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5. Hammer-Drill Sites (1180–1182)[1]

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BACKGROUND AND OBJECTIVES: SITES 1180 AND 1181

Sites 1180 and 1181 were hastily located in an effort to find a spot near Guam suitable for testing the hard-rock reentry system (HRRS or hammer drill). Relocation of the HRRS test was forced by lost time owing to a medical evacuation and the need to obtain a new brake band for the drawworks winch. Transiting to Guam from Japan gave personnel on shore the time to purchase and ship the new part. It also minimized the weather factor; by testing the HRRS near Guam, it was possible to free time for testing that would have gone to contingency because of the transit-time uncertainty resulting from the ever-present tropical storms and typhoons in the region.

Several considerations dictated the choice of HRRS test sites. A hard-rock, preferably igneous, outcrop was sought in moderately shallow water depths (1000–2000 m). Additionally, because the ship had to go to Guam to pick up the new brake band, the location had to be near Guam to minimize transit time. The best option seemed to be to drill on top of one of the arc volcanoes near Guam. After consulting with experts on shore, an unnamed seamount 37 km west of Rota Island was chosen. A dredge from this seamount recovered pumice and basaltic andesite blocks, suggesting that basalt might be found (Dixon and Stern, 1983). Although the precise age of the volcano is not known, it appears to have erupted in recent geologic time but is not currently active. Bathymetry maps also indicated the seamount has a caldera on its western flank with rims slightly deeper than 1000 m (Stern et al., 1989), fitting the sought-after depth profile.

Objectives at Sites 1180 and 1181 were as before for the HRRS test: to attempt spud-in with redesigned ring-type and underreamer bits and to attempt to drill in a casing string. Because of time limitations, it was

[1]Examples of how to reference the whole or part of this volume.

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thought that only one attempt at casing installation and perhaps limited spud-in tests were possible.

OPERATIONS: SITES 1180 AND 1181

The transit from Kushiro to Guam began at 0720 hr on 28 August and ended at 1415 hr on 3 September (universal time coordinated [UTC] + 10 hr) when the *JOIDES Resolution* met the supply boat *Shamrock* near Rota Island. The brake band part was transferred on board and repairs proceeded immediately. On the way to the rendezvous, the *JOIDES Resolution* made a pass over the summit of the unnamed seamount. After the rendezvous, a short survey was made over the seamount, from 1500 to 2210 hr, with the 3.5- and 12.0-kHz echo sounders and magnetometer.

After the end of the survey, the ship was positioned by Global Positioning System (GPS) at Site 1180 and thrusters were lowered. The vibrational isolated television (VIT)/subsea television (TV) camera was lowered to survey the seafloor. By 0100 hr on 4 September, the seafloor had been seen to have sediment upon it. It was not clear whether hard rock lay beneath, so it was decided to rig up the hammer drill and see if the bottom was suitable for drilling. A deck test of the hammer was made, and then it was run to the seafloor. Hole 1180A was spudded at 2162 meters below rig floor (mbrf) at 1315 hr on 4 September (Table T1). The bottom was soft, consisting of sandy sediments, probably volcanic ash. Because the seafloor was not firm, the hammer would not come up to full pressure; instead, the drill fluid flushed away the sediments, allowing the hammer to jet in. Hole 1180A penetrated 5 meters below seafloor (mbsf) before formation collapse necessitated pulling the hammer free of the sediment. The drill string was pulled clear at 1345 hr, and Hole 1180B was spudded nearby at 1400 hr. After 8 mbsf penetration, the same thing happened at Hole 1180B. The hole was terminated at 1415 hr, and Hole 1180C was spudded after a short offset at 1545 hr. This hole produced the same results and was ended at 1600 hr after 3 mbsf penetration.

T1. Operations summary, Sites 1180 and 1181, p. 42.

It was decided that the sediments at Site 1180 were unsuitable for testing the HRRS, and the sonar on the VIT/subsea TV frame showed a smooth morphology in the vicinity. Consequently, the camera and pipe were tripped back to 800 mbrf. The *JOIDES Resolution* moved ~3 nmi upslope to the caldera rim and dropped a beacon to establish Site 1181. The pipe was run to the seafloor, and Hole 1181A was spudded at 0115 hr on 5 September in coarse rubble. This formation also proved unsuitable for HRRS tests because the drilling fluid mobilized the seafloor material, resulting in hole collapse around the drill string and loss of circulation. Hole 1181A was terminated at 0130 hr after 3 mbsf penetration. The results for the next two holes were similar. After offsetting 45 m south, Hole 1180B was spudded at 0315 hr and terminated at 0330 hr after 3 mbsf penetration. The ship offset 80 m north, and Hole 1180C was drilled from 0415 to 0430 hr with 3 mbsf penetration. After these unsatisfactory results, the ship moved in dynamic positioning mode ~250 m northeast, over the rim of the crater, so that we could look for a better spot to drill. Rubble and ash were all that were seen. The drill string and VIT/subsea TV frame were recovered, and the ship made ready to move to a new location; however, it became necessary to vacate the site because a low-pressure cell had intensified into a typhoon, named Saomai, and it was headed toward the area. After the poor luck in finding a suitable drilling location, it was decided to give the unnamed seamount the name Inutil, which is Spanish for "worthless."

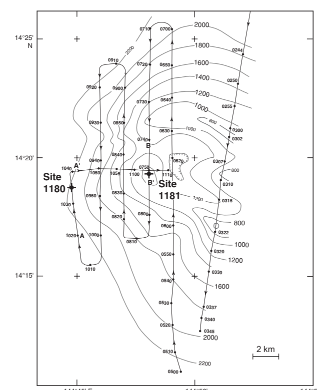
It was necessary to head southwest away from the typhoon, so another potential site was located in conference with colleagues on shore. The new site was a seamount on the spreading ridge of the Mariana Trough, ~70 nmi southwest of Guam.

SITE GEOPHYSICS: SITES 1180 AND 1181

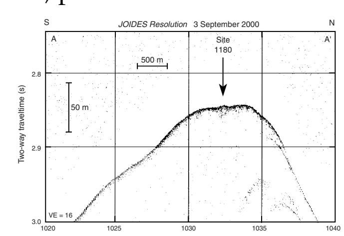
Because drilling near Guam was not envisioned as part of the Leg 191 plan, no maps of the drill site were on board the *JOIDES Resolution*. Two published small-scale maps were faxed from shore. A low-resolution map of the eastern side of Inutil Seamount had been derived from echo-sounder profiles taken in 1983 during a dredging cruise of the *Thomas Washington* (Dixon and Stern, 1983). At the time of writing, the date and navigation parameters of that cruise were not known. A later publication contained low-resolution bathymetric contours from U.S. Navy SASS multibeam coverage (Stern et al., 1989). The data are presumably as accurate as possible with mid-1970s navigation and multibeam echo sounding, but the details of this survey are classified. In addition, the contours are generalized and sometimes moved slightly in order to get them declassified (N.C. Smoot, pers. comm., 1990). Nevertheless, comparison of the two maps showed no apparent offset in position.

From 0230–1110 hr UTC on 3 September 2000, the *JOIDES Resolution* made a short survey of the western part of Inutil Seamount using the 3.5- and 12.0-kHz echo sounders and magnetometer (Fig. F1). The survey showed a crater >200 m in depth with breached walls on the western side. Slopes on the volcano's flanks are typically ~14°, and sharp-topped ridges surround the crater. Site 1180 was chosen at a depth of slightly >2100 m on the lower flanks where the slope seemed less steep (Fig. F2). Site 1181 was chosen at the top of the crater rim, where survey profiles indicated a possible graben (Fig. F3).

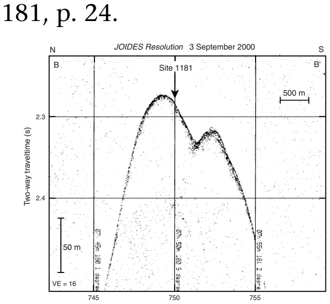
F1. Bathymetry map of Inutil Seamount, p. 22.



F2. Echo-sounder profile over Site 1180, p. 23.



F3. Echo-sounder profile over Site 1181, p. 24.



BACKGROUND AND OBJECTIVES: SITE 1182

Having been frustrated at Sites 1180 and 1181 on Inutil Seamount by bad weather and an unsuitable lithology, we sought another location for HRRS tests. A suggestion from a colleague on shore led us to a volcano located in the southern Mariana Trough near the backarc spreading center axis, ~70 nmi (130 km) west-southwest of Guam. Because this volcano was close to the *JOIDES Resolution's* path away from Typhoon Saomai and because it was likely to be basaltic, we decided to try the hammer drill on the volcano. At the time of the cruise, we knew little about the seamount other than the fact that it is located near the backarc spreading center, had been surveyed by Hawaii MR-1 sidescan sonar, and has a summit depth of ~2880 meters below sea level (mbsl). Because of the successful hammer drill tests conducted at this seamount, we propose to name it "Martillo" Seamount, meaning "hammer" in Spanish.

Objectives at Site 1182 were similar to those at previous HRRS test sites. Originally, it was hoped that spud-in tests with several different hammer drill bits and casing emplacement tests could be run during Leg 191. However, owing to the shortness of remaining time in the leg, it was decided that there was sufficient time only for the spud-in tests at Site 1182.

OPERATIONS: SITE 1182

Escaping from Typhoon Saomai, the *JOIDES Resolution* sailed southwest past Guam beginning 1015 hr (UTC + 10 hr) on 5 September. The destination was an unnamed seamount located at 12°57′N, 143°37′E near the Mariana Trough spreading center axis. Arriving near the site at 1950 hr, we conducted a short survey of the volcano using the 3.5- and 12.0-kHz echo sounders and magnetometer. The survey was completed at 0000 hr on 6 September, and the ship was positioned over the volcano summit, the thrusters were lowered, and a beacon was dropped to establish Site 1182.

A bottom-hole assembly (BHA) with the hammer drill was made up and run down to the seafloor with the VIT/subsea TV camera. By 0745 hr, the seafloor was in view on the TV screen and a short survey of the seafloor was done. The bottom appeared to be the rough surface of a submarine lava flow with typical pillow structures and debris. Roughness appeared to be on the order of 1 m in most places.

Hole 1182A was initiated at 0845 hr at a depth of 2878 mbrf and drilled to 2 mbsf (Table T2). The drill string was pulled clear of the seafloor 15 min later and moved 5 m. From 0915 to 0930 hr, Hole 1182B was drilled to 1.5 mbsf, also beginning at 2878 mbrf. Both holes were drilled with the VIT camera in place to observe the progress of the drill bit, but this meant that no rotation was possible. The VIT/subsea TV camera was recovered and Hole 1182C was drilled from 1045 to 1345 hr, beginning at 2878 mbrf and penetrating to 5 mbsf. The VIT/subsea TV camera was again lowered to check the drilling results. After offsetting 20 m north, Hole 1182D was spudded at 1530 hr and drilled to 1 mbsf, beginning at 2877 mbrf. The VIT/subsea TV camera was recovered and drilling in Hole 1182D was continued. Soon rotation was lost and increasingly more weight was required to cause the hammer to actuate. The BHA was worked free at 1825 hr and tripped back to the rig floor to check the hammer.

T2. Drilling summary, Site 1182, p. 43.

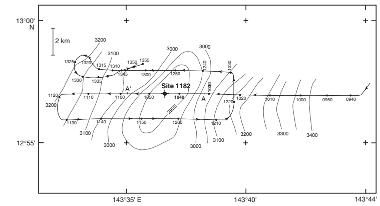
By 0030 hr on 7 September, the hammer was back on the rig floor and found to be in good condition. The bit was changed, and the drill string, along with the pulsation sub, was tripped back to the seafloor with the VIT/subsea TV camera. After another short reconnoiter of the seafloor, Hole 1182E was spudded at 1030 hr and was drilled to 4.5 mbsf, from 2870 mbrf. Moving 5 m north, Hole 1182F was started at 2872 mbsf and drilled to 7 mbsf, from 1130 to 1345 hr. Following another 5-m offset, Hole 1182G, the final spud test, was started at 1530, from 2873 mbrf. Penetration was 5 mbsf.

The drill string was tripped back to the seafloor; the BHA cleared the rotary table at 0215 hr on 8 September. After cleaning up the rig, thrusters were raised and the *JOIDES Resolution* made way to Guam, arriving at 1400 hr on 8 September, bringing Leg 191 to a close.

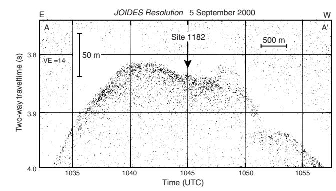
SITE GEOPHYSICS: SITE 1182

Because drilling near Guam was not envisioned as part of the Leg 191 plan, no maps of the drill site were on board the *JOIDES Resolution*. During the cruise, we had only the position of the backarc volcano and its summit depth. Consequently, a short survey of the volcano summit was conducted by the *JOIDES Resolution* from 0940 to 1355 hr (UTC) on 5 September using the 3.5- and 12.0-kHz echo sounders and magnetometer (Fig. **F4**). The volcano was found to have flank slopes of ~5° and a relatively flat summit at a depth of about 2874 m (Fig. **F5**). Site 1182 was chosen to be in the middle of the summit platform (Fig. **F4**).

F4. Bathymetry map of Martillo Seamount, p. 25.



F5. Echo-sounder profile over Site 1182, p. 26.



HRRS TEST RESULTS

Introduction

The HRRS was developed to provide the Ocean Drilling Program (ODP) with the ability to establish a reentry casing on sloped and fractured hard-rock outcrops on the seafloor. The system uses a downhole fluid hammer developed by SDS Digger Corporation of Canning Vale, Western Australia. The hammer along with a bit is used to advance the hole while casing is installed simultaneously.

Presently, 13.375-in casing is being used in the prototype development program. The hammer performed satisfactorily during Leg 179, despite problems with severe sea states (3- to 4-m heaves) and vibration throughout the derrick caused by improperly secured standpipe lines in the derrick. Premature failure of the bits during Leg 179 resulted in testing of only the hammer and bits. The rough sea states also demonstrated the need for a more robust bit that could withstand the torque, lateral pivoting (i.e., rocking) movements, and weight-on-bit fluctuations encountered during the first offshore trial.

The next generation of bits designed for Leg 191 were tested onshore with corrections and improvements made based on observations during onshore quarry tests leading up to Leg 191. Although the bits were tested onshore, actual offshore conditions are difficult to duplicate.

During Leg 191, there was not enough time to test the casing running tool used to support the 13.375-in casing during the installation sequence and the modified reentry cone or the assembly/operation procedures devised for the HRRS. This was due in part to modifications to the Leg 191 operations program, which reduced the time scheduled for HRRS testing from 12.5 days to 4 days. With the change in operational plans, a new site also had to be located, surveyed, and selected before any test spuds with the fluid hammer and underreamer bits could be attempted.

Despite having only 4 days to accomplish what was planned for 12.5 days, two underreamer bits were tested without casing. Although the drilling surface was different from planned, the location provided lava flows at the seafloor interface and presented a hard-rock environment to demonstrate the performance of the modified bits.

The second deployment of the 260 fluid hammer and associated hardware was a success for the limited testing achieved. The fact that the bits and hammer withstood the forces to which they were subjected while achieving reasonable penetration rates clearly demonstrates that advances in bit technology have been made since Leg 179. The addition of the active heave compensator to the *JOIDES Resolution* contributed to the success of the hammer tests during significant rig floor heave. The modifications to the derrick coupled with the introduction of the pulsation sub allowed the hammer to be operated at full pressure and flow rate. A summary of the highlights from Leg 191 include the following:

1. The 260 fluid hammer was successfully tested in 2880 m of water at the Mariana backarc location without any damage to the hammer or bits.
2. The acceptability of two types of underreamer bits (i.e., dual cam and three-level pilot) was tested and confirmed.
3. Bare-rock spudding was performed in volcanic lava flows with rates of penetration ranging from 2.7 to 9 m/hr in 2.5- to 4-m rig-floor heaves.
4. Both underreamer bits (dual cam and three-level pilot) survived without any damage to the bit body/arms and without losing any tungsten carbide compacts compared to those tested during Leg 179.
5. Supplemental bracing of the *JOIDES Resolution* standpipe during dry docks and the introduction of a pulsation sub resolved the harmonic vibrations experienced during Leg 179.

This section summarizes the Leg 191 hammer-drill testing operations. It includes a description of events and hardware tested and provides conclusions and recommendations drawn from completion of the HRRS prototype bit testing.

Test Program Background

There have been five series of field test programs for SDS Digger's fluid hammer and prototype bits. Prior to Leg 191, these five test programs included the following:

Feasibility Study Program—August 1996,
Hammer/Bit Testing Program—April 1997,
Closing Force Test Program—September 1997,
Leg 179 Sea Trials—July 1998, and
Onshore Quarry Testing Program—March 2000.

Feasibility Study Program

The first test series was performed during the summer of 1996 to establish whether the concept of drilling in casing with a hammer was feasible. The tests were performed with an SDS Digger 4.75-in hammer using a 7.25-in bit. The tests indicated that the concept was viable and resulted in several recommendations for improvement before the technique and/or equipment could be deployed offshore.

Hammer/Bit Testing Program

The 260 fluid hammer was first assembled and tested in SDS's yard on 31 January 1997. ODP representatives witnessed the successful hammer test. Subsequent SDS hammer testing with a 12.25-in bit was performed during February and March 1997 at a local quarry. This testing was conducted in an open hole until problems with near-surface rubble and loss of circulation stopped the testing. Short sections of casing (<3 m) were then installed to isolate the upper rubble at the quarry site. Penetration rates for the 260 fluid hammer with a standard 12.25-in (311.15 mm) bit ranged from 3 to 5 m/hr.

ODP requested that SDS measure the closing force of the hammer during the April 1997 bit-testing program. Closing forces were recorded at four flow rates with a considerable amount of data scatter. The results indicated, based on linear projections of the data, that a closing force in excess of 4000 kg would be required at the recommended hammer flow rate of 2250 L/min. This value turned out to be above the acceptable closing force range even when using 9.5-in drill collars, allowing a variation of 10,000 lb for the passive heave compensator (PHC). It was calculated that the 9.5-in drill collars would buckle under 23,000 lb and the 8.25-in drill collars under 14,500 lb. Therefore, subtracting the closing force and 10,000 lb for the PHC left ~4000 lb in reserve before a catastrophic event might occur with the 9.5-in drill collars. Engineers felt that 4000 lb was not a large enough safety factor with the 9.5-in drill collars, considering the magnitude of external forces involved. Therefore, ODP recommended that the hammer closing force be reduced before the hammer could be operated offshore in the proposed mode.

As a result, several modifications were made to the hammer during the April 1997 test program that reduced the closing force to an acceptable level for use with the 9.5-in drill collars in the BHA. Even though a closing force benchmark was established with the hammer, a more accurate means of measuring this closing force was required. There was also an operational requirement to demonstrate that the hammer could operate for a minimum of 12 hr. These recommendations set the stage for modification of the hammer by SDS to reduce the closing force. It also allowed SDS to demonstrate that the hammer could be operated without any performance degradation for the length of time that ODP felt was a minimum acceptable level.

The second field test program was performed in April 1997. In addition to the hammer-drill testing, two prototype Holte underreamer bits were tested during the land test program. These bits were unique in that they could pass through the internal diameter (ID) of the casing and then be opened up (similar to the underreaming concept) for drilling. Two types of underreamer bits were tested, an eccentric bit with a single opening arm and a concentric bit that had three equally spaced arms set back 11 in from the piloted face. These bits did not require a casing shoe, similar to the prototype ring bit tested during the initial quarry test program in 1996. Both styles of underreamer bits (concentric and eccentric) performed as designed and produced similar penetration rates. Testing was limited to 1.25-m penetration on the concentric bit and <0.5 m on the eccentric bit. Total time accumulated in the field on both bits was <3 hr but consumed several days because of ancillary equipment problems.

Closing Force Test Program

This third test program was conducted at Rogaland Research Facility in Stavanger, Norway. The tests demonstrated that the minimum operating requirements of the 260 fluid hammer were met. Modifications made to the hammer reduced the closing forces to 1500 kg at a flow rate of 2250 L/min. Additional modifications made to the hammer also resulted in lowering the operating pressure, which allowed the hammer to work in greater water depths without having to upgrade the existing mud pumps on the vessel.

Leg 179 Sea Trials

The fourth test program, Leg 179, was designated as the first offshore tests of the hammer drill-in casing system. This test program relied primarily on the Holte-type underreamer bits.

There were five primary objectives for HRRS system during Leg 179. These included the following:

1. Characterization of the hammer operating parameters (i.e., flow rates, pump pressures, weight on bits, etc.),
2. Characterization of the hammer-drill and bit-spudding capabilities without casing,
3. Testing the entire HRRS system by drilling in >20 m of 13.375-in casing in a fractured hard-rock environment with little or no overlying sediment or talus and with little or no slope,
4. Testing the entire HRRS system by drilling in >20 m of 13.375-in casing on a sloped fractured hard-rock environment with little or no overlying sediment or talus, and
5. Testing the entire HRRS system by drilling in >20 m of 13.375-in casing on a sloped fractured hard-rock environment with overlying sediment or talus.

Unfortunately, only the first two objectives were achieved during Leg 179. Loss of tungsten carbide buttons on the underreaming arms of the bits and the loss of one of the hammers were a direct result of the rough sea states that were seen at the offshore test site. Secondary factors that contributed to the program's inability to meet leg objectives included a 2-week port delay because of repairs to the ship's lower guide horn. In addition, some HRRS hardware and bits did not arrive during the scheduled port call, requiring fabrication of substitute parts.

A small vessel was chartered to deliver three additional bits to the *JOIDES Resolution*. Because only two underreamer designs (eccentric and concentric) were originally pursued, there were not many options that had not already been tried by the time the bits arrived. The field modifications and trials with these bits during Leg 179 confirmed the requirement for major design improvements in the bits.

The original design of the Holte bit presented a steep and abrupt jump between the pilot bit and the wings. This irregularity seemed to cause the bits to stall when the wings came into contact with the formation. This stalling resulted in the drill string torquing up. Once the formation broke free or the bit heaved off the bottom, the buttons on the arms were damaged to the extent that they were no longer usable.

The Leg 179 tests did successfully demonstrate the ability of the SDS fluid hammer to instantaneously spud a bore hole on bare hard-rock formations with sloping surfaces using an unsupported BHA. The majority of the holes attempted during Leg 179 were spudded without significant weight on bit (WOB). Despite the light bit weights used, spudding was successfully carried out on the sloped seafloor surface.

The slow response time of the passive compensator coupled with high seas did result in the bit lifting off the seafloor and starting a new hole on a number of occasions. Some minor problems were seen with the hammer, such as cracking of a valve and galling of the piston. The remaining objectives of Leg 179 were not met primarily because of the premature failure of the Holte-designed underreamer drill bits as a result of the large WOB variation from the high sea states.

The outcome of this leg led to a reevaluation of the drill bit design. ODP approached several other bit suppliers in search of a suitable design to install the casing system. ODP then worked with SDS to improve the current design and review new concepts.

Onshore Quarry Testing Program

In January 1999, SDS presented several preliminary bit designs to ODP. These included three main concepts with two variations on each design theme. Two of the concepts centered on an underreamer approach. The third design was a ring-type bit. All bits presented at this time were essentially modifications of the original Holte design. The specific names of the three bits that were selected and evolved from the meeting included (1) 14.75-in three-level pilot underreamer bit, (2) 14.75-in dual cam underreamer bit, and (3) 12.25-in pass-through friction-drive ring bit.

All of designs except one (12.25-in ratchet-style ring bit) allowed a standard 12.25-in oilfield bit to pass through the casing shoe to continue with the hole after the casing was installed. The friction-drive bit was favored over the ratchet-style bit, primarily because it would allow a larger bit to pass after the pilot bit was removed.

Initially, all three bit prototypes were to be tested in March 1999. Problems with two of the bits resulted in tests having to be repeated. These additional tests were performed in August 1999 and further testing was undertaken in February 2000. This test program finally resulted in the availability of two underreamer and two ring-style bits for Leg 191.

Test Plan for Leg 191

Based on the results of the three quarry test programs conducted during 1999 and 2000, eight bits were readied for the 12.5 days allotted for HRRS testing during Leg 191. Leg 191 included the installation of a borehole seismometer and battery package as part of the International Ocean Network (ION) objective followed by HRRS tests at Shatsky Rise. It was recognized that two high-priority projects could be competing for time should problems and/or weather become a factor during the leg. The leg began in Yokohama, Japan on 16 July 2000 and ended in Piti, Guam, on 8 September 2000.

There were five primary objectives for the HRRS testing on Leg 191. These included the following:

1. Characterization of the 260 hammer operating parameters (i.e., flow rates, pump pressures, weight on bits, etc.),
2. Characterization of the hammer-drill and bit-spudding capabilities without casing,
3. Testing the entire HRRS system by drilling in >20 m of 13.375-in casing on a fractured hard-rock environment with little or no overlying sediment or talus and with little or no slope,
4. Testing the entire HRRS system by drilling in >20 m of 13.375-in casing on a sloped fractured hard-rock environment with little or no overlying sediment or talus, and
5. Testing the entire HRRS system by drilling in >20 m of 13.375-in casing on a sloped fractured hard-rock environment with overlying sediment or talus.

The actual drilling plan for the HRRS was first to familiarize the drillers with the fluid hammer operation and the WOB requirements for these types of bits. Because the fluid hammer operates with very high pressure and flow requirements, it also would allow the pumps and other ancillary pieces of equipment to be checked to ensure that adequate drilling parameters could be maintained during the course of the HRRS work.

The hammer and ancillary hardware were to be tested by first deploying the fluid hammer with an underreamer bit and without casing. A number of shallow holes were to be made while instructing the drilling crew in the proper drilling technique required for this fluid hammer. The drill string would then be round tripped and the bit changed to the alternate version of underreamer bit. The testing of the second underreamer bit would provide comparative information between the two types of bits. A similar number of shallow holes would be made with this bit to establish operating characteristics.

The ring bits must be run with casing and were to be picked up only after it had been demonstrated that the hammer could be adequately operated with the flow and pressures generated by the mud-pump system. The first bit type to be run with casing would be selected based on the drilling results of the first two underreamer bits and the sea states at that time. Once the bit was selected, a short length of 13.375-in casing (10 to 30 m) would be picked up and attached to the lower section of HRRS casing running tool. Once assembled and the space-outs confirmed, the whole casing/BHA would be lowered to the seafloor on drill pipe. The VIT would be deployed to assist in locating an appropriate location at which to spud. The bit would be placed on the seafloor during VIT recovery. The casing would then be drilled to depth. The VIT would again be deployed to confirm that the casing was in the proper position before installing the reentry funnel.

The VIT would be recovered and the reentry funnel assembled around the drill string. The modified free-fall funnel (FFF) would be released and the VIT once again deployed to verify proper position of the modified FFF before releasing the running tool. Upon verification, a dart would be pumped down the drill string to shift a sleeve so the BHA and bit could be withdrawn from the installed casing. A simplified schematic of this operation is presented in Figure F6 with a more detailed view of the running tool and BHA being withdrawn illustrated in Figure F7.

Prior to recovering the VIT, a survey of the site and installed HRRS would be performed.

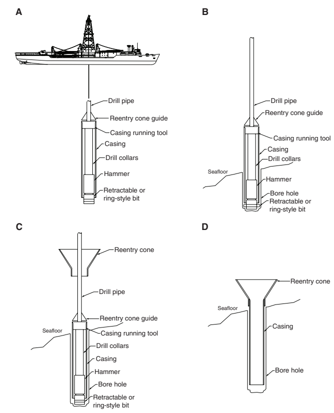
If all the operations went as planned, the scenario would be repeated two more times but with progressively longer strings of casing as the comfort level and success of the operation was achieved. The additional lengths of casing installation would be solely dependent upon the success of the previous installation.

Included in the second tier of hardware to be tested were tornado and pulsation subs. These subs were experimental tools designed to reduce pulsations seen propagating back through the fluid column in the drill string during Leg 179. These tools could be run independently in the BHA or in tandem. Figure F8 illustrates the location of these tools in the BHA. The combination of these tools coupled with the work completed on bracing the standpipe in the derrick should eliminate the pulsation problems seen the last time the hammer was run on the *JOIDES Resolution*.

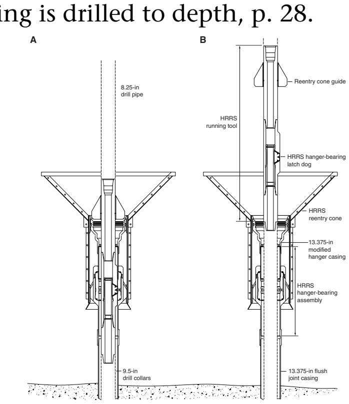
Hardware Prepared

Of the eight bits prepared for Leg 191, four were new bits and four were reconditioned prototype bits previously used during the quarry test program. These bits included the following:

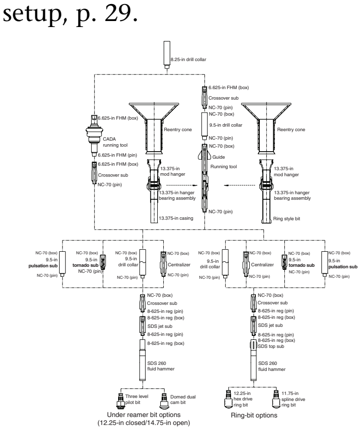
F6. Hard-rock reentry system deployment, p. 27.



F7. Running tool release after casing is drilled to depth, p. 28.



F8. Hard-rock reentry system setup, p. 29.



1. Refurbishment of the prototype 12.25-in three-level pilot bit,
2. Manufacture of a second 12.25-in three-level pilot bit,
3. Refurbishment of the prototype 12.25-in dual cam bit,
4. Manufacture of a second 12.25-in dual cam bit,
5. Refurbishment of the prototype 11.75-in spline drive ring bit,
6. Manufacture of two new 11.75-in spline drive ring bits, and
7. Refurbishment of the prototype 12.25-in friction-drive ring bit into a new hex-drive ring bit.

Other hardware preparations for Leg 191 included the following:

Connections were recut on the tornado sub.

Two top hammer subs with an outer diameter (OD) of 10.23 in and with ODP-recommended 8.625 regular (reg) connections including bore-back and stress-relief grooves were manufactured.

Two jet subs with an OD of 10.125 in and with ODP-recommended 8.625 reg connections including bore-back and stress-relief grooves were manufactured.

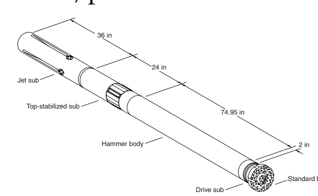
Bit breakers for all four types of bits were prepared.

Two 260 fluid hammers were modified to the ODP closing force requirements.

One set of internal 260 fluid hammer components and miscellaneous tools and hardware necessary to operate and change out hammer components were prepared.

A schematic of the hammer and bits are shown on Figures **F9** and **F10.**

F9. SDS Digger Tools 260 fluid hammer, p. 30.

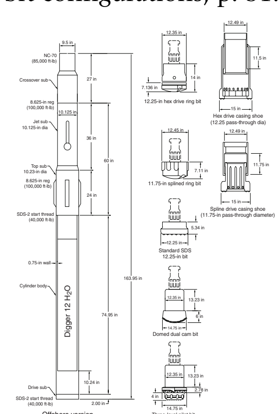


Leg 191 Scheduling Changes

Several events occurred during the course of Leg 191 that caused delays in the schedule before the HRRS could be deployed. First, several typhoons were headed toward the ION site that required the *JOIDES Resolution* to leave the location for almost 4 days.

The next unfortunate event involved one of the Transocean Sedco Forex crew members, who needed to be medivaced to rendezvous with a Japanese Coast Guard vessel. The *JOIDES Resolution* ended up transiting nearly all the way to Japan to await the return of the ship's doctor, who had accompanied the crewmember to the onshore Japanese hospital. Once the doctor was picked up, transit began to the HRRS test location at Shatsky Rise. However, it was discovered that the drawworks brake band was cracked and that it could not be repaired. A spare part was not in the ship's inventory. Arrangements were then made for the part to be sent to Guam while the *JOIDES Resolution* transited south to Guam, the port call location for the next leg.

F10. SDS 260 fluid hammer and test bit configurations, p. 31.



Because the *JOIDES Resolution* had traveled to Guam to receive the part, there was not enough time remaining in the schedule to return to Shatsky Rise where hammer-drill operations had originally been planned. The science party contacted several associates onshore about potential sites near Guam. One site in particular stood out as a possible target to conduct the HRRS operations. This site was near the island of Rota. Ultimately, a second site named Mariana backarc-1 was sourced when drilling conditions near Rota-1 proved to be unsatisfactory for HRRS operations.

A small vessel was chartered to meet the *JOIDES Resolution* at the new HRRS drilling location ~6 hr north of Guam. While the brake band was being installed on the rig, a site survey was performed with a 3.5-kHz echo sounder. The site survey was required because little information existed about this drilling location (Rota-1) off Guam.

Once the rig was operational, the *JOIDES Resolution* commenced spud tests on 4 September 2000. Attempts were made to drill at this location but were soon abandoned with little hope of finding any hard-rock outcrops at the seafloor. Another site was recommended 100 nmi south of Guam. This location was designated as the Mariana backarc. After transiting to this location, short seismic and VIT surveys were performed and spud tests commenced midmorning on 6 September 2000. Testing continued until late in the day on 7 September 2000. At this point, there was not enough time in the schedule to attempt a casing deployment, so further HRRS testing was suspended and the *JOIDES Resolution* set sail around sunrise on 8 September 2000 for Guam. The first line ashore was recorded at 1500 hr on 8 September 2000.

If both Rota and Mariana backarc sites are considered as productive HRRS test sites, then <4 days of the leg were spent on HRRS work. This represents a 68% reduction in the original time planned for HRRS work. However, if only the Mariana backarc site (where hard rock was actually found) is considered as usable test time, then just over 2.25 days were allocated to HRRS work during the entire Leg 191. This represents an 82% reduction from the 12.5 days originally planned. A breakdown of the testing time is provided in Table **T3.** Actual time spent conducting spud tests between the two sites amounted to just under 9 hr, or 7% of the 4 days allocated for HRRS work.

T3. Breakdown on HRRS activities, p. 44.

Hardware Tested

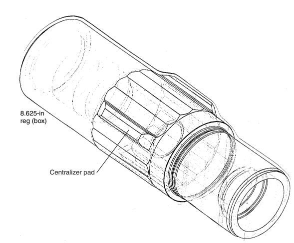
Two underreamer-style bits were tested during Leg 191 with the 260 fluid hammer. The two types of underreamer bits were the dual cam and the three-level pilot. The fluid hammer also had a couple of new components that were redesigned after a failure was noted during Leg 179. These parts were the top sub and jet sub. In addition, a pulsation sub was added to the BHA as a means of reducing the vibration generated by the hammer.

Top and Jet Subs

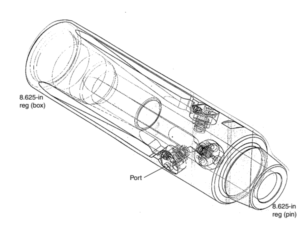
Two new hammer components were tested for the first time during Leg 191. These included the top and jet subs. Both parts were redesigned after Leg 179 because of connections that were unbalanced pertaining to their bending strength ratio (BSR). The new parts used an 8.625 reg API connection on the 10.23-in and 10.125-in bodies of the two subs, respectively. Additional changes between these subs and those used during Leg 179 were that Baker float valves were installed in both components.

The jet sub has three ports that can be outfitted with different sized jets depending upon the well configuration. For the Leg 191 test spud application, all of the jets were blanked off. The top sub also has four fixed-wing centralizer pads. These pads were installed primarily to keep the hammer and BHA from moving to one side of the casing and possibly causing difficulty with the underreamer bits being retracted inside the casing. A schematic of the top sub and jet sub are shown on Figures **F11** and **F12.**

F11. SDS modified top sub with centralizer pads, p. 32.



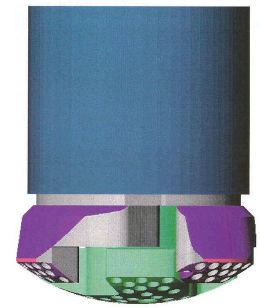
F12. SDS modified jet sub, p. 33.



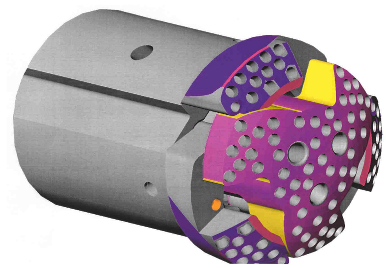
Dual Cam Underreamer Bit

The Dual Cam bit is shown in Figures F13, F14, F15, F16, and F17. This bit was designed after problems were experienced during Leg 179. The dual cam bit has a continuous convex face to allow the bit to pivot when starting a new hole from the seafloor and to reduce the torquing up seen during Leg 179 tests. The arms have a generous chamfer to assist in closing the bit when pulled back inside of the installed casing.

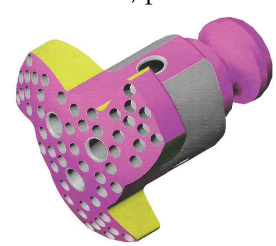
F13. Profile of the dual cam underreamer bit, p. 34.



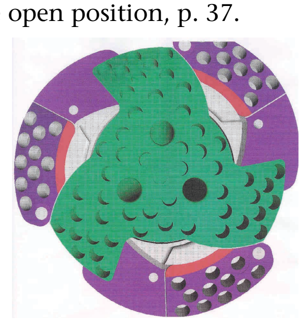
F14. Side view of the dual cam underreamer bit with arms open, p. 35.



F15. Pilot shank of the dual cam underreamer bit, p. 36.



F16. Dual cam underreamer bit in the open position, p. 37.



Three-Level Pilot Underreamer Bit

The three-level pilot bit is similar to the original bits used during Leg 179 but with several noted changes. The long pointed pilot on the Holte bit was exchanged for a standard SDS "W"-profile flat-face bit. The arms are only 4 in back from the face, and they have three levels of buttons that gradually ramp up to the full OD gauge of the underreamer arms. On early bits, all the buttons on the OD gauge were placed on the same elevation. This early design appeared to create much of the slip-stick noted during the Leg 179 sea trials. The new bits also have twice the number of buttons on the arms and a much tighter fit between all of the moving components. Additionally, the pilot bit shank has three small holes that allow continual flushing of the internal portion of the bit. This prevents the accumulation of cuttings in the moving mechanism of the bit so that it can be retracted when required. Illustrations of the three-level pilot underreamer bits are shown in Figures F18 and F19.

Pulsation Sub

A pulsation sub was developed for ODP Leg 191 by Houston Engineers. This piece of equipment was used to help combat the problem seen during Leg 179 of a standing wave being propagated by the hammer back through the fluid column inside the drill pipe. Once the standing wave entered the standpipe on the rig, severe vibration occurred in the long spans between the supports. The tool is quite simple; it has a nitrogen-charged piston on one side and is open to the fluid column on the other. A schematic of the pulsation sub is shown in Figure F20.

Drilling Operations

A summary of HRRS activities after arriving on site at Rota-1 is presented in Table T3. The following sections describe the sites, drilling conditions, and what was accomplished at each.

Rota-1 (Sites 1180 and 1181)

Rota-1 was selected as a site to conduct HRRS operations on 30 August 2000 while underway to a rendezvous point to pick up needed parts to repair the rig. The site was selected from limited data transmitted to the ship via fax and e-mails. This information was passed on to ODP for additional review and drilling clearances. We thought this location might be ideal, as all indications from previous studies suggested it was a submerged volcano.

Once this location was established as the first potential candidate site, arrangements were made to establish it as the rendezvous point for the *Shamrock*. A rendezvous was necessary so time could be saved for the drilling operations instead of first transiting to Guam to pick up the needed parts to repair the drilling rig. The *JOIDES Resolution* arrived on site at ~1400 hr on 3 September 2000 and was met by the ship chartered to bring the replacement brake bands for the drawworks.

Upon arriving at the site designated as Rota-1 and performing a 3.5-kHz survey, three potential drilling targets were identified. The rig was repaired while the 3.5-kHz survey was performed to establish the potential drilling sites with respect to water depth and seafloor topography. At ~2200 hr on 3 September 2000, the VIT/subsea TV system was deployed to hunt for specific drilling sites at the deepest of the three targets identified in the seismic survey. The survey was concluded within 3 hr, and the first location was selected in 2157 m of water.

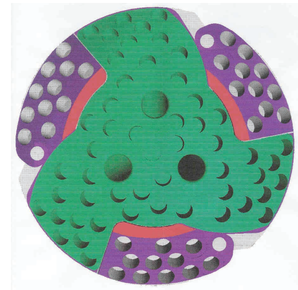
The VIT/subsea TV system was recovered, and the hammer with a dual cam bit and 9.5-in drill collars was made up and racked in the derrick. The hammer was then deck tested prior to deploying the system to the seafloor. As the hammer was being tripped to the seafloor, the VIT was again deployed to assist in locating a specific drill site. The hammer was placed on the seafloor, and flow was initiated (Hole 1180A). The hammer met no refusal and penetrated to >3 m in <15 min from jetting alone (no rotation) with 20–40 strokes per minute (spm). From observations with the VIT/subsea TV, it appeared that white volcanic ash was all that was present and that the hammer was only firing intermittently, as not enough weight could be placed on the bit to close the internal hammer piston.

The next hole (Hole 1180B) selected to perform a spud test was several meters away from Hole 1180A. Similar occurrences of soft seafloor were again noted, with the bit penetrating to ~9 m in 15 min of circulation. After a few minutes of circulation, the white volcanic ash being expelled from around the BHA disappeared. This indicated that circulation to the surface had been lost. The BHA had to be worked to free it from the collapsing volcanic ash. Flow rates of 20–40 spm were again used. After freeing the BHA, a third hole (1180C) was attempted before deciding that this location was too soft to perform HRRS spudding tests. This test spud penetrated ~2.5 m in 10 min of jetting with the hammer.

The top drive was then set back and the drill string pulled to 800 mbrf while the *JOIDES Resolution* was offset with the dynamic positioning (DP) system to a shallower upslope location. Water depth at Site 1181 was ~980 m. Three holes were tried at this location with similar results to those encountered at Site 1180. Water depths ranged between 970 and 995 m over the three holes. The holes did produce a little more resistance, but it was observed that circulation was lost with <1 m of penetration. Total penetration in all three holes was <3 m with significant overpulls being noted for the shallow penetrations. After these three attempts did not produce any better results than those at Site 1180, it was decided to abandon the location, not only because of the lack of unsuitable hard rock at the seafloor, but also because of another approaching Typhoon named Saomai. Almost 2 days of time accumulated while trying to locate and spud a series of test holes at these sites until the Rota-1 location was abandoned. The actual time that flow was circulated through the hammer was only 1 hr for all six holes.

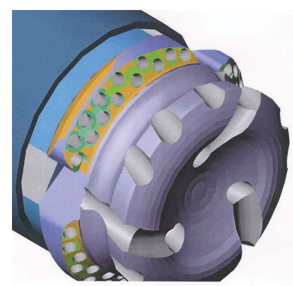
In summary, the reason for abandonment was not due to any mechanical problems but the fact that what appeared to be a hard bottom from the survey turned out to be a dense ash-covered sea mound resembling wet talcum powder. The hammer basically penetrated under its own weight, without rotation, and with only 20–40 spm (100–200

F17. Dual cam underreamer bit in the closed position, p. 38.

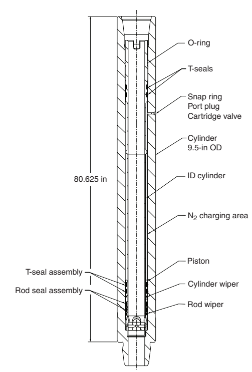


F18. Three-level flat-face underreamer pilot bit, p. 39.

F19. Three-level flat-face underreamer bit, p. 40.



F20. Pulsation sub, p. 41.



gpm) of pump flow. It was observed that the ash closed around the hammer/BHA and the circulation path to the surface was lost. Furthermore, the hammer never met enough resistance to fire more than several times during the course of the six holes that were attempted at the Rota-1 location. The lack of hard material to drill near the surface coupled with the ash closing in around the BHA increased the potential to become stuck. This, coupled with another approaching typhoon, resulted in the Rota-1 site being abandoned after fewer than two days of operations. A summary of the test spuds is presented in Table T4.

T4. HRRS operation summary, Sites 1180 and 1181, p. 45.

Mariana Backarc (Site 1182)

While attempting to perform spud tests at the Rota-1 location, the Leg 191 science party continued to locate other sites in the vicinity that might provide a better environment for testing the HRRS. Another site, named the Mariana backarc, was located ~100 nmi south of Guam.

The location was out of the current path of Typhoon Saomai, so plans were made to transit to this location. The new location was ~10 hr from the Rota-1 location.

Upon arriving onsite, a short 3.5-kHz survey was conducted to verify a general location to perform the spud tests. On the morning of 6 September 2000, the drill pipe was lowered and test spuds began with a dual cam bit. The seafloor appeared to be dark lava flows. Water depth at the Mariana backarc site was generally in the neighborhood of 2875 m. The first two test spuds (Holes 1182A and 1182B) were without rotation and with the camera still down. The camera was left down to verify that the material was indeed hard. Penetrations of nearly 2 m were achieved in ~25 min of hammering with the 260 fluid hammer. Circulation to the surface was lost and the BHA required some overpull to free it from the formation.

The camera was then pulled and attempts to spud blind in Hole 1182C were made. A 95-min test resulted in a penetration of 5 m with rotation. The drilling achieved an average ROP of 3.16 m/hr. This ROP was considered quite good, taking into account the fact that this was a bare rock spud and that the seas were building with 1- to 2-m heaves noted due to the arrival of Typhoon Saomoi in the general area. The VIT was jumped and the bit was observed being pulled clear of the seafloor. The vessel was then offset 20 m to the north.

A second hole (Hole 1182D) with rotation was also attempted with the dual cam bit. This hole produced a total penetration of 3.5 m in 45 min, representing an ROP of 4.67 m/hr. The drill string actually had to be worked over an hour to free it from the formation. It was noted that without circulation exiting at the seafloor, the potential for getting the BHA stuck became quite high. At the conclusion of these four holes, the BHA was recovered so another type of underreamer bit could be tested along with the pulsation sub. Before the dual cam bit was removed from the hammer, the system was tested on the rig floor. This ensured that the hammer was still operating and that the slower ROPs seen were due to cuttings not being removed from the hole and not to the performance of the hammer itself.

A three-level pilot underreamer bit replaced the dual cam underreamer bit. A pulsation sub was positioned immediately above the hammer and charged with 3500 psi of nitrogen. The pulsation sub was added to see if any noticeable difference might be observed when this piece of equipment was in the BHA. The VIT/subsea TV was deployed after the bit was near the seafloor so a general spudding location could be observed with the camera. Because seas were continuing to build, the bit was not actually placed on the seafloor while the VIT frame was being recovered. Once the VIT/subsea TV was recovered, Hole 1182E was spudded. Drilling was performed to a depth of 4.5 m in 30 min, producing an ROP of 9 m/hr. Penetration in this hole was quite rapid at times, indicating that pillow lava might have been encountered. Hole 1182E was terminated at 4.5 m penetration. The bit was lifted out of the hole with some overpull. The vessel was then offset 5 m north.

The second test spud with a three-level pilot underreamer bit penetrated to 7 m in 145 min, producing an ROP of 2.9 m/hr. It was again felt that cuttings remained in the hole, causing the ROP to slow as the bit had to regrind cuttings. It also appeared at times that the bit might be drilling in breccia. There was some difficulty lifting the bit out of the hole at the conclusion of drilling Hole 1182F. The hammer was running intermittently (i.e., <50% of the time) because of the light WOB necessary during the spudding operations. The intermittent running of the hammer was caused by the bit lifting off the bottom of the hole, as the light WOB was outside of the AHC performance specification. The loss of WOB control was easily recognized by a large drop in operating pressure when the hammer went into the bypass flushing mode.

A final hole (1182G) was attempted after offsetting the *JOIDES Resolution* another 5 m. The final hole was drilled to 5-m penetration in 112 min, producing an ROP of 2.68 m/hr. Similar problems keeping the hammer continuously firing were noted. A summary of the holes drilled at the Mariana backarc location is present in Table **T5.** Further details are provided in Table **T6.**

T5. HRRS operation summary, Site 1182, p. 46.

T6. Drilling rates, Site 1182, p. 47.

At this point, there was not enough time left in the leg to recover the BHA and attempt to drill in casing and there was very little additional information that could be learned from further spud tests with either underreamer bit. Therefore, we decided to pull out of the hole and secure the hardware for transit to Guam. All the hardware was back on deck and the vessel was underway to Guam by early morning on 8 September 2000. The vessel arrived alongside the dock at 1500 hr on 8 September 2000.

Auxiliary Equipment Issues

The performance evaluation of the standpipe modifications, Hydril pulsation dampner, downhole pulsation dampner, and AHC are reviewed below.

Standpipe Vibration

The operation of the 260 fluid hammer on all runs during Leg 191 was significantly quieter than any of those experienced during Leg 179. The most significant improvement resulted from the addition of new braces to the standpipe throughout the derrick. There were a number of long, unsupported spans of standpipe within the derrick that went into resonance frequency when subjected to the reverberating hammer frequency through the fluid column in the drill string. A finite element analysis (FEA) was performed during the summer of 1999, simulating the frequency of the hammer to determine the consequences of exciting the standpipe and causing it to vibrate. As a result of the analysis, new standpipe braces were installed and this resulted in eliminating the vibration problems experienced previously during Leg 179.

Hydril Pulsation Dampner

The Hydril pulsation dampner located on the mud pumps was precharged to 900 psi. Over the past two years, SDS had been experimenting with pulsation dampners on other rigs when the hammer was being used onshore. The precharge pressure that SDS recommended could not be met because Trans-Sedco Forex policy specifies that the rated 5000-psi pulsation dampners could not be charged higher than 1000 psi. SDS recommended that the pulsation dampner be set at 1500–2000 psi.

Pulsation Sub

ODP and Houston Engineers developed a pulsation-dampner sub to be positioned immediately above the hammer. This dampner sub has a piston that is open to the inside of the pipe on one side and precharged to hydrostatic pressure with nitrogen on the other side. The concept was devised in hopes of eliminating fluid pulsations that might propagate up the drill string. The concept was to allow the piston to compress the nitrogen and damp out standing or random pressure pulses generated by the hammer. The first series of tests (Holes 1180A–1182D) were performed without the pulsation sub in the BHA. Once the pulsation sub was introduced in Hole 1182E, the slight vibration that was present before was further damped to only a slight audible hum.

About midway through the final spud test, a slight vibration reappeared. We thought that the seals in the piston might have deteriorated to a point where the nitrogen escaped and rendered the pulsation sub ineffective. However, upon recovering the BHA and checking the pressure behind the piston, the full 3500 psi was still intact. The ID of the tool was cleaned with a high-pressure car-wash nozzle before bleeding off the nitrogen to 100 psi for storage.

We planned to disassemble the tool to see if there was visible damage either to the seals or internal cylinder or piston. However, this was not completed because the seas were too rough to move the pulsation sub into the core tech shop for disassembly. The sub was recrated for offloading and storage in Guam.

Standpipe pressures were recorded to determine if the pulsation sub did, in fact, contribute to reduction in pulsation propagated through the fluid in the drill pipe. The data collected will be reduced on a time-available basis.

Active Heave Compensator

During spudding tests at Holes 1182E–1182G, the hammer constantly lifted off the bottom of the hole because the driller was unable to maintain a constant WOB while using the AHC. The lower-than-expected ROPs from the spud tests were a direct result of the hammer operating only 40%–50% of the time. The low ROP was caused by trying to maintain the 8000–10,000 lb recommended WOB on the hammer. This resulted in the bit being lifted off the seafloor 50%–60% of the time.

It was later learned that the low WOB was below the design criteria of the active heave system for absolute drill string motion. The AHC maintains drill string motion to between 4 and 6 in absolute from the seafloor. Due to drill string properties and stretch, this absolute motion results in a WOB variation of 7,000 to 10,000 lb.

With the hammer operating in an on/off mode, the generated cuttings were not removed from the bit face and thus were being reground. This regrinding of cuttings and the inability to keep the hammer running continuously significantly reduced the overall ROP.

The inability to compensate with <10,000-lb WOB was noted by the pressure drop that occurred in the hammer, indicating that the bit was off the bottom and in a flushing mode. However, the rod-bias load (i.e., WOB) displayed by the TruVu system was still reporting a weight above 10,000 lb anywhere from 5 to 15 s after the hammer went into flushing mode. This discrepancy is a result of the methodology used by the active heave compensator to calculate the rod-bias load. During a post-leg debriefing, we learned that Maritime Hydraulics (MH) added an algorithm to the operational software to obtain a usable AHC WOB based on the bias force. The algorithm performs an average of the AHC hydraulic forces over a 30-s period. The output is the so-called AHC WOB bias force, which although it is updated each second, exhibits a lag as it is averaged over the previous 30 s. This explains the large lag time between the AHC WOB readings and the standpipe pressure. Not having this knowledge prior to Leg 191 spudding tests severely hampered the operation and frustrated the drilling crew. It was also revealed after Leg 191 that there is no way to change this averaging function without having Maritime Hydraulics change the software code or until a filtered WOB circuit can be implemented.

To compound this problem, it appeared that the amount of weight necessary to close the hammer piston was higher than it should be for the hammer to fire and begin cycling. As testing progressed, higher WOBs were tried to keep the hammer operating to avoid the on/off scenario that was experienced earlier. This action was challenging, because bare-rock spudding operations require the driller to accurately know the amount of WOB being applied to the bit/BHA. The driller was able to increase the spudding weight to ~15,000 lb in order to keep the hammer firing. This was higher than the accepted spudding weight for the BHA, but it appeared that the displayed WOB was less than what was actually reaching the bit while attempting to maintain the WOB for bare-rock spud-in between 5,000 and 10,000 lb. The lag time in response between the pressure gauge reading and the driller's reaction to counteract the WOB reduction added to the driller's difficulty in operating the fluid hammer and subjected the BHA to high axial loads.

The hammer-drill operation has elevated the need for a reliable and stable hook-load measurement. The inertial effects on the traveling block from the AHC imparts a dynamic response exhibited by needle bounce on the Martin Decker weight indicator. The inertial effects of the traveling block responding to ship motion have been measured as creating a 5000- to 10,000-lb WOB variation on the Martin Decker gauge. The addition of the AHC and its rapid response of the hook-load signal from the crown-mounted load cell have resulted in unusable Martin Decker gauge data.

Thus, the Martin Decker weight indicator could not be used because the unfiltered data measurements supplied caused wild swings (i.e., needle bounce) in the displayed weight. A filter was supposed to have been prepared and installed to correct this problem with the Martin Decker gauge as well as the input signal supplied to the TruVu rig instrumentation system during Leg 191. However, by the time this equipment was needed for the HRRS, the wire connecting the crown-mounted load cell had been damaged and a replacement was not available. Therefore, only the rod load bias force (i.e., WOB) averaged over a

30-s period and displayed on the TruVu console could be used by the driller as a guide to what the actual WOB might be.

Postcruise, it was suggested that possibly the other forces were not being taken into account and may need to be added into the WOB recorded by TruVu. It is unfortunate that this possibility was not previously known; if it had been, it could have been applied at sea during the spud tests conducted with the SDS hammer. Additional weight was added to the spudding weight, but this was an estimate by the driller because the only indication was that the hammer was not firing at a known closing force of 8000 lb.

Leg 191 Highlights

Despite time constraints that prevented thorough testing of the HRRS, a number of accomplishments were realized within the time frame that was available. These included the following:

1. The 260 fluid hammer was successfully operated in 2880 m of water at the Mariana backarc location.
2. Two types of underreamer bits (i.e., dual cam and three-level pilot) were tested and confirmed acceptable (without any damage to the bit body/arms and without loosing any tungsten carbide compacts).
3. Bare-rock spudding was performed in volcanic lava flows with ROPs ranging from 2.7 to 9 m/hr.
4. Supplemental bracing of the *JOIDES Resolution* standpipe during dry dock resolved the harmonic vibrations experienced during Leg 179.
5. The pulsation sub appears to assist in reducing vibration in the *JOIDES Resolution* standpipe.
6. Bare-rock spuds were successfully performed in sea states of 2.5–4 m with the use of the AHC.
7. The hammer operated flawlessly without damaging or breaking any internal hammer components.
8. Holes were spudded, both visually with the assistance of the VIT/subsea TV, as well as blind.
9. The 260 fluid hammer was operated with the AHC, despite stiffness and lag time of the system.
10. The drill crew was comfortable with the hammer operation.
11. No new operational problems were noted during the hammer tests while operating at full flow rates of 80–90 spm.
12. Redesign of the 260 fluid hammer jet and top sub connections resulted in a stronger BHA that withstood bare rock spudding in heave states of 2.5–4 m.
13. Data gathered pertaining to the drill ship and traveling block acceleration validated the real-time dynamic analysis that will be used to resolve weight indicator fluctuations in the future during AHC operations.

Conclusions

The second deployment of the 260 fluid hammer and associated hardware was a success for the limited testing that was achieved. The fact the bits and hammer withstood the forces they were subjected to with the 2.5- to 4-m rig-floor heave while achieving reasonable penetration rates clearly demonstrates that advances in bit technology have been made since Leg 179. The addition of the AHC to the *JOIDES Resolution* contributed to the success of the hammer tests during significant rig floor heave, not withstanding the dynamic effects on the Martin Decker weight indicator. Even though <9 hr of actual hammer drilling took place, none of the hardware was damaged on either of the bits or hammer. The modifications to the derrick coupled with the introduction of the pulsation sub allowed the hammer to operate at full pressure and flow rate.

It was realized long before the conclusion of Leg 191 that not all the test objectives for the HRRS project would be attempted because of the loss of time due to circumstances beyond our control. Leg 193 was identified as a potential leg where the HRRS might be deployed to drill in a short string of casing to establish a foothold from which to conduct coring operations. Therefore, plans were put in place before the end of Leg 191 to have the HRRS equipment stored in Guam and remobilized onboard during Leg 193.

Recommendations

Short Term

1. Have the top sub and jet sub modified to accept the necessary Baker float valves for subsurface operation.
2. Manufacture a retainer ring for the connections where the Baker float valve resides.
3. Explore the possibilities with Trans-Sedco Forex on whether the Hydril pulsation dampner attached to the mud pumps onboard the *JOIDES Resolution* can be set at a higher operating pressure when the fluid hammer is operated.
4. Finalize the design of the WOB filter and install it on the *JOIDES Resolution* as an operational system to counteract the inertial effects of the traveling block and the lag time in WOB response.
5. Develop a set of curves or other means to account for drill string physical properties and absolute motion on the WOB.
6. Reduce the data recorded and assess whether the pulsation sub contributed to reducing the vibration generated by the hammer and whether further use of this sub on subsequent HRRS work is warranted.

Long Term

1. Obtain time during upcoming legs when the HRRS testing can be completed as outlined in the Leg 191 prospectus.
2. Prepare the necessary crossover subs for using 8.25-in drill collars in place of the 9.5-in drill collars.

REFERENCES

Dixon, T.H., and Stern, R.J., 1983. Petrology, chemistry, and isotopic composition of submarine volcanoes in the southern Mariana arc. *Geol. Soc. Am. Bull.,* 94:1159–1172.

Stern, R.J., Bloomer, S.H., Lin, P.-N., and Smoot, N.C., 1989. Submarine arc volcanism in the southern Mariana arc as an ophiolite analog. *Tectonophysics,* 168:151–170.

Figure F1. Bathymetry map of Inutile Seamount made by the *JOIDES Resolutio*n using the 3.5-kHz echo sounder. Contour interval is 200 m, and depths are labeled in uncorrected meters. Thin lines show ship tracks with time in UTC. Crosses show the locations of Sites 1180 and 1181. A–A′ and B–B′ indicate locations of echo sounder profiles in Figures F2, p. 23, and F3, p. 24.

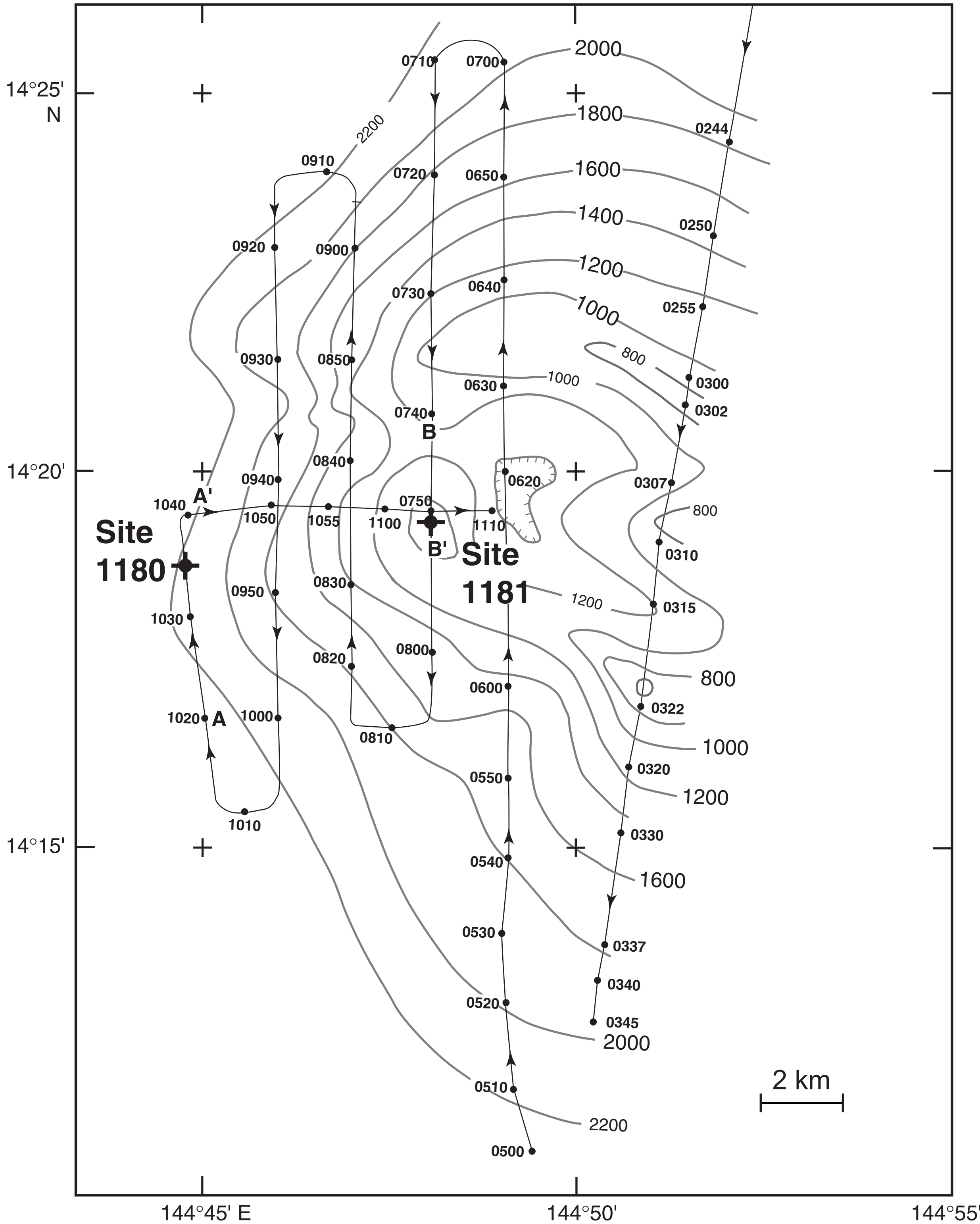


Figure F2. Site 1180 3.5-kHz echo-sounder profile. A–A′ corresponds to labels showing track on Figure F1, p. 22.

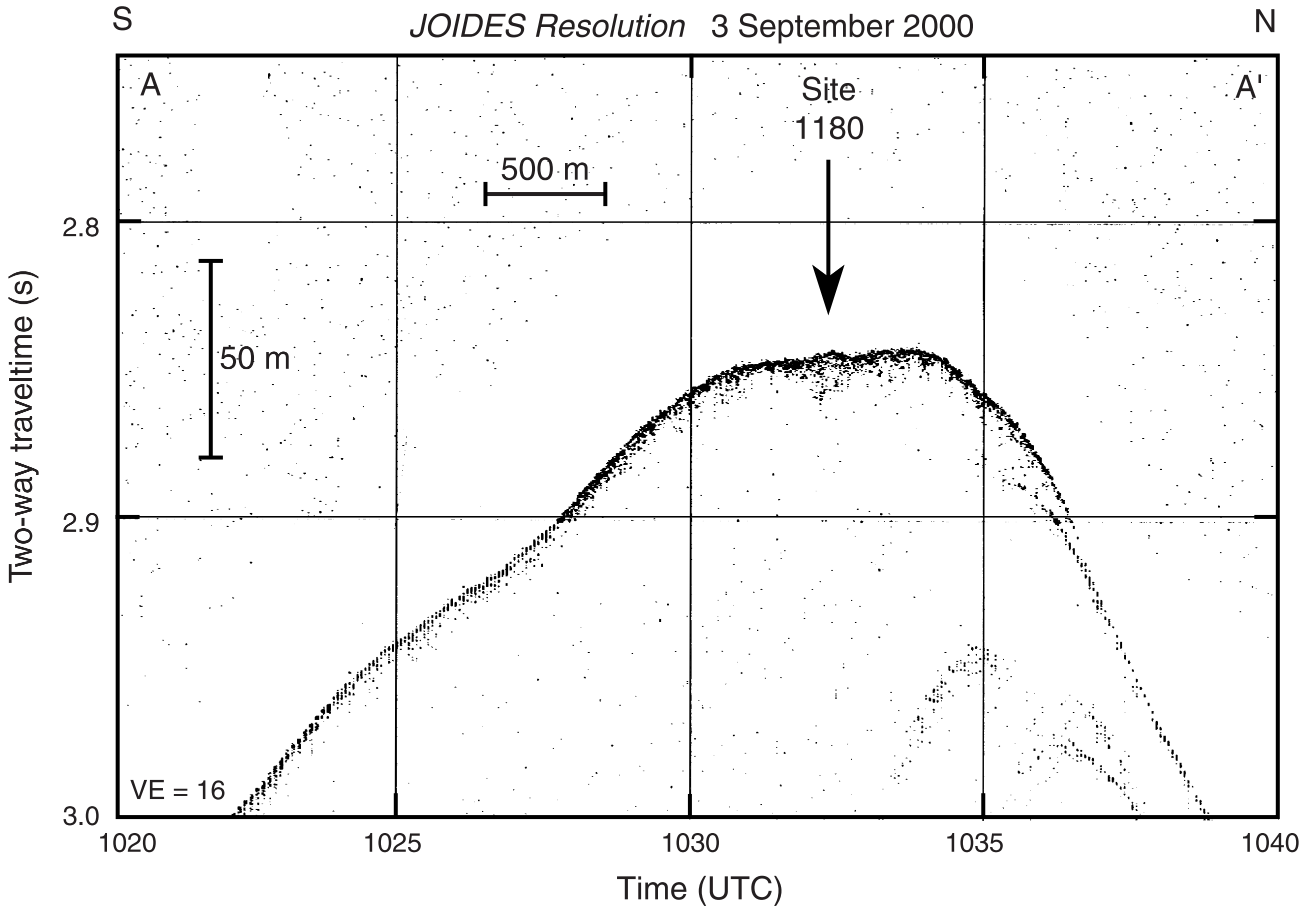


Figure F3. Site 1181 3.5-kHz echo-sounder profile. B–B′ corresponds to labels showing track on Figure **F1**, p. 22.

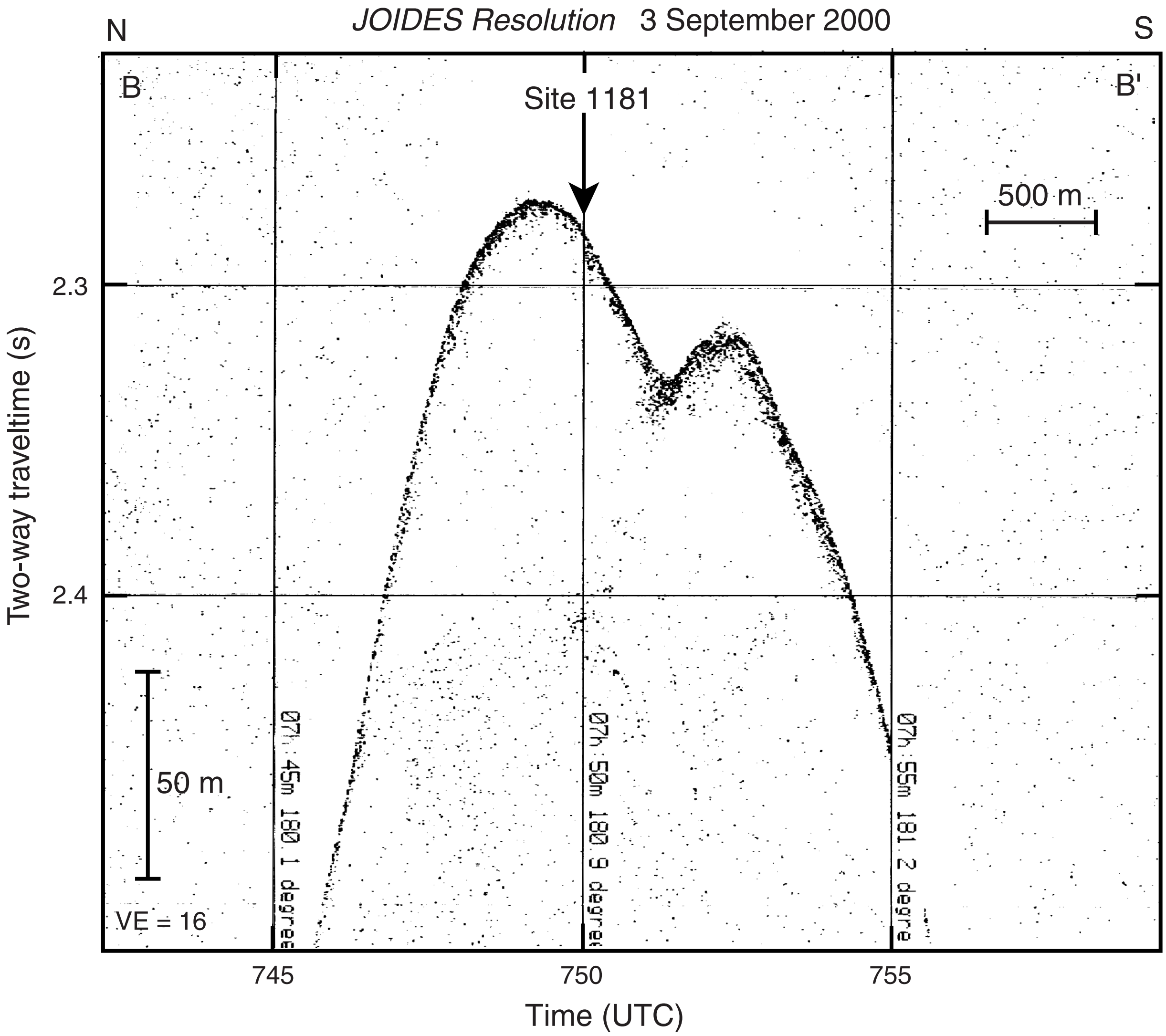


Figure F4. Bathymetry map of Martillo Seamount made by the *JOIDES Resolution* using the 3.5-kHz echo sounder. The contour interval is 50 m, and depths are labeled in uncorrected meters. Thin lines show ship tracks with time in UTC. The cross shows the location of Site 1182. A–A′ indicates the limits of the echo-sounder profiles in Figure F5, p. 26.

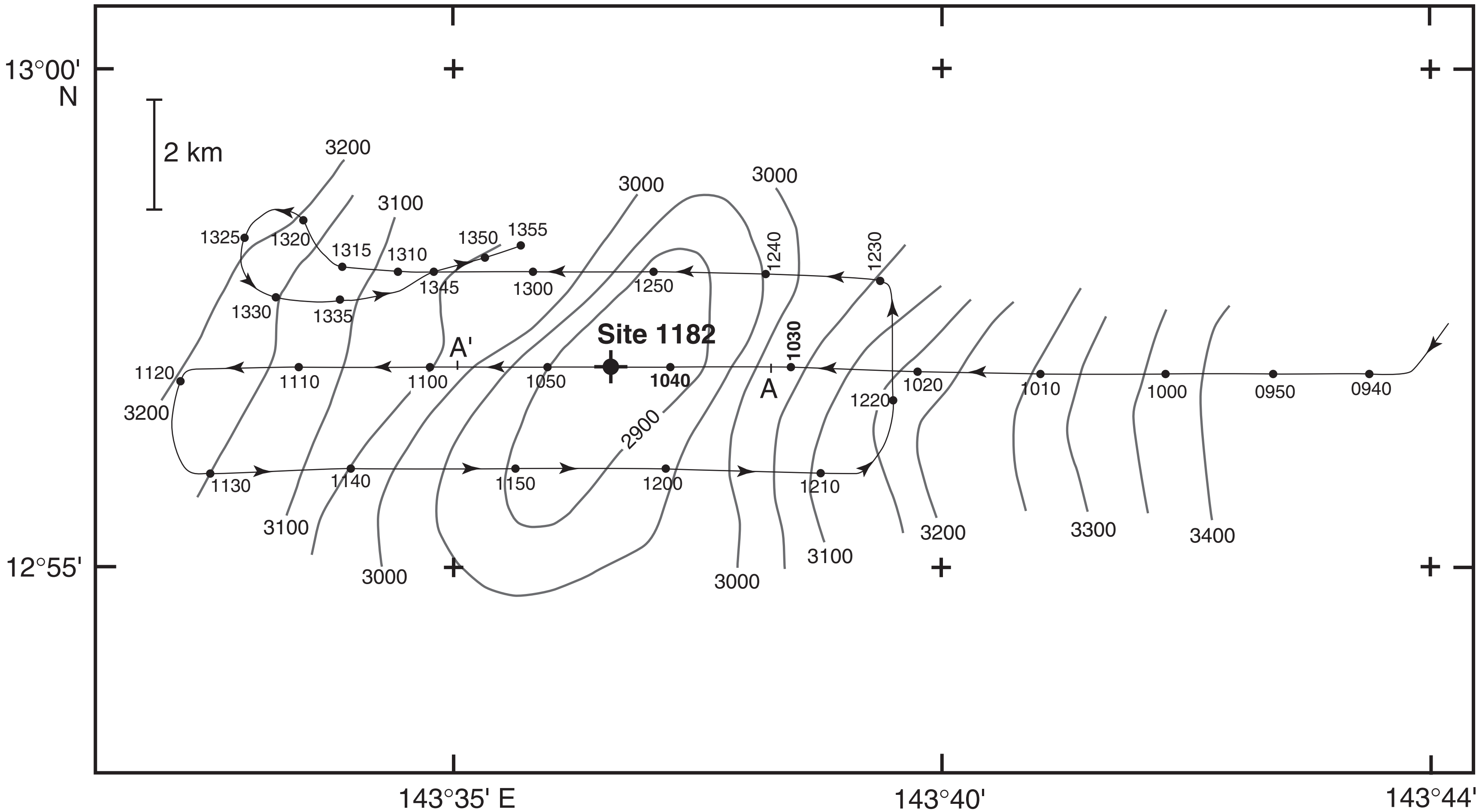


Figure F5. 3.5-kHz echo-sounder profile over Martillo Seamount. A–A′ corresponds to labels showing track on Figure **F4,** p. 25.

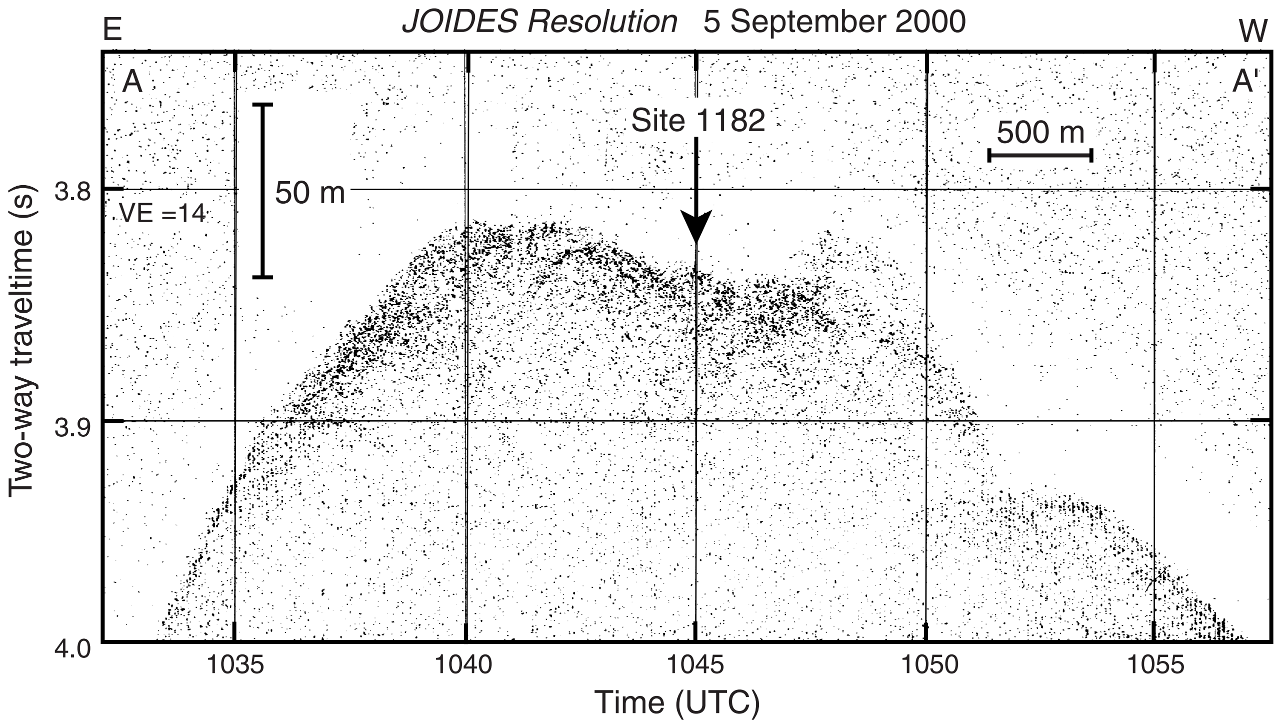


Figure F6. Hard-rock reentry system (HRRS) deployment. **A.** HRRS assembly tripped to the seafloor. **B.** HRRS drilled in. **C.** HRRS reentry cone free-fall deployment. **D.** Completed HRRS installation.

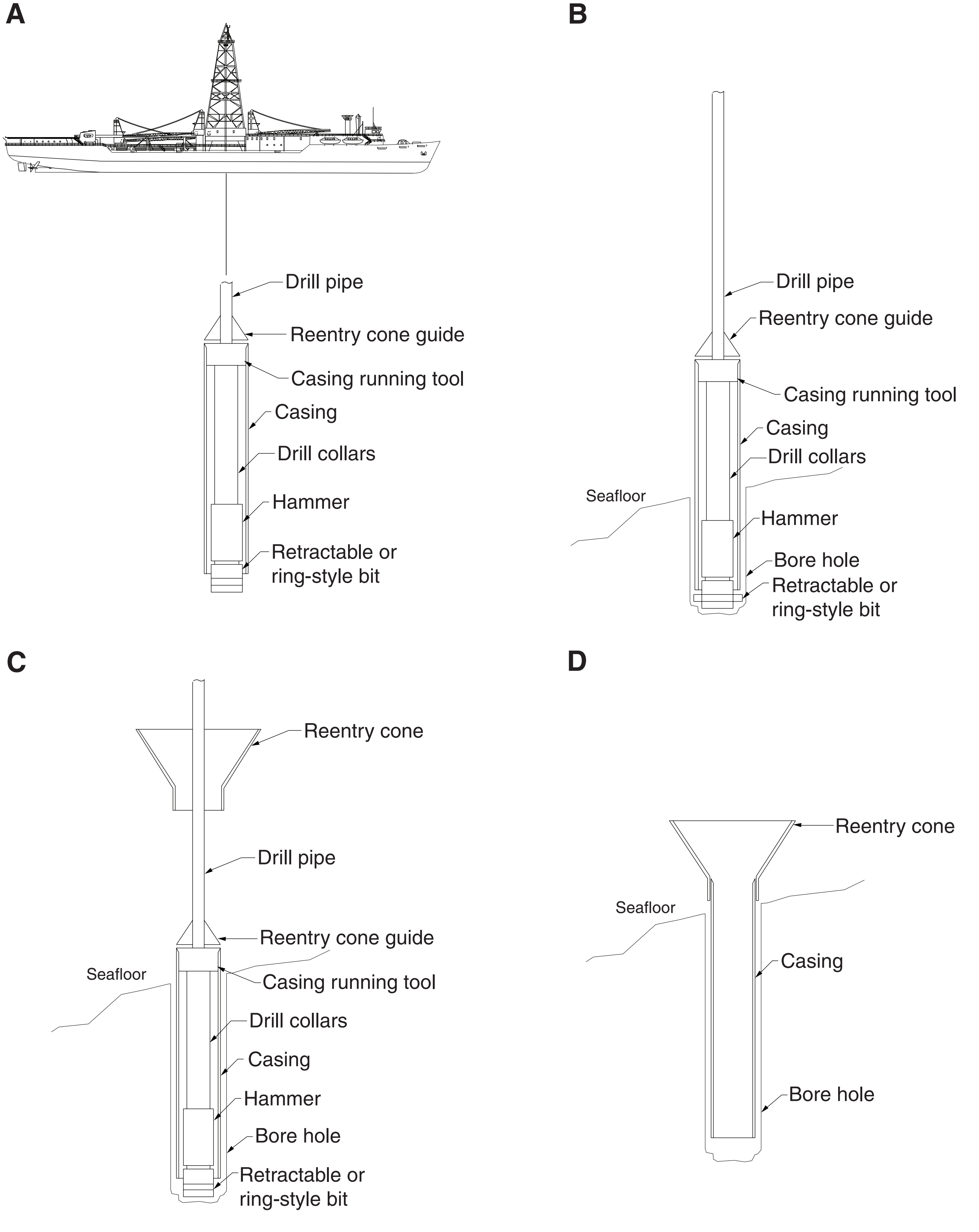


Figure F7. Running tool release after casing is drilled to depth. **A.** Reentry cone is deployed after casing is drilled in. **B.** Running tool is withdrawn after the dogs are released. Dashed lines show non-running tool components.

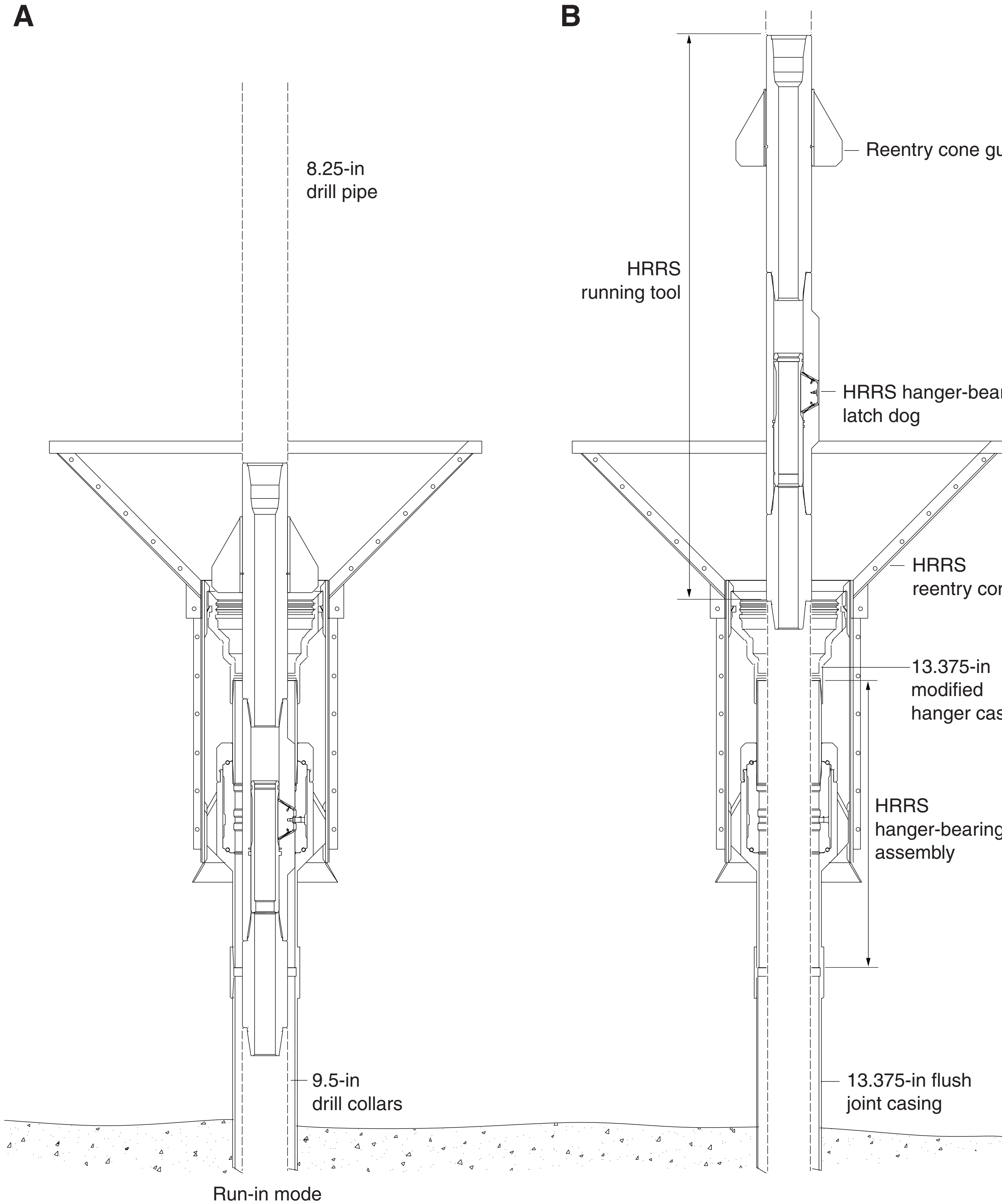


Figure F8. Hard-rock reentry system setup. NC-70 connections are cut on 9.5-in bodies. FHM = full hole modified, CADA = cam actuated drilling assembly.

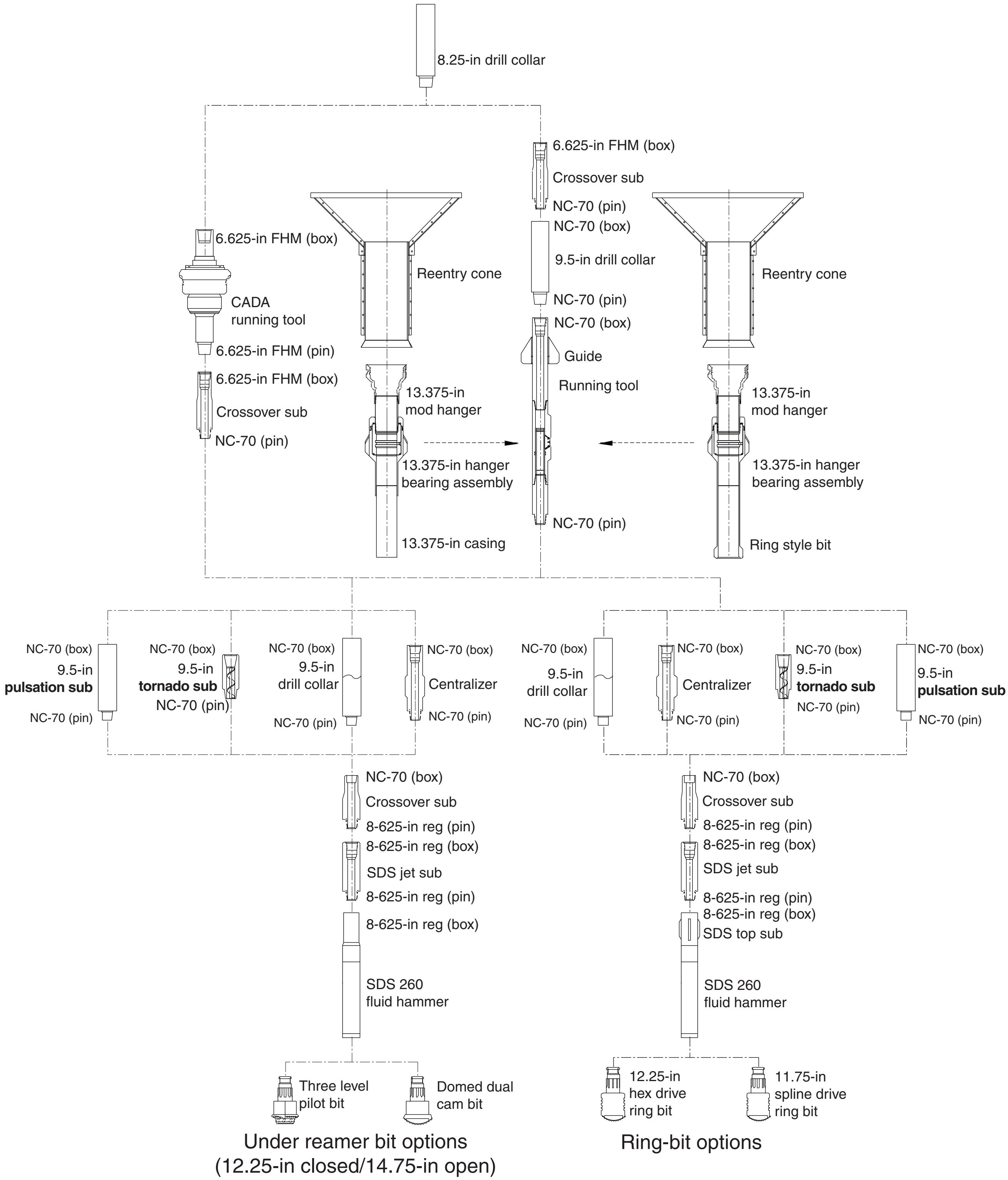


Figure F9. SDS Digger Tools 260 fluid hammer.

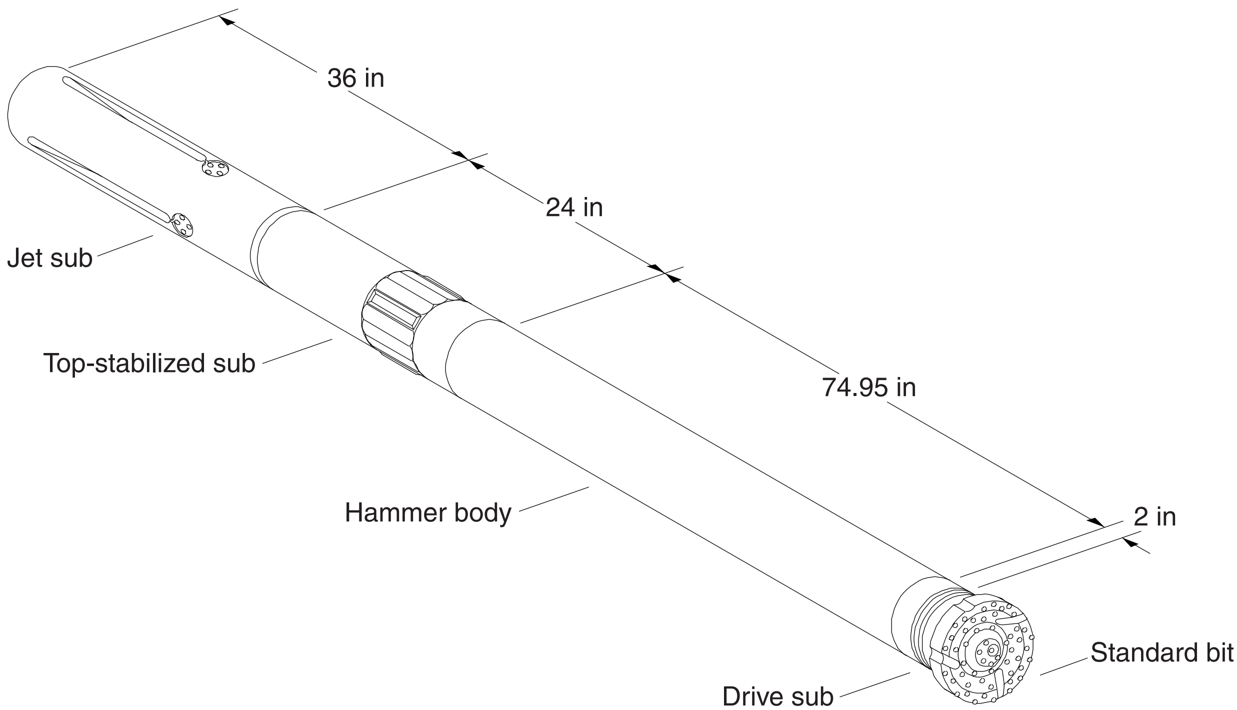


Figure F10. SDS 260 fluid hammer and test bit configurations. The make-up torque is shown in parenthesis.

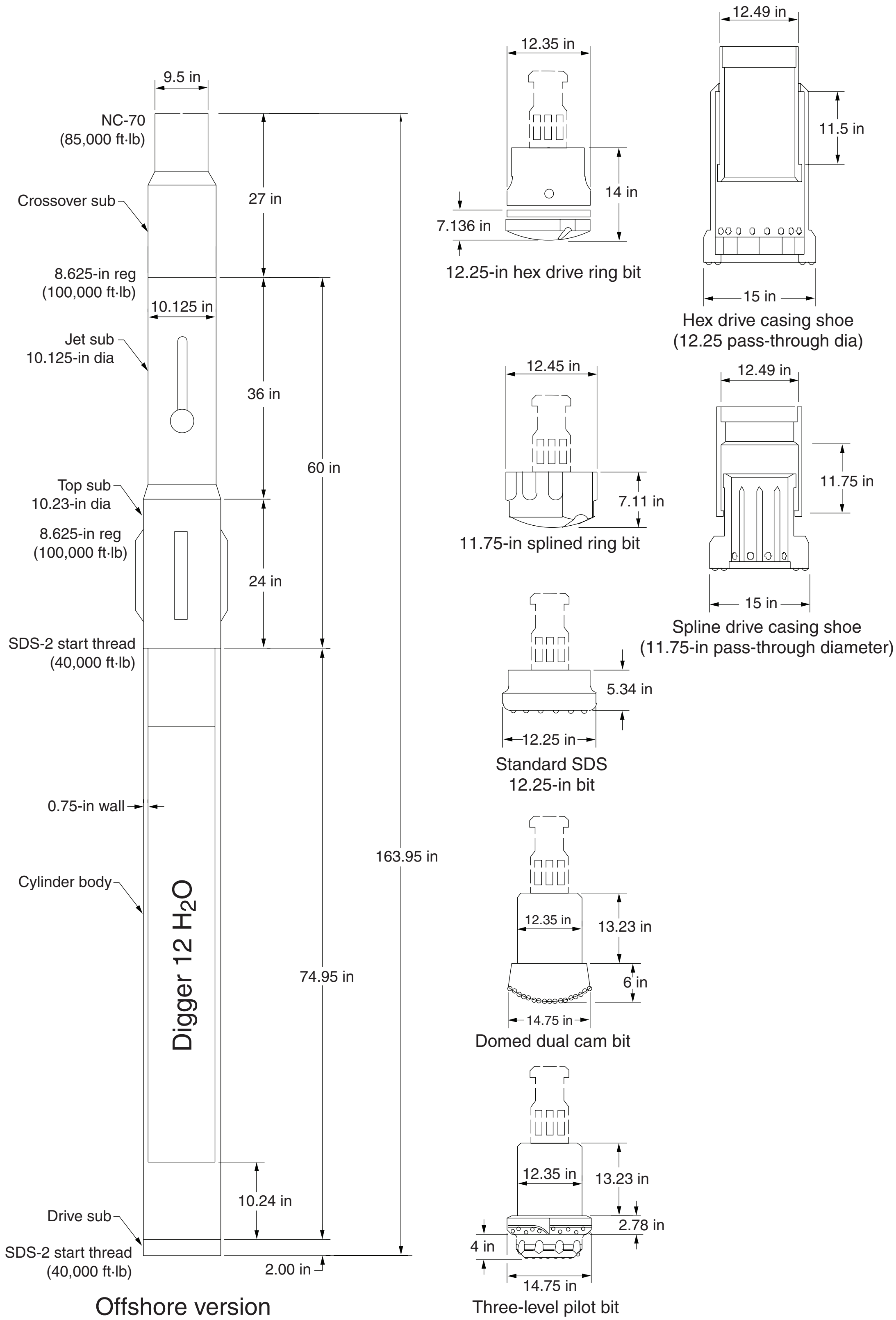


Figure F11. SDS modified top sub with centralizer pads (ODP style with 8.625-in reg box connection).

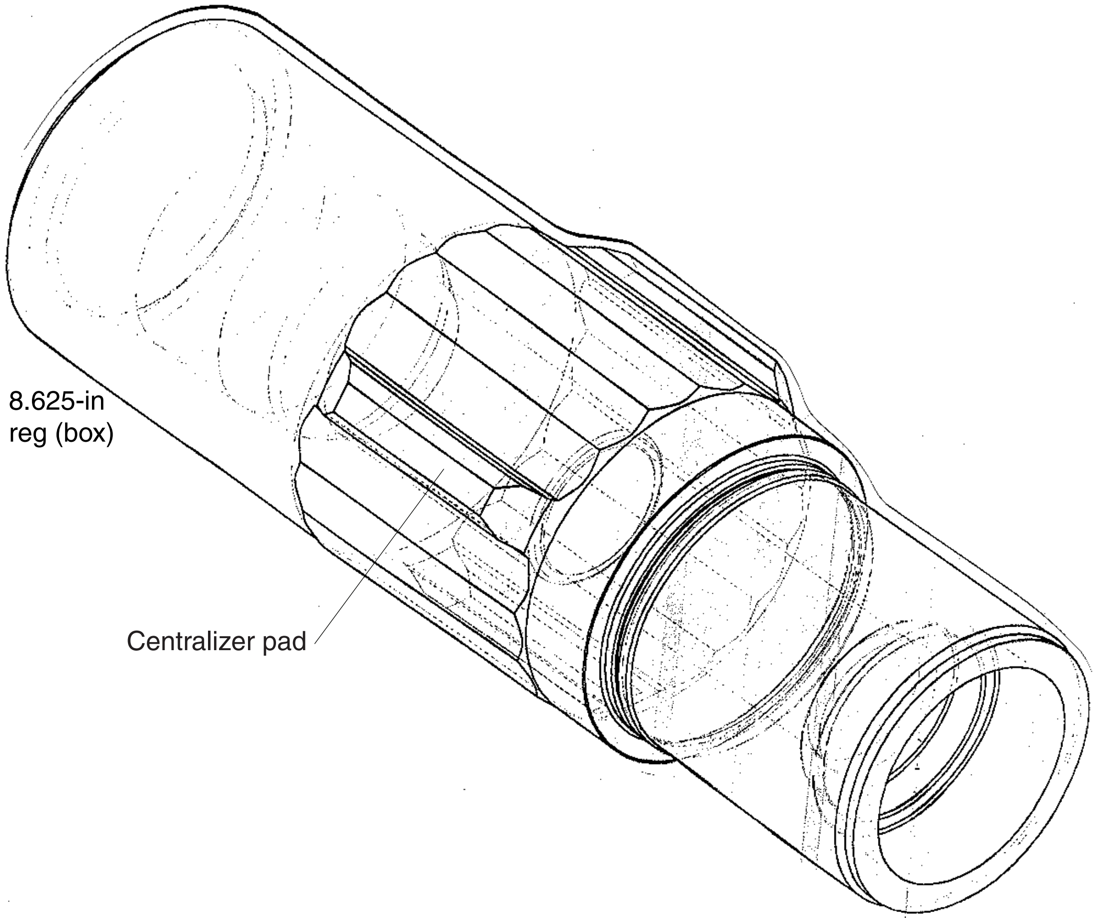


Figure F12. SDS modified jet sub (ODP style with 8.625-in reg connections).

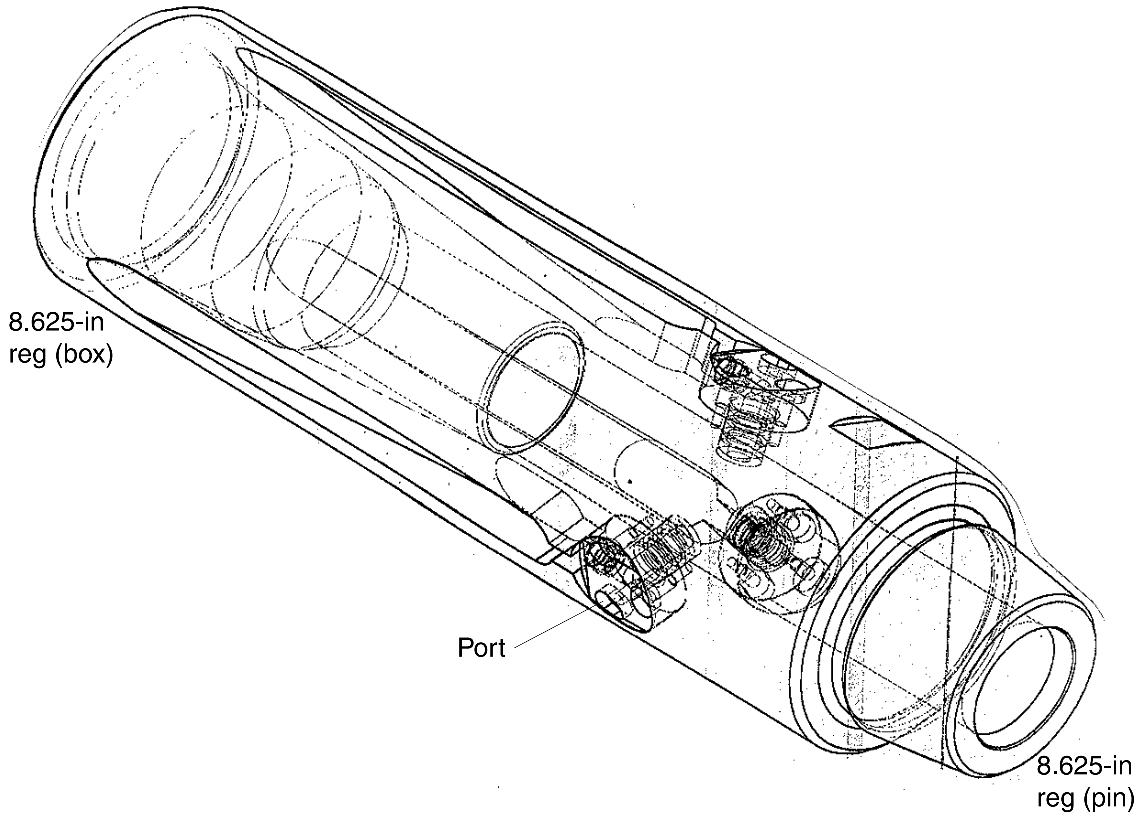


Figure F13. Profile of the dual cam underreamer bit. Tungsten carbide inserts are not illustrated.

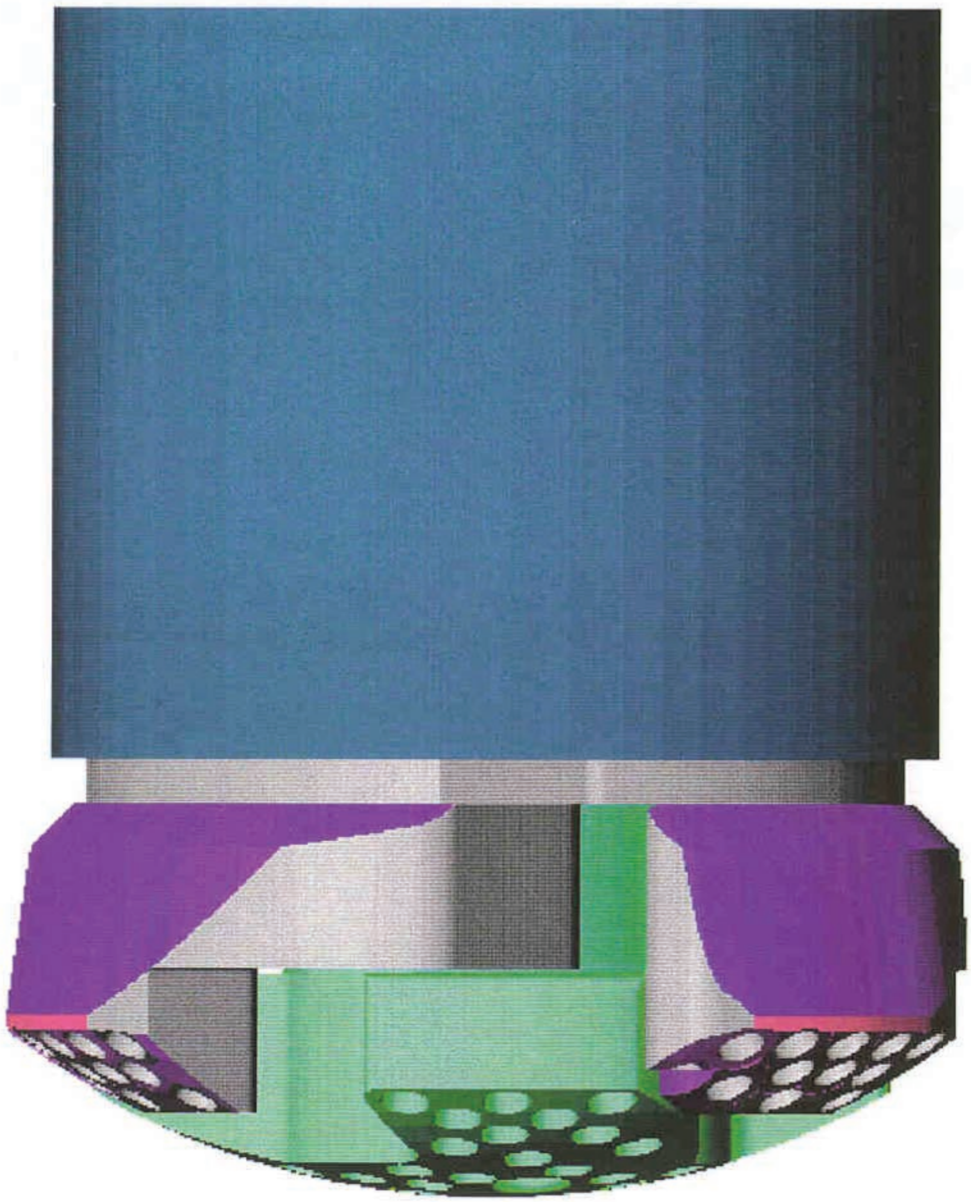


Figure F14. Side view of the dual cam underreamer bit with arms open. Tungsten carbide inserts are not illustrated.

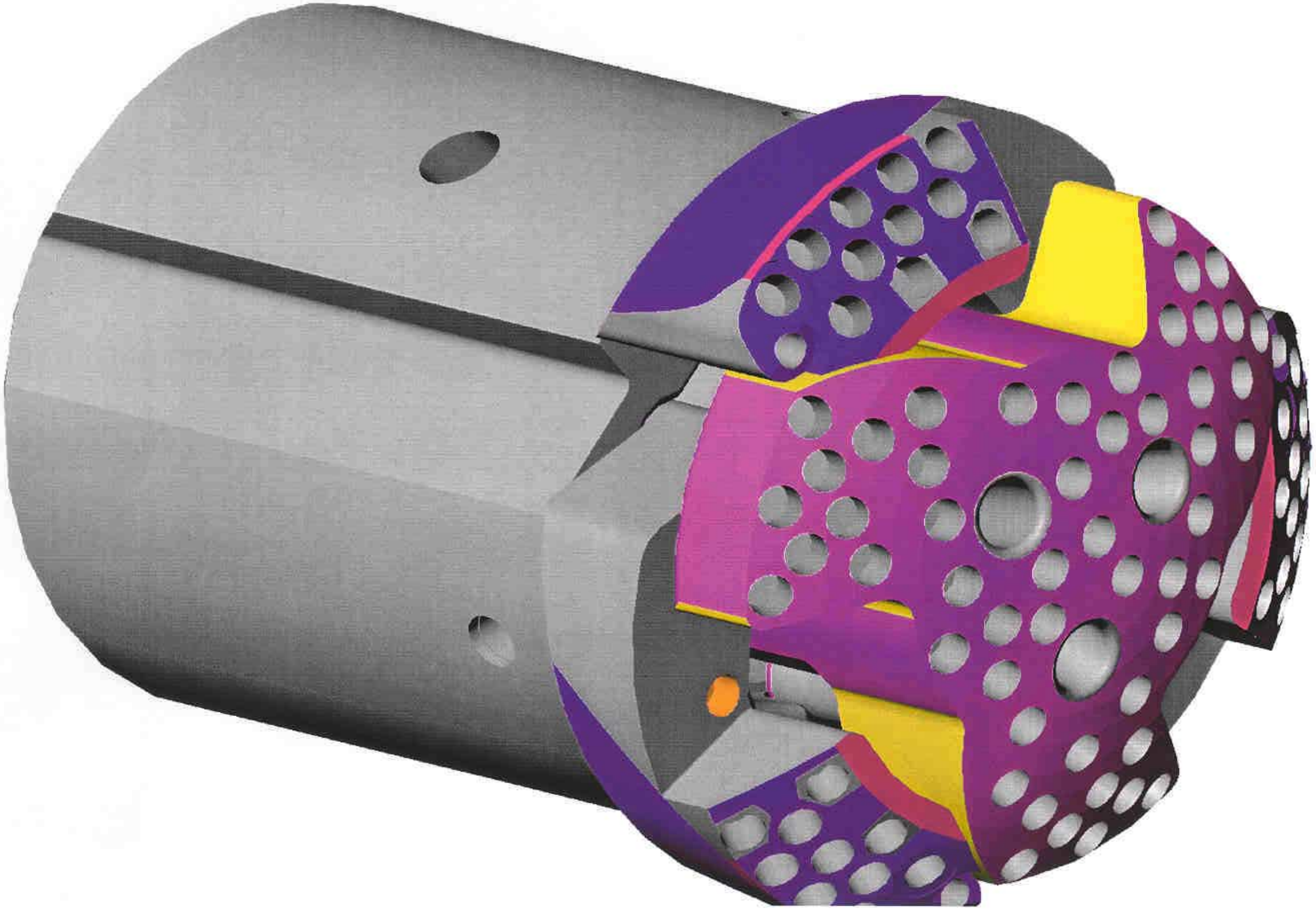


Figure F15. Pilot shank of the dual cam underreamer bit. Tungsten carbide inserts are not illustrated.

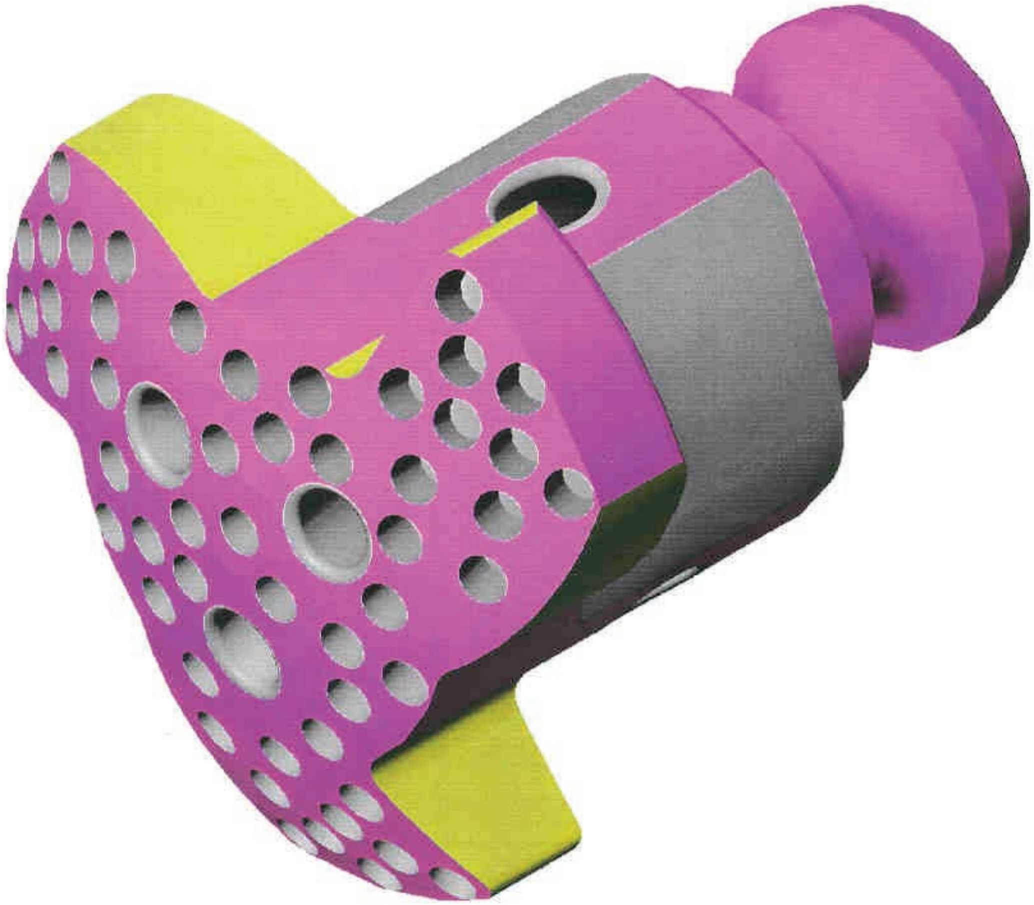


Figure F16. Dual cam underreamer bit in the open position. Tungsten carbide inserts are not illustrated.

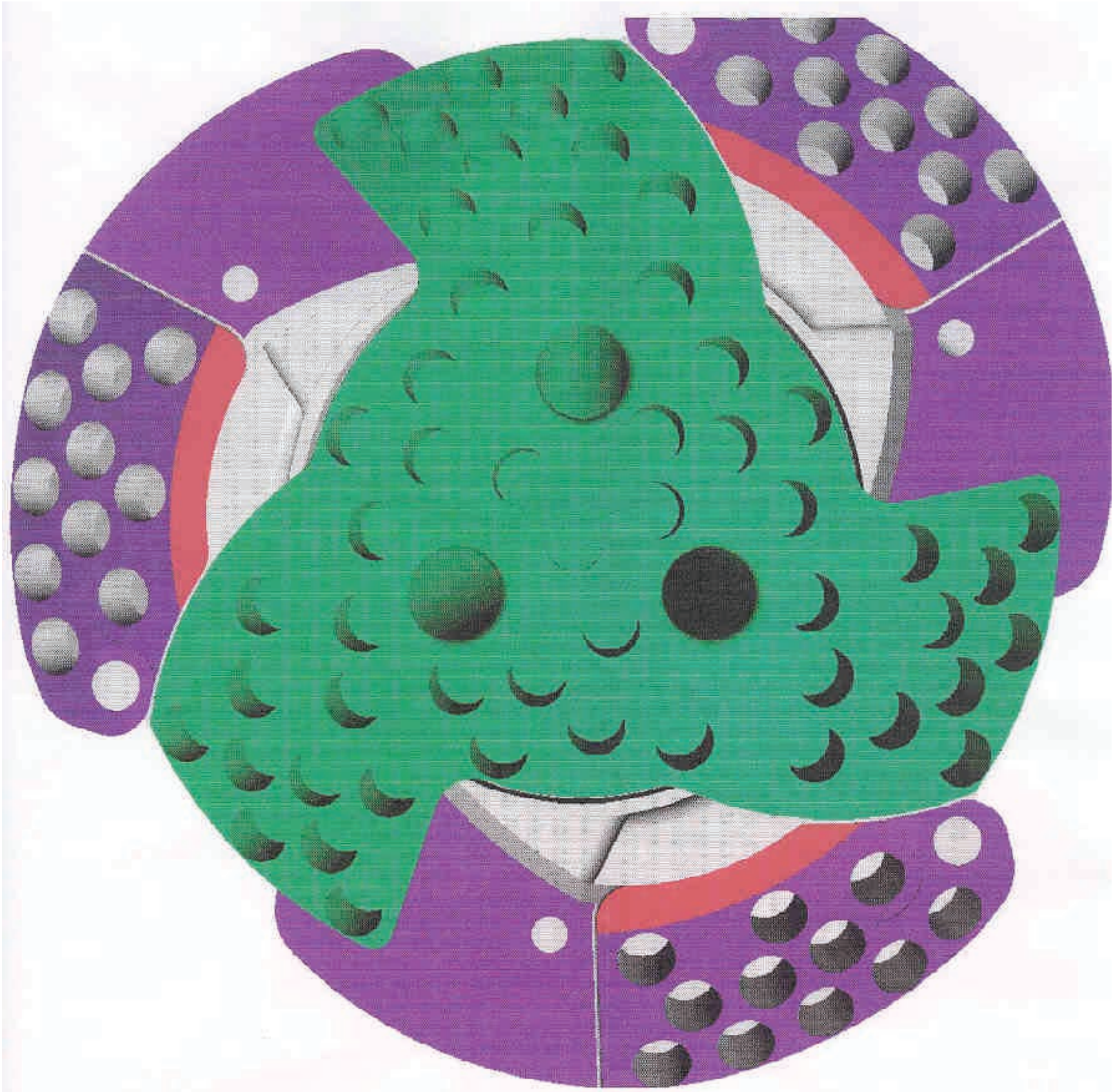


Figure F17. Dual cam underreamer bit in the closed position. Tungsten carbide inserts are not illustrated.

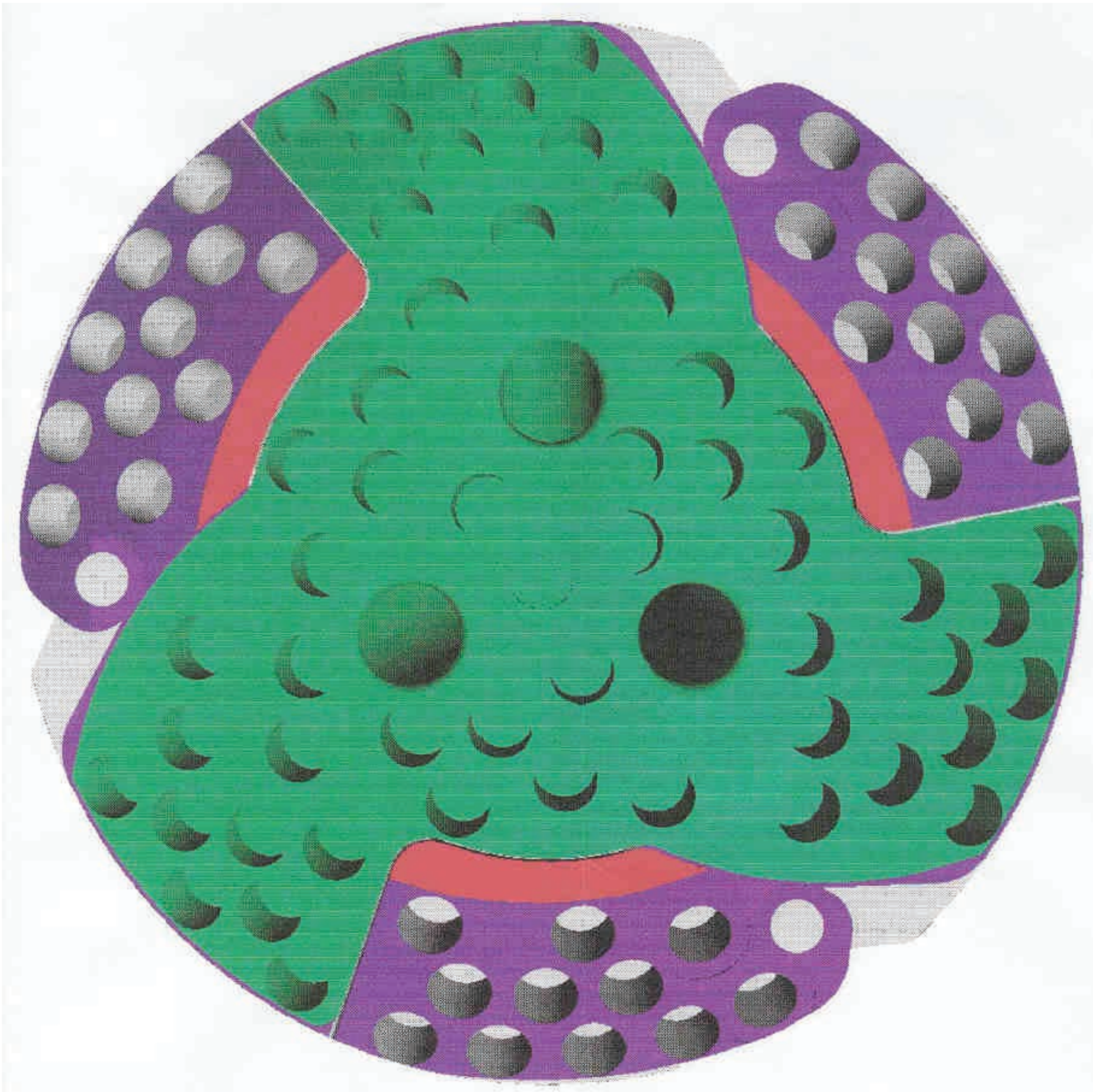


Figure F18. Three-level flat-face underreamer pilot bit. Tungsten carbide inserts are not illustrated.

Figure F19. Three-level flat-face underreamer bit. Tungsten carbide inserts are not illustrated.

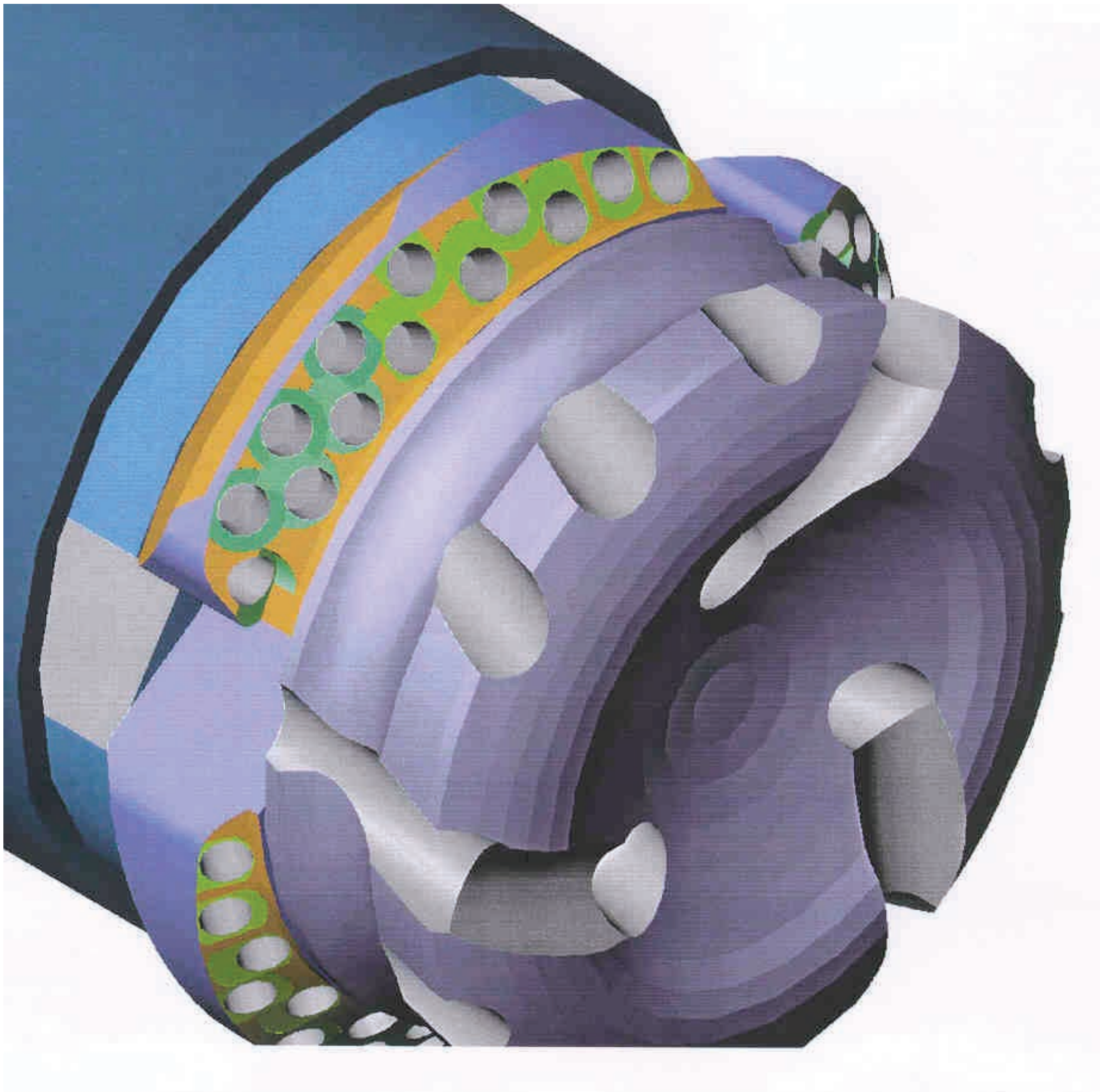


Figure F20. Pulsation sub. Both connections are NC-70. OD = outer diameter, ID = inner diameter.

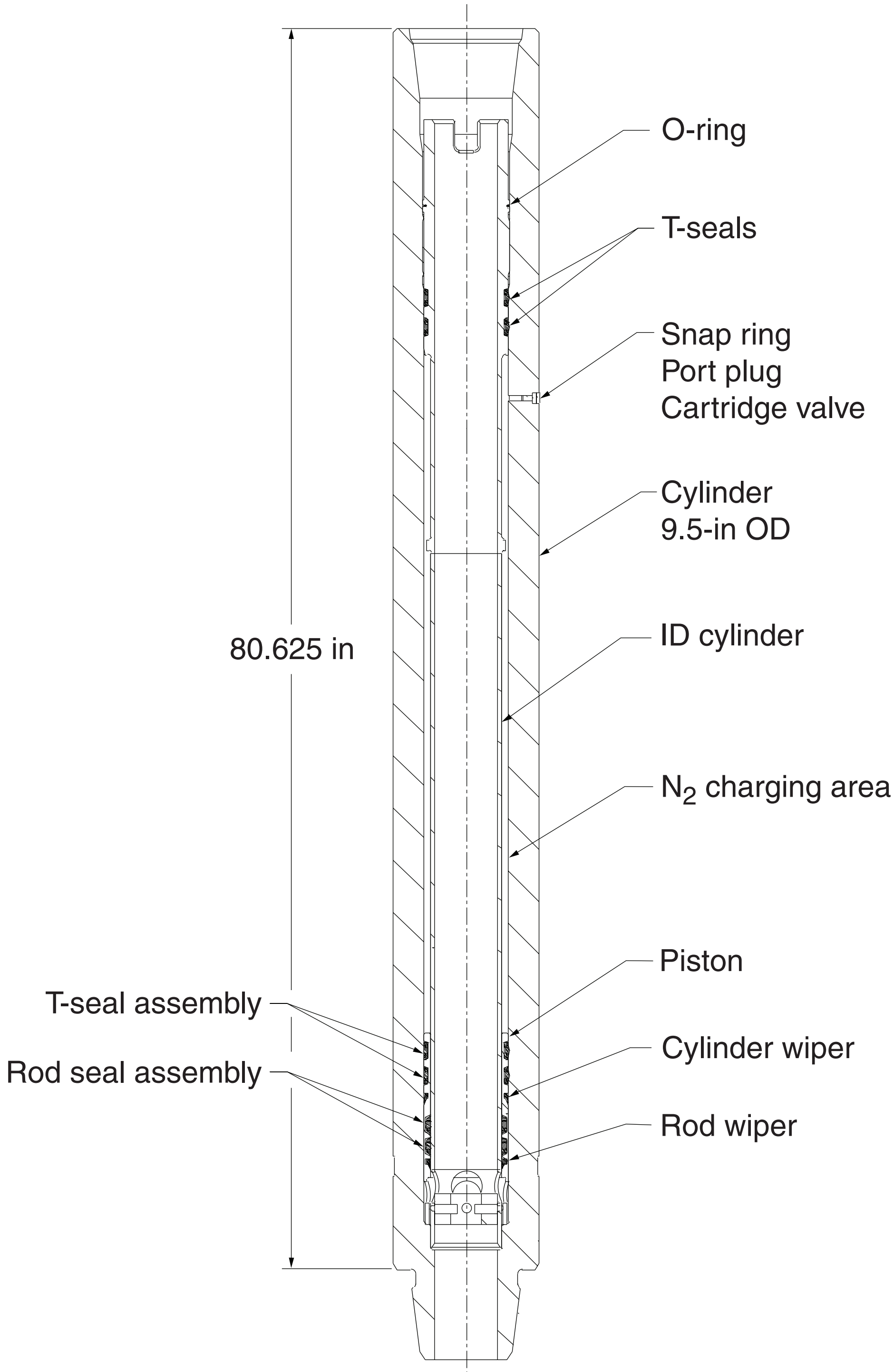


Table T1. Operations summary, Sites 1180 and 1181.

Hole 1180A
Latitude: 14°19.25′N
Longitude: 144°48.00′E
Time on site (hr): 18.0
Time on hole (hr): 15.75 (2200 hr, 3 September–1345 hr, 4 September 2000)
Seafloor (drill-pipe measurement from rig floor, mbrf): 2157.0
Distance between rig floor and sea level (m): 11.5
Water depth (drill-pipe measurement from sea level, m): 2145.5
Total depth (drill-pipe measurement from rig floor, mbrf): 2162.0
Total penetration (meters below seafloor, mbsf): 5.0
Comments: hammer drill system testing only; no coring

Hole 1180B
Latitude: 14°19.25′N
Longitude: 144°48.00′E
Time on hole (hr): 0.5 (1345 hr, 4 September–1415 hr, 4 September 2000)
Seafloor (drill-pipe measurement from rig floor, mbrf): 2157.0
Distance between rig floor and sea level (m): 11.5
Water depth (drill-pipe measurement from sea level, m): 2145.5
Total depth (drill-pipe measurement from rig floor, mbrf): 2165.0
Total penetration (meters below seafloor, mbsf): 8.0
Comments: hammer drill system testing only; no coring

Hole 1180C
Latitude: 14°18.51′N
Longitude: 144°44.84′E
Time on hole (hr): 1.75 (1415 hr, 4 September–1600 hr, 4 September 2000)
Seafloor (drill-pipe measurement from rig floor, mbrf): 2132.0
Distance between rig floor and sea level (m): 11.5
Water depth (drill-pipe measurement from sea level, m): 2120.5
Total depth (drill-pipe measurement from rig floor, mbrf): 2135.0
Total penetration (meters below seafloor, mbsf): 3.0
Comments: hammer drill system testing only; no coring

Hole 1181A
Latitude: 14°19.25′N
Longitude: 144°48.00′E
Time on site: 11.0 hr
Time on hole (hr): 2.25 (2315 hr, 4 September–0130 hr, 5 September 2000)
Seafloor (drill-pipe measurement from rig floor, mbrf): 995.0
Distance between rig floor and sea level (m): 11.5
Water depth (drill-pipe measurement from sea level, m): 983.5
Total depth (drill-pipe measurement from rig floor, mbrf): 998.0
Total penetration (meters below seafloor, mbsf): 3.0
Comments: hammer drill system testing only; no coring

Hole 1181B
Latitude: 14°19.25′N
Longitude: 144°48.00′E
Time on hole (hr): 2.0 (0130 hr, 5 September–0330 hr, 5 September 2000)
Seafloor (drill-pipe measurement from rig floor, mbrf): 981.0
Distance between rig floor and sea level (m): 11.6
Water depth (drill-pipe measurement from sea level, m): 969.4
Total depth (drill-pipe measurement from rig floor, mbrf): 984.0
Total penetration (meters below seafloor, mbsf): 3.0
Comments: hammer drill system testing only; no coring

Hole 1181C
Latitude: 14°19.25′N
Longitude: 144°48.00′E
Time on hole (hr): 6.75 (0330 hr, 5 September–1015 hr, 5 September 2000)
Seafloor (drill-pipe measurement from rig floor, mbrf): 970.0
Distance between rig floor and sea level (m): 11.6
Water depth (drill-pipe measurement from sea level, m): 958.4
Total depth (drill-pipe measurement from rig floor, mbrf): 973.0
Total penetration (meters below seafloor, mbsf): 3.0
Comments: hammer drill system testing only; no coring

Table T2. Drilling summary, Site 1182.

Hole 1182A
Latitude: 12°57.0′N
Longitude: 143°36.6′E
Time on site (hr): 53.25
Time on hole (hr): 7.0 (0200, 6 September–0900, 6 September 2000)
Seafloor (drill-pipe measurement from rig floor, mbrf): 2874.0
Distance between rig floor and sea level (m): 11.7
Water depth (drill-pipe measurement from sea level, m): 2862.3
Total depth (drill-pipe measurement from rig floor, mbrf): 2876.0
Total penetration (meters below seafloor, mbsf): 2.0
Comments: hammer drill system testing only; no coring.

Hole 1182B
Latitude: 12°57.0′N
Longitude: 143°36.6′E
Time on hole (hr): 0.5 (0900 hr, 6 September–0930 hr, 6 September 2000)
Seafloor (drill-pipe measurement from rig floor, mbrf): 2878.0
Distance between rig floor and sea level (m): 11.7
Water depth (drill-pipe measurement from sea level, m): 2866.3
Total depth (drill-pipe measurement from rig floor, mbrf): 2879.5
Total penetration (meters below seafloor, mbsf): 1.5
Comments: hammer drill system testing only; no coring.

Hole 1182C
Latitude: 12°57.0′N
Longitude: 143°36.6′E
Time on hole (hr): 5.75 (0930 hr, 6 September–1515 hr, 4 September 2000)
Seafloor (drill-pipe measurement from rig floor): 2878.0 mbrf
Distance between rig floor and sea level: 11.7 m
Water depth (drill-pipe measurement from sea level): 2866.3 m
Total depth (drill-pipe measurement from rig floor, mbrf): 2883.0 mbrf
Total penetration (meters below seafloor, mbsf): 5.0 mbsf
Comments: hammer drill system testing only; no coring.

Hole 1182D
Latitude: 12°57.0′N
Longitude: 143°36.6′E
Time on hole (hr): 10.75 (1515 hr, 6 September–0200 hr, 7 September 2000)
Seafloor (drill-pipe measurement from rig floor, mbrf): 2877.0
Distance between rig floor and sea level (m): 11.7
Water depth (drill-pipe measurement from sea level, m): 2865.3
Total depth (drill-pipe measurement from rig floor, mbrf): 2880.0
Total penetration (meters below seafloor, mbsf): 3.0
Comments: hammer drill system testing only; no coring.

Hole 1182E
Latitude: 12°57.0′N
Longitude: 143°36.6′E
Time on hole (hr): 9.00 (0200 hr, 7 September–1100 hr, 7 September 2000)
Seafloor (drill-pipe measurement from rig floor, mbrf): 2870.0
Distance between rig floor and sea level (m): 11.7
Water depth (drill-pipe measurement from sea level, m): 2865.3
Total depth (drill-pipe measurement from rig floor, mbrf): 2881.5
Total penetration (meters below seafloor, mbsf): 4.5
Comments: hammer drill system testing only; no coring.

Hole 1182F
Latitude: 12°57.0′N
Longitude: 143°36.6′E
Time on hole (hr): 3.75 (1100 hr, 7 September–1445 hr, 7 September 2000)
Seafloor (drill-pipe measurement from rig floor, mbrf): 2872.0
Distance between rig floor and sea level (m): 11.7
Water depth (drill-pipe measurement from sea level, m): 2860.3
Total depth (drill-pipe measurement from rig floor, mbrf): 2875.75
Total penetration (meters below seafloor, mbsf): 3.75
Comments: hammer drill system testing only; no coring.

Hole 1182G
Latitude: 12°57.0′N
Longitude: 143°36.6′E
Time on hole (hr): 16.5 (1445 hr, 7 September–0800 hr, 8 September 2000)
Seafloor (drill-pipe measurement from rig floor, mbrf): 2873.0
Distance between rig floor and sea level (m): 11.7
Water depth (drill-pipe measurement from sea level, m): 2861.3
Total depth (drill-pipe measurement from rig floor, mbrf): 2878.0
Total penetration (meters below seafloor, mbsf): 5.0
Comments: hammer drill system testing only; no coring.

Table T3. Breakdown of HRRS activities during Leg 191.

Date (Sept 2000)	Activity	Time (local)			Time breakdown				
		Beginning	Ending	Total	Transit	Survey	Tripping	Testing	Miscellaneous
3	3.5-kHz survey while drawworks are being repaired	1445	1830	3.75		3.75			
3	VIT seafloor survey	1830	0000	5.50		5.5			
4	VIT seafloor survey	0000	0100	1.00		1			
4	Recover VIT; pull out of hole; deck-test hammer	0100	0600	5.00			5		
4	Run in hole	0600	1315	7.25			7.25		
4	Spud tests, Holes 1180A-1180C	1315	1600	2.75				2.75	
4	Move vessel in dynamic positioning mode to Site 1181	1600	0000	8.00	8				
5	Run in hole and space out	0000	0115	1.25			1.25		
5	Spud tests, Holes 1181A-1181C	0115	0430	3.25				3.25	
5	VIT seafloor survey	0430	0645	2.25		2.25			
5	Pull out of hole; rig down	0645	1015	3.50			3.5		
5	Transit to Mariana backarc-1	1015	2000	9.75	9.75				
5	3.5-kHz survey	2000	0000	4.00		4			
6	3.5-kHz survey	0000	0030	0.50		0.5			
6	Lower thruster and drop beacon	0030	0200	1.50					1.5
6	Run in hole; space out; VIT survey	0200	0845	6.75			6.75		
6	Spud tests, Holes 1182A-1182D	0845	1830	9.75				9.75	
6	Pull out of hole; change bit; run in hole	1830	0000	5.50			5.5		
7	Run in hole	0000	1030	10.50			10.5		
7	Spud tests, Holes 1182E-1182G	1030	1800	7.50				7.5	
7	Pull out of hole	1800	0000	6.00			6		
8	Pull out of hole	0000	0215	2.25			2.25		
8	Lay out equipment and rig down	0215	0715	5.00					5
8	Transit to Guam	0715	1500	7.75	7.75				
	Total time (hr):			112.5	17.75	17	48	23.25	6.5

Activity	Time (hr)	Time (days)	% of total
Actual operating time less transit	94.75	3.95	NA
Pipe tripping	48.00	2.00	51
Survey	17.00	0.71	18
Miscellaneous activities	6.50	0.27	7
Actual spud tests	8.78	0.37	9
Additional survey/offset between spud tests	14.47	0.60	15
Total:	175.03		85

Notes: VIT = vibration isolated television. NA = not applicable.

Table T4. Summary of 260 fluid hammer operations, Sites 1180 and 1181 (Rota-1).

Hole/test	Latitude	Longitude	Water depth (m)	Operation (min)	Flow rate (spm)	Penetration depth (m)	Material	Lost circulation	Rotation	Heave (m)	Hammer/bit	ROP (m/hr)
Deck test			NA	5	20-40	NA	NA	NA	No	<0.6	260 FH/DCUR	NA
Flow test			2150	5	20-40	NA	NA	NA	No	<0.6	260 FH/DCUR	NA
1180A	14°19.25′N	144°48.00′E	2157	15	20-40	3	Volcanic ash	No	No	<0.6	260 FH/DCUR	NA
1180B	14°19.25′N	144°48.00′E	2157	15	20-40	9	Volcanic ash	Yes	No	<0.6	260 FH/DCUR	NA
1180C	14°18.51′N	144°44.84′E	2132	10	20-40	2.5	Volcanic ash; rubble	Yes	No	<0.6	260 FH/DCUR	NA
1181A	14°19.26′N	144°48.00′E	995	5	20-40	2.5	Volcanic ash; rubble	Yes	No	<0.6	260 FH/DCUR	NA
1181B	14°19.26′N	144°48.00′E	981	5	20-40	3	Volcanic ash; rubble	Yes	No	<0.6	260 FH/DCUR	NA
1181C	14°19.26′N	144°48.00′E	970	10	20-40	3	Volcanic ash; rubble	Yes	No	<0.6	260 FH/DCUR	NA

Notes: ROP = rate of penetration. spm = strokes per minute (~5 U.S. gal/stroke [i.e., 20 strokes equals 100 U.S. gal/min.]) NA = not applicable. DCUR = dual cam underreamer bit, FCUB = flat-face underreamer bit. Only 40% of the optimum flow rate through the hammer allows the hammer to jet into the seafloor while being observed by the VIT. The hammer fired only a few times because sufficient material strength to close the hammer to initiate operation was not present. Only the hammer and underreamer bits were being used, no casing installation was attempted.

Table T5. Summary of 260 fluid hammer operation, Site 1182 (Mariana backarc).

Hole/test	Latitude	Longitude	Water depth (m)	Operating time (min)	Flow rate (spm)	Penetration depth (m)	Material	Lost circulation	Rotation	Heave (m)	Hammer/bit	ROP (m/hr)
1182A	12°57.0′N	143°36.6′E	2874	25	20-40	2	Lava flows	Yes	No	1-2	260 FH/DCUR	NA
1182B	12°57.0′N	143°36.6′E	2878	15	20-60	1.5	Lava flows	Yes	No	1-2	260 FH/DCUR	NA
1182C	12°57.0′N	143°36.6′E	2878	95	20-80	5	Lava flows	Yes	Yes	1-2	260 FH/DCUR	3.16
1182D	12°57.0′N	143°36.6′E	2878	45	20-80	3.5	Lava flows	Yes	Yes	1-2	260 FH/DCUR	4.67
1182E	12°57.0′N	143°36.6′E	2878	30	20-80	4.5	Lava flows	Yes	Yes	2.5-4	260 FH/FCUR	9
1182F	12°57.0′N	143°36.6′E	2872	145	20-90	7	Lava flows	Yes	Yes	2.5-4	260 FH/FCUR	2.9
1182G	12°57.0′N	143°36.6′E	2873	112	20-90	5	Lava flows	Yes	Yes	2.5-4	260 FH/FCUR	2.68
Totals:				467		28.5						

Notes: ROP = rate of penetration. spm = strokes per minute (~5 U.S. gal/stroke [i.e., 20 strokes equals 100 U.S. gal/min.]) NA = not applicable. DCUR = dual cam underreamer bit, FCUB = flat-face underreamer bit. Only 40% of the optimum flow rate through the hammer allows the hammer to jet into the seafloor while being observed by the VIT. The hammer fired only a few times because sufficient material strength to close the hammer to initiate operation was not present. Only the hammer and underreamer bits were being used, no casing installation was attempted.

Table T6. Drilling rates for Holes 1182C–1182G.

Hole	Bit	Penetration (m)	Time (min)	Time (hr)	ROP (m/hr)
1182C	DCUR	1	15	0.25	4
		1	11	0.18	5.45
		1	17	0.28	3.53
		0.5	21	0.35	1.43
		0.5	11	0.18	2.73
		0.5	10	0.17	3
		0.5	10	0.17	3
	Totals:	5	95	1.58	3.16
1182D	DCUR	1.5	5	0.08	18
		1	15	0.25	4
		1	25	0.42	2.4
	Totals:	3.5	45	0.75	4.67
1182E	TLUR	3	10	0.17	18
		1	5	0.08	12
		0.5	15	0.25	2
	Totals:	4.5	30	0.5	9
1182F	TLUR	1	5	0.08	12
		1	8	0.13	7.5
		1	14	0.23	4.29
		1	15	0.25	4
		1	38	0.63	1.58
		1	35	0.58	1.71
		1	30	0.5	2
	Totals:	7	145	2.42	2.9
1182G	TLUR	1	3	0.05	20
		1	7	0.12	8.57
		1	15	0.25	4
		0.5	15	0.25	2
		0.5	17	0.28	1.76
		0.5	25	0.42	1.2
	Totals:	5	112	1.87	2.68

Notes: ROP = rate of penetration. DCUR = dual cam underreamer bit, TLUR = three-level underreamer bit.