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HORIZONTAL CORING USING AIR AS THE CIRCULATING FLUID:

SOME PROTOTYPE STUDIES CONDUCTED IN G TUNNEL AT THE
NEVADA TEST SITE FOR THE YUCCA MOUNTAIN PROJECT

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ABSTRACT

Horizontal coring using air as the circulating fluid has been conducted in the G Tunnel Underground Facility (GTUF) at the Nevada Test Site. This work is part of the prototype investigations of hydrogeology for the Yucca Mountain Project. The work is being conducted to develop methods and procedures that will be used at the Department of Energy's Yucca Mountain Site, a candidate site for the nation's first high-level nuclear waste repository, during the site characterization phase of the investigations. The United States Geological Survey (USGS) is conducting this prototype testing under the guidance of the Los Alamos National Laboratory (LANL) and in conjunction with Reynolds Electrical & Engineering Company (REECo), the drilling contractor.

INTRODUCTION

The Nuclear Waste Policy Act of 1982, Public Law 97-425, and the Nuclear Waste Policy Amendments Acts of 1987 direct the Department of Energy to characterize the Yucca Mountain Site in Nye County, Nevada (figure 1) as a possible candidate site for the first geological repository for commercial nuclear reactor fuel rods packages. This characterization is a program of studies that collect geological information necessary to demonstrate the suitability of the site for potential licensing as a repository. The Site Characterization Plan (SCP), DOE RW-0199, describes conceptual designs for the repository and presents study plans to obtain the geological and hydrological information required to demonstrate the suitability of the site for a repository. This Plan is mandated by the 10 CFR Part 60, which amends the Nuclear Waste Policy Act, and by siting guidelines.

The Subsystems Design Requirements Document (SDRD) provides functional requirements and performance criteria for all systems within the scope of the Exploratory Shaft Facility in accordance with guidance of Office of Geologic Repositories document OGR-R-B-2, Appendix E. The SCP and the SDRD mandate the need for the development of equipment, operational support and instrumentation for the tests described within the Site Characterization Plan.

Many of these tests will be conducted in the Exploratory Shaft Facility (ESF), which will be constructed at the Yucca Mountain Site. Horizontal boreholes and core samples will be required for some of the tests. Much of the hydrological testing conducted in the ESF will be investigating the hydrogeology of the 539.5 meter thick unsaturated zone (UZ). To properly characterize the UZ, the in-situ properties of the rocks must be minimally disturbed by borehole drilling. Coring, using air as the circulating fluid, has been suggested as one possible way to accomplish this.

Eight boreholes, six of which were air-cored, provided data for recent prototype drilling that will be used for hydrological testing. Four of the boreholes were located in nonwelded tuffs and two were in a highly fractured, densely welded tuff. Longyear drilling rigs and two Atlas Copco dust collection systems were used during the coring of the boreholes. Various types of core bits were tested in an effort to maximize penetration rates while providing optimum core recovery. The boreholes were completed with relatively few drilling related problems. Core recovery was very good and the condition of the boreholes, in most cases, provided easy access for borehole logging and instrumentation.

PROTOTYPE TESTS DESCRIPTIONS

G Tunnel Underground Facility

The Yucca Mountain Site is a geologic structure of volcanic rocks within the Nevada Basin and Range Province. The candidate geological horizon for the ESF is a welded, fractured volcanic tuff called the Topopah Spring Member (figure 2). In order to develop the tests with the required quality assurance before the Site Characterization commenced, a rock unit with similar properties as the Yucca Mountain rock unit was required.

The G Tunnel Underground Facility (GTUF) at the Nevada Test Site (NTS) was selected in the late 1970's as the site for prototype testing (figures 3 and 4) because the volcanic rocks exposed there were similar to the volcanic rocks at the Yucca Mountain Site. This facility is the site of the horizontal coring, with air as the circulating fluid. The facility is located in the G Tunnel complex in the north-central portion of the

Fig. 1. Location of the Yucca Mountain Site in southern Nevada (USDOE, 1988).

Fig. 2. East-west geological cross section of the Yucca Mountain Site (USDOE, 1988).

Nevada Test Site, Nye County, Nevada. The G Tunnel complex is shared with the nation's defense weapons testing program. The portal is located in the southeast corner of Rainier Mesa, a topographic highland composed of a thick sequence of pyroclastic rocks, which reaches an altitude in excess of 2300 meters. The mesa has a total upland surface of approximately 11.7 square kilometers. The escarpment in the vicinity of the G Tunnel portal is over 400 meters in height, going from 1850 meters at the portal to 2300 meters at the caprock above the complex. This change in elevation occurs within a horizontal distance of 1100 meters.

Hydrological Tests Description

Eight horizontal boreholes were cored to fulfill the requirements of three prototype investigations. The boreholes ranged in depth from 8.9 meters to 45.7 meters. These prototype studies required dry-cored boreholes and core samples that had minimally disturbed *in-situ* hydrologic properties. The methods of dry coring had been previously developed in the Air Coring Test (Newsom and Ray, 1988).

Fig. 3. Layout of the G Tunnel Complex.

Fig. 4. Plan view of the G Tunnel Underground Facility (GTUF), northwest section.

In the Wet Versus Dry Drilling Test, pairs of boreholes were drilled, each pair consisting of one hole drilled dry and the other drilled wet. Information collected from the pairs of holes provided data on the effects that the drilling fluids have on the *in-situ* borehole and core sample conditions and how quickly and to what extent the conditions in the borehole equilibrate after drilling had ended. Two dry-cored boreholes from this test, U12g.12 DD-1 and U12g DD-2, provided dry-coring data. One was drilled into Tunnel Bed 5 and the other was drilled into the Grouse Canyon Member. The other two holes, U12g WD-1 and U12g WD-2, were drilled with water. Boreholes DD-1 and WD-1 were cored in the U12g.12 Drift Extension and DD-2 and WD-2 were cored in the Laser Drift.

The Drillhole Instrumentation Test was designed to investigate borehole instrumentation packages and to develop methods for the *in-situ* recalibration of instruments in a borehole. The instrument packages included pressure transducers, thermistors and thermocouple psychrometers and were isolated in the boreholes by inflatable packers. Borehole U12g.12 DI-2 was drilled into the Tunnel Bed 5 in the U12g.12 Drift Extension to provide the data for this investigation.

The other prototype test which contributed data was the Perched Water Test. This test investigated the methods of coring using air and of monitoring perched-water zones in an excavated underground opening. Three boreholes cored for this test provided data on horizontal air coring. Boreholes U12g PW-1 and U12g PW-2 were cored into Tunnel Bed 4 in the Puff-N-Tuff Drift and borehole U12g PW-3 was cored into the Grouse Canyon Member in the Laser Drift. When completed, these boreholes were instrumented with packer instrument systems for monitoring and sampling the perched-water zones.

Fig. 5. Cross Section of the Rainier Mesa at G Tunnel.

Unit/Zone	Thickness (meters)	Brief Description
Paintbrush Tuff	50 ±	Nonwelded, vitric, ash-fall tuff
Grouse Canyon/Upper Transition	3.0-3.5	Partially welded, devitrified ash-fall tuff
Grouse Canyon/Moderately Welded	4.0-5.0	Moderately welded, devitrified ash-flow tuff, highly fractured
Grouse Canyon/Lower Rubble	2.0-2.5	Igneous lithic fragments (<1 mm to 450 mm) in a poorly indurated crypto-crystalline matrix
Grouse Canyon/Densely Welded	8.0-10.0	Densely welded, devitrified ash-flow tuff, highly fractured
Grouse Canyon/Lower Rubble	0.2-1.2	Igneous lithic fragments (<1 mm to 450 mm) in a poorly indurated crypto-crystalline matrix
Grouse Canyon/Basal vitrophyre	2.0-3.0	Moderately welded, vitric ash-flow tuff, moderately fractured. Grades downward into partially welded vitric ash-flow tuff and intermittent lithic-rich flow

Table 1. G Tunnel Stratigraphy.

Geology and Hydrology

The volcanic stratigraphy exposed at Rainier Mesa escarpment at the G tunnel portal consists of Tunnel Beds 2, 3 and 4 of the Indian Trail Formation overlain in ascending order by Tunnel Bed 5 of the Belled Range Tuff, the Paintbrush Tuff and the Rainier Mesa Member of the Timber Mountain Tuff (figure 5). The units are silicic pyroclastic deposits, either ash-fall or ash-flow tuffs. The units range from nonwelded to densely welded and from vitric to devitrified. The primary glass in many of the vitric nonwelded units has been altered to zeolites and clays. The G Tunnel portal is collared in Tunnel Bed 2 of the Indian Trail Formation. This unit is a zeolitized, nonwelded ash-fall tuff. The dip of the beds drops the tunnel level stratigraphy at the GTUF area.

The stratigraphy at the GTUF, in ascending order, consists of the Tunnel Bed 5 of the Indian Trail Formation and the Grouse Canyon Member of the Belled Range Tuff (table 1). These rocks have hydrogeological properties similar to the pyroclastic rocks which will be encountered in the ESF at Yucca Mountain. The fractured, densely welded Grouse Canyon Member is representative of the fractured, moderately to densely welded members of the Paintbrush Tuff which occur at Yucca Mountain. These two members, the Tiva Canyon and the Topopah Spring, comprise over 350 meters of the stratigraphic section above the water table in the vicinity of the ESF. The host rock for the repository at Yucca Mountain is a fractured, densely welded unit located near the base of the Topopah Spring Member. The Tunnel Bed 5 is similar to the nonwelded tuffs which occur between the Tiva Canyon and the Topopah Spring Members and is representative of the Calico Hills unit which is beneath the Paintbrush Tuff Formation. Lithologies of the units from which information was gathered for the prototype investigations are summarized in table 2.

The GTUF is located approximated 600 meters above the carbonate aquifer static water level (SWL) (Zimmerman and Finley, 1987). Zones of perched or transient water occur in the GTUF and in the Puff-n-Tuff Drift, which is the site of two dry-cored boreholes used in this study.

Borehole Number	Depth (meters)	Formation	Geological Name	Lithologic Description
U12g-12 01-1	11	Belled Range	Tunnel Bed 5	ash-fall, nonwelded, vitric, zeolitized, contains silicified ash beds
U12g-12 00-1 and 00-2	9.7	Belled Range	Tunnel Bed 5	Tuff, ash-fall, nonwelded, vitric, zeolitized, contains silicified ash beds
U12g 00-2 and 00-2	9.1	Belled Range	Grouse Canyon	Tuff, ash-flow, moderately to densely welded, devitrified, contains pumice fragments and argillized pumice fragments
U12g 00-1	9.2	Indian Trail	Tunnel Bed 4	Tuff, ash-fall, nonwelded, vitric, zeolitized and argillized
U12g 00-2	8.9	Indian Trail	Tunnel Bed 4	Tuff, ash-fall, nonwelded, vitric, zeolitized and argillized
U12g 00-3	31.5	Belled Range	Grouse Canyon	Tuff, ash-flow, moderately to densely welded, devitrified, contains devitrified, flat-topped pumice fragments and argillized pumice fragments

Table 2. Horizontal Coring Borehole Lithologies.

These zones are created when precipitation falling on the mesa is conducted along fractures to areas where the downward flow of the water is impeded. The termination of fractures at stratigraphic contacts, secondary filling of fractures, and permeability barriers created by faulting are areas where the downward migration of water can be impeded. This water can be stored in fractures and along bedding planes or imbibed into the matrix, creating perched-water zones. Similar conditions may exist at the ESF site, where the host rock for the repository is 90 meters above the SWL.

The physical properties of pyroclastic deposits are influenced by the degree of welding. More dense welding results when pyroclastic rocks are buried by subsequent deposits prior to cooling. Overburden in the cooling pyroclastic deposit causes compaction of the ash and pumice fragments. It also insulates the unit, resulting in slower cooling and the formation of a crystalline matrix. Densely welded pyroclastic rocks have low porosities and high bulk densities. Pyroclastic rocks which quickly cooled in a near-surface environment have a vitric matrix, higher porosities and lower bulk densities. The Grouse Canyon Member has the following average physical properties: Bulk density of 2.36 grams/cubic centimeter (g/cm^3), grain density of 2.60 g/cm^3 , porosity of 15%, compressive intact rock strength of 96 MPa saturated, and tensile intact rock strength of 9.6 MPa (Zimmerman and Finley, 1987). Tunnel Bed 5 has the following average physical properties: Bulk density of 1.67 g/cm^3 , grain density of 2.42 g/cm^3 , porosity of 48.9%, compressive intact rock strength of 25.9 MPa, and tensile intact rock strength of 0.8 MPa (Zimmerman and Finley, 1987, and Warpinski et al, 1981). Tunnel Bed 4, although not included in table 1, has properties which are similar to those listed for Tunnel Bed 5.

DRILLING EQUIPMENT

Drill Rigs

Two drill rigs manufactured by Longyear were used for coring in the three tests. The names of the rigs are Longyear 34 and Longyear 38, both skid-mounted. The Longyear 34, with approximately 35.5 metric horsepower and a reduction gear drum hoist, was used on the Wet and Dry Drilling and Borehole Instrumentation tests (Longyear, 1982). The Longyear 38, with 40.6 metric horsepower and a planetary drum hoist, was used on the Perched Water test (Longyear, 1983). Figure 6 shows a typical setting of a rig and dust collection system in use in GTUF.

The miners first drilled holes into the tunnel floor and then set rockbolts into the holes with resin epoxy. They brought the rig in and, to obtain the correct rig height, steel "I" beams underneath the rig were bolted to the invert (floor) by the rock bolts and more steel beams were stacked and welded on top of the floor beams as needed.

Fig. 6. General Configuration of Horizontal Coring Equipment at GTUF (Newsom and Ray, 1988).

Drill String and Core Barrels

The string consisted of an HQ3 coring bit, a diamond-set reaming shell, an outer tube assembly, a stabilizer, drill rods and the air swivel. The core barrel assembly consisted of Lexan liner inside of a split inner-tube assembly. This assembly was attached to the latch head assembly which was caught by the overshot assembly when the core barrel assembly was pulled out (figure 7).

Fig. 7. Schematic of Drill String and Inner Core Barrel (Newsom and Ray, 1988).

Dust Collectors

The use of air as the drilling fluid necessitated the implementation of dust collectors for health regulations compliance to collect dust from the annulus of the core string into bags that could be sealed. An arrangement that provided a sealed pathway for the cuttings and dust from the annulus to the dust collector was developed during a prior prototype test, the Air Coring Test, by John Newsom of Newsom Industries. The rock surface at the borehole location was smoothed out by an impact hammer. Rock bolts were drilled into the area near the borehole to provide anchoring for the dust manifold. The manifold was attached to the rock bolts, the suction air line was connected from the manifold to the dust collector, and a secondary line from the dust collector was inserted into the ventilation return line. A rubber seal was placed in the manifold and sulfaset compound placed between the manifold and the rock surface to provide a seal from outside air. The manifold was then tightened and coring commenced after the sulfaset compound cured. Figure 8 shows the dust collectors used on

Fig. 8. Schematic of Atlas Copco Dust Collection System (Newsom and Ray, 1988).

the tests, which were manufactured by Atlas Copco. The first collector, model DCT-90, is operated pneumatically with a venturi and has a capacity of 300 liters/ second (l/s). The second collector, model DCT 220-10F, is operated hydraulically with electric pumps and has a capacity of 680 l/s. The collectors employed cyclone separation to make the cuttings and dust fall into a collection bag sealed on the bottom of the collector.

Core Bits

Several diamond coring bits, manufactured by Geoset and Longyear, were used on the three tests. Bit selection was determined by the tuff welding characteristics of the rock. In the nonwelded units, tungsten carbide chisel tooth bits with diamond impregnated matrices were used. In the densely welded units, different types of diamond impregnated coring bits were used.

HOLE DATA

Tables 3 through 10 list the drilling parameters that were recorded during the coring of the eight boreholes. Drilling variables collected were core run number, interval drilled in feet, core length received, drill bit type, drilling fluid, time started and stopped, weight on bit, revolution per minute, cubic feet of air through drill string to bit, and remarks. The values listed are the averaged values per core run. The drilling data collected was evaluated to determine what combination of drilling parameters and coring bits were more effective for coring with air in the UZ. Table 11 lists the bits used on the three tests and presents data on the performance of those bits.

CONCLUSIONS

Drilling Performance

Coring, using air as the circulating fluid, in an excavated underground opening is a method which can be used when *in situ* hydrological conditions must be maintained. The horizontal dry-coring conducted in the GTUF for the three prototype tests has provided data which can be used to evaluate the effectiveness of this type of coring. Coring the nonwelded unit presented no problems. The penetration rates were high and bit life was very good. The highly fractured, densely welded tuff was more difficult to core with air. The penetration rates were about half the rates for the nonwelded tuffs. Bit life was also shorter in the densely welded tuff. The average penetration rate for coring with air in the nonwelded tuffs was 4.6 meters/hour (average low rate of 3.7 and average high rate of 5.6). For the densely welded tuff,

the average penetration rate was 2.2 meters/hour (average low rate of 1.4 and average high rate of 2.8).

Drilling variables, other than the type and condition of the core bit, which could influence the penetration rates were the weight of the bit, the revolutions per minute, and the volume of circulating fluid passing through the bit. In the nonwelded tuffs, the weight on the bit varied from 907 to 2268 kilograms. The rotary speed varied from 40 to 250 revolutions per minute (rpm). The volume of air circulated varied from 47.2 to 129.8 liters/second (l/s). Weight on bit in the densely welded tuff varied from 45 to 4536 kilograms. Hydraulic problems with the Longyear 34 rig limited the amount of weight on the bit when using that rig. In the densely welded tuff, the rotary speed used was from 45 to 285 rpm. Volume of air circulated varied from 37.8 to 188.8 l/s.

The maximum penetration rate for coring in the nonwelded tuffs was 6.9 meters/hour; weight on bit was from 1814 to 2268 kilograms; rotary speed was 40 to 60 rpm; the volume of circulating air was 94.4 l/s. In the highly fractured, densely welded tuff, the maximum penetration rate was 4.0 meters/hour; weight on bit for this core run is not available, but probably ranged from 90 to 130 kilograms; rotary speed was 260 rpm; volume of air circulated was 113.3 l/s. The maximum penetration rate in the welded tuff was attained after a new core bit was run into the borehole.

Drill Bits

When the rig and dust collecting system were working properly, bit performance was very good. When the dust collector was not operating at full capacity, a build up of cuttings and dust in the borehole caused excessive heat generation at the bit. This caused some of the bits to wear quickly, losing diamonds and shortening the bit life. Bit performance is directly related to arrangements and operations of the drilling equipment for the particular rock type that one is coring.

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Core Run Number	Drilled Interval (meters)	Length Received (meters)	Drill Bit Type	Fluid	Time Start/Stop	Weight on Bit (kg/mm)	RPM	Cubic Meters of Air per Minute	Remarks
1	0.00-1.05	0.27	1C Diamond Corundum	Air	1055/1500 hrs			3.60	
2	1.05-1.83	1.52	***	-	0844/	1814		6.75	
3	1.83-3.37	1.40	***	-	1055/1110	1814	120	5.40	
4	3.37-5.09	1.52	***	-	1315/1335	1814	120	5.40	
5	5.09-6.61	1.49	***	-	1355/1418	1814	60	4.96	
6	6.61-8.14	1.50	***	-	0815/0842	1508	85	4.96	Chatter at 7.8 m
7	8.14-9.66	1.56	***	-	0917/0935	1814	75	4.96	

Table 3. Drilling Data for Hole U12g.12 DD-1.

Core Run Number	Drilled Interval (meters)	Length Received (meters)	Drill Bit Type	Fluid	Time Start/Stop	Weight on Bit (kg/mm)	RPM	Cubic Meters of Air per Minute	Remarks
1	0.00-1.37	1.34	Longyear Corundum	Water	1425/1448 hrs	1814	120-150	37.9	
2	1.37-2.90	1.49	***	-	0930/0952	2041	120-150	37.9	
3	2.90-4.42	1.55	***	-	1015/1037	2041	120-150	37.9	
4	4.42-5.94	1.52	***	-	1245/1302	2041	120-150	37.9	
5	5.94-6.89	0.98	***	-	1220/1335	2041-2268	120-150	37.9	
6	6.89-7.47	0.52	***	-	1425/1435	2041-2268	120-150	37.9	
7	7.47-8.90	1.52	***	-	1455/1503	2041-2268	120-150	37.9	

Table 4. Drilling Data for Hole U12g WD-1

Core Run Number	Drilled Interval (meters)	Length Received (meters)	Drill Bit Type	Fluid	Time Start/Stop	Weight on Bit (kg/mm)	RPM	Cubic Meters of Air per Minute	Remarks
1	0.00-1.43	1.43	Diamond Impregnated	Air	1002/1023 hrs	3631	120	2.27	
2	1.43-2.44	1.01	***	-	1430/1510	3650	95-120	1.96	
3	2.44-3.47	1.04	***	-	0835/0904	3631	90-120	4.25	
4	3.47-4.76	1.22	***	-	1025/1105	3631	90-150	4.25	
5	4.76-5.99	0.76	***	-	1230/1330	3400	150	2.83	
6	5.99-5.94	0.46	***	-	1347/1407	2950	100	2.83	
7	5.94-7.53	1.37	***	-	1425/1445	4530	100	4.25	
8	7.53-9.11	1.28	***	-	0820/0847	3177	60	4.25	

Table 5. Drilling Data for Hole U12g.12 DD-2

Core Run Number	Drilled Interval (meters)	Length Received (meters)	Drill Bit Type	Fluid	Time Start/Stop	Weight on Bit (kg/grams)	RPM	Cubic Meters of Air per Minute	Remarks
1	0.00-1.50	1.50	Longyear Diamond Impregnated	Water	1310/1425 hrs	1495	120-150	37.9-56.7	
2	1.50-1.17	1.52	***	*	1410/1435	2940	150	37.9-56.7	Fracture at 1.50 and at 1.36 meters
3	1.17-4.70	1.48	***	*	0830/0935	2940	150	37.9-56.7	
4	4.70-6.22	1.52	***	*	0955/1035	2940	150	37.9-56.7	
5	6.22-7.50	1.32	***	*	1055/1305	2940	150	37.9-56.7	
6	7.50-7.86	0.24	***	*	1325/1330	2940	120-150	37.9-56.7	

Table 6. Drilling Data for Hole U12g WD-2

Core Run Number	Drilled Interval (meters)	Length Received (meters)	Drill Bit Type	Fluid	Time Start/Stop	Weight on Bit (kg/grams)	RPM	Cubic Meters of Air per Minute	Remarks
1	0.00-1.03	1.70	Longyear Diamond Impregnated	Air	1150/1425 hrs	907 to 1500		900	
2	1.03-3.35	2.40	***	*	0901/0919	1500 to 1814		1100	
3	3.35-4.88	1.53	***	*	0950/1010	1814	110	1100	
4	4.88-5.30	0.43	***	*	1242/	1814	100	1000	Jammed up bit
5	5.30-6.40	1.04	***	*	1313/1337	1500	110	1000	
6	6.40-7.52	1.50	***	*	1400/1423	1500	115	1000	
7	7.52-9.45	1.52	***	*	0850/0913	1814	85	900	
8	9.45-10.97	1.50	***	*	0950/1000	2041	50	900	Pipe chattering, slowed RPM
9	10.97-12.50	1.49	***	*	1020/1046	2041	51	900	
10	12.50-14.02	1.49	***	*	1247/1302	1814	52	900	
11	14.02-15.55	1.56	***	*	1320/1340	1814	57	900	
12	15.55-17.07	1.52	***	Air	0857/0927	1814	55	900	
13	17.07-18.50	1.49	***	*	0940/1017	1814	55	900	
14	18.50-20.12	1.56	***	*	1252/1318	2041	52	900	
15	20.12-22.17	1.49	***	*	1325/1353	1500	55	900	
16	22.17-23.17	1.56	***	*	0913/0930	1500	55	900	
17	23.17-24.70	1.52	***	*	0940/1002	1500	52	900	
18	24.70-26.21	1.56	***	*	1244/1307	1500	52	900	
19	26.21-27.74	1.56	***	*	1324/1340	1814	52	900	

Table 7. Drilling Data for Hole U12g OI-2

Core Run Number	Drilled Interval (meters)	Length Received (meters)	Drill Bit Type	Fluid	Time Start/Stop	Weight on Bit (kg/grams)	RPM	Cubic Meters of Air per Minute	Remarks
1	0.00-1.52	1.46	Longyear Carbide Impregnated	Air	1030/1100 hrs		150	3.96	At 5 degrees above horizontal
2	1.52-3.05	1.52	***	*	1300/1320		160	2.83	lots of dust, about 1 foot of core stuck in drill bit
3	3.05-4.57	1.43	***	*	1340/1400		250	2.83	Increased rpm to 270
4	4.57-6.10	1.49	***	*	0955/1018		140	4.25	
5	6.10-7.65	1.52	***	*	1255/1316		150	4.25	lots of dust.
6	7.65-9.17	1.52	***	*	1401/1419		160	4.25	Less dust, more chattering

Table 8. Drilling Data for Hole U12g.12 PW-1

Core Run Number	Drilled Interval (meters)	Length Received (meters)	Drill Bit Type	Fluid	Time Start/Stop	Weight on Bit (kg/grams)	RPM	Cubic Meters of Air per Minute	Remarks
1	0.00-1.52	1.43	Longyear Carbide Impregnated	Air	0905/0924 hrs		100-150	2.63	
2	1.52-2.99	1.49	***	*	1003/1021		200	2.63	lots of dust, barrel blocked off
3	2.99-4.57	1.52	***	*	1047/1112		110	2.83	Less dust
4	4.57-6.10	1.28	***	*	1455/1408		150	2.83	water flowing from adjacent hole, clay encountered
5	6.10-7.47	1.46	***	*	0830/0950		100	4.25	Clay at top of core no more water
6	7.47-8.93	1.58	***	*	0945/1000		140	4.25	Barrel blocked off, clay at top of core

Table 9. Drilling Data for Hole U12g.12 PW-2

Core Run Number	Drilled Interval (meters)	Length Received (meters)	Drill Bit Type	Fluid	Time Start/Stop	Weight on Bit (kg/grams)	RPM	Cubic Meters of Air per Minute	Remarks
1	0.00-1.52	1.19	Diamond Impregnated	Air	1310/1420 hrs		140	4.25	
2	1.52-2.53	0.95	***	*	0950/1100		227	140-150	4.53
3	2.53-3.94	1.43	***	*	1109/1351		150	4.53	Big hydraulic problems
4	3.94-5.46	1.49	***	*			227	160	4.25
5	5.46-6.95	1.49	***	*	0830/0900		272	225	4.25
6	6.95-8.53	1.58	***	*	0925/1000		200	4.25	Broken cones in core
7	8.53-10.12	1.52	***	*	1010/1106		210	4.25	
8	10.12-10.85	0.79	***	*	1312/1335		210	3.96	Barrel blocked off
9	10.85-11.92	0.71	***	*	1407/1414		170	4.25	Barrel blocked off
10	11.92-13.26	0.33	***	*	1435/1450		280	4.25	
11	13.26-13.81	1.18	***	*	0856/0907		182	230	4.25
12	13.81-14.01	0.55	***	Air	1012/1028		182	240	5.66
13	14.01-14.75	0.95	***	*	1245/1315		227	240-250	5.10
14	14.75-16.06	1.31	***	*	1340/1418		45-136	240-260	5.46
15	16.06-17.04	0.98	***	*	1443/1500		250	4.25	Hydraulic problem
16	17.04-18.20	1.16	***	*	0900/0937		91	182-210	4.25
17	18.20-19.32	1.13	***	*	1000/1041		136	260	4.25
18	19.32-20.67	1.34	***	*	1104/1300		91-136	220	4.25
19	20.67-21.15	0.49	***	*	1323/1344		240	4.25	Barrel blocked off
20	21.15-22.31	0.91	***	*	1034/1052		260	5.66	
21	22.31-23.77	1.30	***	*	0845/0910		170	6.00	
22	23.77-24.84	1.07	***	*	1240/1313		260	7.93	
23	24.84-26.37	1.52	***	*	1355/1400		285	8.50-11.33	
24	26.37-27.48	0.61	***	*	1440/1500		200-250	5.66-6.60	
25	27.48-28.47	0.80	***	*	0835/0855		245	5.66	
26	28.47-29.00	0.63	***	*	0915/0930		260	7.00	Big hydraulics not working properly
27	29.00-29.99	0.91	***	*	0955/1020		220	7.00	
28	29.99-31.52	1.52	***	*	1040/1110		170	6.52	

Table 10. Drilling Data for Hole U12g.12 PW-3

Hole Number	Manufacturer	Type and Series	Matrix	Crown Type	Back Type	Length (meters)
PW-1	Longyear		Diamond Impregnated	Longyear carbide toothed	Remanoided	9.2
PW-2	Longyear		Diamond Impregnated	Longyear carbide toothed	Remanoided	8.9
PW-3	Longyear	HQ3 Series 2 serial #134901	Diamond Impregnated		Densely welded	21.2
"	Longyear	HQ3M Series 1 #022175, serial #34945	Diamond Impregnated		Densely welded	10.4
OI-2	Longyear	Synlux series serial #135004	Diamond Impregnated	Groset Longyear carbide toothed	Remanoided	45.7
OD-1	Longyear		Diamond Impregnated	Groset Longyear carbide toothed	Remanoided	9.7
WD-1	Longyear		Diamond Impregnated	Groset Longyear carbide toothed	Remanoided	
OD-2	Longyear	Series 1, serial #130726	Diamond Impregnated		Densely welded	6.6
"	Longyear	Series 1, serial #130727	Diamond Impregnated		Densely welded	3.1
WD-2	Longyear	Series 1	Diamond Impregnated		Densely welded	

Table 11. Core Bits Used for Horizontal Coring Tests.

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