored ahead of the main bit body so that the full weight of the bit is distributed over two distinct areas (Table 2). The change would allow the bit to core its way out of the chert layer before breaking off a section (usually triangular) and causing a core jam. Two types of pilot bits (Longyear X-profile and Huddy modified X-profile) were brought for this site. While each has some distinct characteristics, the Longyear bit was selected as the first one to try for this location.

This location used a modified version of ODP's reentry cone to establish a seafloor platform for the DCS coring to be initiated. Three borings were performed at the location prior to setting the reentry cone in order to determine where the first chert sequence would be encountered. The APC was run to 127.1 mbsf (417 ft) before the chert was located. Material recovered above the chert was soft to firm calcareous silt and chalk. Based on the depth where the chert was found, it was decided to set the 16 in. surface casing to approximately 50 mbsf (164 ft) and drill the BHA to 111 m (364 ft) beyond the casing. This would allow the DCS 16 m (52.5 ft) of softer material to core before encountering the chert. This overlap could then be used as a comparison against the APC samples from the same depths.

The plan to set casing was aborted when the casing broke free of the casing hanger while still in the moonpool. It was then decided to continue with the deployment of the reentry cone but rather than using the casing, just the BHA would be run. Weight needed for tension would be provided by using all drill collars (instead of drill pipe) and weighting the reentry cone with ingots left over from the ballasting of the mini-HRB. The reentry cone was deployed and landed without incident. However, in trying to establish the drill-in BHA, some problems were encountered. The BHA was finally backed off, but failure of the C-ring lead to the loss of the BHA below the conductor pipe. This prohibited the BHA from being reentered to retrieve the center bit. Therefore, the hole at Shatsky Rise was abandoned without any attempt at coring with the DCS. A schematic of the reentry cone along with the elevations for the proposed casing and BHA are presented in Figure 9.

FIELD PERFORMANCE

Core Barrels

The whole core barrel system worked as designed and presented very few problems throughout the leg. The total amount of core recovery for the Bonin site was well below what would normally be expected with this type of system. However, the formation found at the Bonin was atypical of what was thought to be there. The recovery percentages did approach over 60% at one time when coring in the young fractured basalt. This percentage is still lower than desired, but probably quite realistic when the amount of void space and the vesicular nature of the formation are taken into account. It should also be pointed out that the DCS was not fully operational when most of the actual coring was performed at Bonin but was being operated in a computer-assisted manual mode. This may have contributed some to the lower

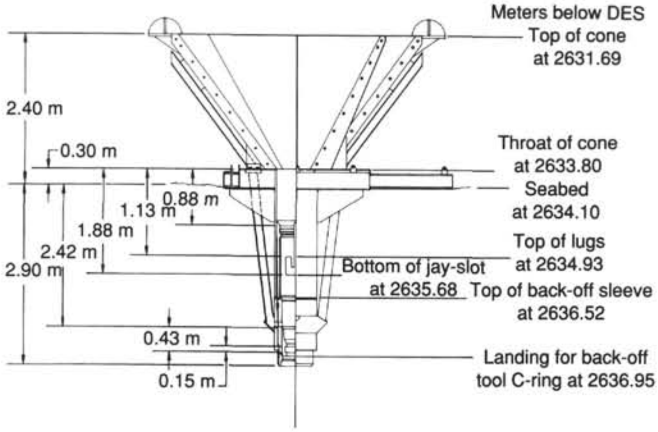


Figure 9. Reentry cone elevations for Shatsky Rise.

recovery, but was not thought to have influenced the recovery by more than a few percent.

Over 20 hr of rotation was placed on the system at the Bonin locations with the following drilling parameters used:

Weight on bit: 500–4,500 lb
Rotational speed: 80–300 rpm
Flow rate: 10–50 gpm

A summary of each core run with the drilling parameters and intervals drilled is presented in Table 7.

It was difficult to make fine adjustments to the core barrels and drilling parameters even when they were within the guidelines recommended by the manufacturer because of the highly variable nature of the material drilled. It was only when breccia or friable material was encountered that recovery dropped significantly. Several makeshift/"quick fix" adjustments/modifications to the barrels produced mixed and limited success. What worked on one run didn't work one the next. The collet-type core catcher worked effectively in catching the massive, fractured basalt at the Bonin location but did not work at all in the material encountered below 32 mbsf (105 ft). Even though no appreciable recovery was reported below this depth, it should not be perceived that the core barrel itself is ineffective for coring this material. A proper spring-type valve or possibly a flapper valve most likely would have produced better results. Some different types of makeshift core catchers were tried but did not produce any better results since much of the material was being fractured and washed away even before entering the throat of the core barrel.

The inner barrels were run both with and without liners to see if the liners might be preventing the material from remaining in the barrel. There was no indication that the liners affected the recovery at all. However, there were a couple of instances where the core liner became damaged when it was being extruded on deck by the piston. The damaged liner was originally thought to be caused by a core jam. The actual damage was most likely caused by some grit inside of the inner barrel not being rinsed with water before reloading the liner. Thus, when it was extruded on deck, the piston collapsed the liner before developing enough force to push the liner out. This has been noted as a common occurrence when core barrels are overdrilled, though this was not the case here.

Retrieval System

The new retrieval/overshot system developed for the core barrels was a vast improvement over that used on Leg 124. The system latched every time it was run. There were also no problems with centralization of the overshot onto the pulling neck. The compact design fit well within the limited space available and was easy to deploy through the top drive. The rope sockets withstood repeated trips to the seafloor without ever having to be changed or the wire rope rebabbited. There were no worn or damaged parts from all the wireline time spent retrieving the core barrels.

Diamond Products

Both of the impregnated diamond drill bits (Longyear Series 2) used on the fractured basalt at the Bonin location came back totally destroyed. It was fairly evident from the coring logs (Table 7) when failure occurred. The first bit was pulled after only 8.4 m of penetration. However, it had been repeatedly drilled through the breccia/rubble layer encountered just below the drilled-in BHA. Slightly over 5 hr of actual rotation time was on this bit before it was pulled. It should also be mentioned that this being the first time the DCS was used, some weight on bit and other drilling adjustments were made during these initial runs that probably had more to do with the bit being damaged than the formation.

The second bit drilled through 65.3 m (214 ft) of basalt, voids, and unconsolidated breccia with over 15 hr of actual rotation time. This bit most likely would have offered longer service; however, with time running out for the site and almost zero recovery for the last 45 m (148 ft), it was decided to reduce the flow rate and increase the weight on bit in an attempt to force material into the barrel. This produced the desired result, but was a calculated gamble that destroyed the bit as well.

Diamond coring is quite different from typical oilfield drilling. Weight on bit, flow rates, and rotational speed play a much greater role toward recovery in diamond coring than in conventional rotary coring. It would be misleading if the human factor was not mentioned as impacting the performance and life of these bits especially since this was the first time the DCS was deployed.

Drilling Fluids

There were no real drilling fluid problems experienced with hole stability or formations throughout the coring operations during Leg 132. Whether this was a direct result of the addition of the Baravis as the drilling fluid cannot be totally answered at this time. However, over 79 m (260 ft) of hole was cored in both hard and friable materials with some breccia layers encountered. The drilling fluids used appeared to keep the hole clean. At no time throughout the boring did the tubing string become stuck or create high torque problems while drilling. At one time Baravis was mixed with drill water and circulated through the annulus of the tubing and borehole. The differences in density of this material to that of the seawater mixture allowed the tubing string to siphon and backfill with cuttings when the pump was turned off. This problem was not experienced when using seawater as a mixing base.

The Baravis was mixed in varying concentrations both with seawater and drill water. The concentration which seemed to produce the best drilling fluid was 2 lb/bbl mixed with seawater. There was some lumping of the product but this was due to the mixing procedure not being followed properly. Once this was corrected, the situation cleared itself.

There was a significant improvement in the rotational speed that the tubing string could be rotated with the addition of the EP Mudlube into the annulus. Critical speed at which severe vibration began was around 100 rpm. However, after the addition of the Mudlube to the annulus, operating speeds of over 300 rpm were not uncommon. Mixing the Mudlube was much more difficult than the Baravis since it tended to float on the surface of seawater and caused irritation with prolonged exposure to the skin. Mixing directions stated that dispersants should be used to suspend the

Table 7. DCS core recovery at Bonin back-arc.

Core no.	Top (m)	Bottom (m)	Penetration (mbsf)	Advanced (m)	Cored (m)	Cumulative cored	Recovered (m)	Cumulative recovered	Recovery (%)	Cumulative (%)	Pump (spm)	Pressure (psi)	RPM	Bit weight (kip)	Time (min)
Seafloor	1802.5		5.9												
1Z	1808.4	1808.7	6.2	0.3	0.3	0.3	0.13	0.13	0.43	43.33	36	80	85	12	
2Z	1808.7	1809.4	6.9	0.7	0.7	1	0.85	0.98	1.21	98.00	10	285	80/117	1–3	20
3Z	1809.4	1811.5	9	2.1	2.1	3.1		0.98	0.00	31.61	10	360	100	1–3	13
4Z	1811.5	1813.1	10:6	1.6	1.6	4.7		0.98	0.00	20.85	10	200	100	1–2	4
5Z	1813.1	1815.9	13.4	2.8	2.8	7.5		0.98	0.00	13.07	10/20	150/380	100/180	1–2	58
Center bit	1815.9	1816.2	13.7	0.3	0.3	7.8		0.98	0.00	12.56	30	650/750	80/150	0.5–1.5	60
Center bit	1816.2	1816.2	13.7	0	0	7.8		0.98	0.00	12.56					
Center bit	1816.2	1816.2	13.7	0	0	7.8	0.98	0.00	12.56						
6Z	1816.2	1816.3	13.8	0.1	0.1	7.9	0.2	1.18	2.00	14.94	30	650	80	0.5–1.5	2
7Z	1816.3	1816.4	13.9	0.1	0.1	8	0.2	1.38	2.00	17.25	35	335	80/150	0–1.5	60
8Z	1816.4	1816.5	14	0.1	0.1	8.1	0.12	1.5	1.20	18.52	15	50/350	100/200	1–2.5	40
9Z	1816.5	1816.8	14.3	0.3	0.3	8.4	0.13	1.63	0.43	19.40	25	500/900	100/200	1–5	45
Totals per bit			14.3	8.4	8.4	8.4	1.63	1.63	19.40	19.40				5.07 hr	
Center bit	1816.8	1816.9	14.4	0.1	0.1	0.1	0	0	0.00	0.00	25	85	100	0.5–1	5
10Z	1816.9	1817.1	14.6	0.2	0.2	0.3	0.14	0.14	70.00	46.67	25	100–180	100	0.5–1	10
11Z	1817.1	1819.9	17.4	2.8	2.8	3.1	1.87	2.01	66.79	64.84	25	50–200	300	1–2	40
12Z	1819.9	1821.9	19.4	2	2	5.1	0.75	2.76	37.50	54.12	26	50–200	300/350	2–3	50
13Z	1821.9	1823	20.5	1.1	1.1	6.2	1.35	4.11	122.73	66.29	20	50–250	300	1–2	8
14Z	1823	1826	23.5	3	3	9.2	1.79	5.9	59.67	64.13	25	50–300	250	1–2	25
15Z	1826	1826.3	23.8	0.3	0.3	9.5	0.14	6.04	46.67	63.58	20	50–200	250/300	1–1.7	14
16Z	1826.3	1828.8	26.3	2.5	2.5	12	1.19	7.23	47.60	60.25	25	50–300	300	0.8–1.5	33
17Z	1828.8	1831.8	29.3	3	3	15	1.48	8.71	49.33	58.07	15	75–170	300	0–1.7	10
18Z	1831.8	1834.8	32.3	3	3	18	0.27	8.98	9.00	49.89	15	75–100	300	0–1.7	9
19Z	1834.8	1837.8	35.3	3	3	21	0	8.98	0.00	42.76	15	75–120	300	0–1.7	9
20Z	1837.8	1840.8	38.3	3	3	24	0	8.98	0.00	37.42	25	75–300	275	0–2	10
21Z	1840.8	1843.8	41.3	3	3	27	0	8.98	0.00	33.26	25	200–380	275	1–4.5	15
Center bit	1843.8	1844.1	41.6	0.3	0.3	27.3	0	8.98	0.00	32.89	20	75–280	125	1–2	15
22Z	1844.1	1846.7	44.2	2.6	2.6	29.9	0.09	9.07	3.46	30.33	10	55–180	100–150	0.5–1.5	26
23Z	1846.7	1847.2	44.7	0.5	0.5	30.4	0	9.07	0.00	29.84	10	80–170	100–150	1–1.8	23
24Z	1847.2	1849.7	47.2	2.5	2.5	32.9	0	9.07	0.00	27.57	10–15	130–150	300	1–2.5	26
Center bit	1849.7	1851	48.5	1.3	1.3	34.2	0	9.07	0.00	26.52	25	150–200	300	1	
25Z	1851	1853	50.5	2	2	36.2	0	9.07	0.00	25.06	20	150–250	250	1–3	20
26Z	1853	1856	53.5	3	3	39.2	0	9.07	0.00	23.14	10	100–200	100	0.5–4	100
27Z	1856	1861.8	59.3	5.8	5.8	45	0	9.07	0.00	20.16	5–7	30–90	80–250	1–2	90
28Z	1861.8	1864.4	61.9	2.6	2.6	47.6	0	9.07	0.00	19.05	5–7	30–60	200	1–3	95
Center bit	1864.4	1876.6	74.1	12.2	12.2	59.8	0	9.07	0.00	15.17	20	100–300	200	1–3	38
29Z	1876.6	1880.1	77.6	3.5	3.5	63.3	0	9.07	0.00	14.33	3–20	100–400	200	1–2	20
30Z	1880.1	1880.6	78.1	0.5	0.5	63.8	0	9.07	0.00	14.22	10–15	40–400	200–250	1.5–2	50
31Z	1880.6	1881.1	78.6	0.5	0.5	64.3	0	9.07	0.00	14.11	5–10–15	35–400	150–250	1.5–2.5	60
Center bit	1881.1	1881.2	78.7	0.1	0.1	64.4	0	9.07	0.00	14.08					30
32Z	1881.2	1881.3	78.8	0.1	0.1	64.5	0.08	9.15	80.00	14.19	30	100–500	200–300	1.5–2.5	15
33Z	1881.3	1881.7	79.2	0.4	0.4	64.9	0.01	9.16	2.50	14.11	20	100–400	200–220	1.5–4	45
34Z	Bit sample		79.2	0	0	64.9	0.34	9.5		14.64					
Totals per bit			79.2	64.9	64.9	64.9	9.5	9.5	14.64	14.64					14.85 hr
Totals for hole			79.2	73.3	73.7	73.3	11.13	11.13	15.18	15.18					19.92 hr

Note: gpm is equal to 1.9 × spm.

product. Several mixtures and concentrations with both Baravis and Minex polymers serving as dispersants seemed to reduce the high torque felt between the two strings. It was surmised that either of the two polymers alone might have produced the same results. It was planned to test this premise on the Shatsky Rise location, but deployment problems of the BHA caused the program to run out of time before DCS coring could be initiated.

Suggested Improvements/Recommendations

The drilling performed during Leg 132 produced a considerable amount of information that can be used to improve the DCS core barrel system. The cited improvements to the core barrel are not only to help in core recovery but also in general handling and operations while aboard the *JOIDES Resolution*. These items include:

1. Grooves on the exterior core liner case might be added on some cases to provide additional flow past the bit,
2. Lengthen the adapter coupling to provide room for make-up and break-out tongs,
3. Develop additional types of core catchers for use in loose unconsolidated sediments, sands, or gravel,
4. Develop a positive means for checking gauge on the core barrels,
5. Modify the position of the springs into the latch dog to provide additional material on top of the latch,
6. Provide additional material for use as shut-off valves,
7. Modify the mini-jar assembly with grooves so that it can be held with a C-plate while reinstalling the locking nut,
8. Modify the bit deplugger with a center hole so that it can also be used as a jetting tool,
9. Lengthen the threaded portion of the center bit rod so that it can be made adjustable,
10. Fabricate steel split liners with slightly smaller diameter so that they will be easier to get into and out of the barrels,
11. Fabricate a handling/transportation/storage carrier or system for the barrels so that they will be protected from the environment when not in use,
12. Conduct or have tests performed with the different drilling fluids to see if polymers alone can be used as friction-reducing agents for circulation between the tubing and drill pipe annulus.
13. Evaluate the possibility of incorporating a float valve into the core barrel.
14. Design and build a small mechanical piston sampler to be used in conjunction with the outer core barrel.
15. Develop a heavy-duty drive sampler to be deployed on the wireline jar.

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