GEOHYDROLOGIC DATA FROM DRILL-BIT CUTTINGS AND ROTARY CORES FROM TEST HOLE USW UZ-13, YUCCA MOUNTAIN AREA, NYE COUNTY, NEVADA

By Jack Kume and Dale P. Hammermeister

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CONVERSION FACTORS

Multiply	*By*	*To obtain*
gram per cubic centimeter (g/cm^3)	0.03613	pound per cubic inch
kilometer (km)	0.6214	mile
kilopascal (kPa)	0.1450	pound per square inch
kilopascal (kPa)	0.01	bar, 14.5 pounds per square inch
liter (L)	0.2642	gallon
millimeter (mm)	0.03937	inch
meter (m)	3.281	foot

Degree Celsius (°C) may be converted to degree Fahrenheit as follows:

$$F = 9/5(°C) + 32$$

The following terms and abbreviations also are used in this report:

gram per gram (g/g)
milliliter (mL)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

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ABSTRACT

Test hole USW UZ-13 is the fourth of a series of shallow unsaturated-zone test holes drilled in and near the southwestern part of the Nevada Test Site, Nye County, Nev., in cooperation with the U.S. Department of Energy. All of these test holes are a part of the Yucca Mountain Project to identify the suitability of the site for the underground storage of high-level radioactive wastes.

This report contains a description of the methods used in drilling and coring of test hole USW UZ-13; a description of the methods used in the collecting, handling, and testing of test-hole samples; lithologic information from the test hole; and water-content, water-potential, bulk-density and grain-density data for the test hole.

Test hole USW UZ-13 was drilled and cored to a total depth of 130.91 meters. The drilling was done using air as a drilling fluid to minimize disturbance to the water content in drill-bit cuttings, rotary cores, and borehole wall rock. Beginning at the land surface, the unsaturated rock that was penetrated consisted of densely and partially welded to nonwelded ash-flow tuffs; bedded ash-fall, bedded reworked, and ash-fall tuffs; poorly to moderately indurated ash-fall tuffs; and moderately and densely welded ash-flow tuffs. Bedded and ash-fall tuffs and partially welded to nonwelded ash-flow tuffs were continuously cored, and moderately and densely welded ash-flow tuffs were cored at selected intervals. Drill-bit cuttings were obtained at 0.61-meter intervals from the land surface to a depth of 125.12 meters.

Gravimetric water content of rotary cores generally was greatest for bedded and reworked tuffs, ash-fall tuffs, and partially welded to nonwelded ash-flow tuffs and were smallest for densely welded ash-flow tuffs. Gravimetric water content generally was larger for rotary cores than for coarse drill-bit cuttings from the same approximate depths. Water potential of rotary cores was more negative for densely welded ash-flow tuffs and was less negative for bedded and ash-fall tuffs and partially welded to nonwelded ash-flow tuffs. Water potential generally was less negative for rotary cores than for coarse drill-bit cuttings from the same approximate depths.

Values of bulk density of rotary cores were largest for densely welded ash-flow tuffs, such as those from the Tiva Canyon and Topopah Spring Members of the Paintbrush Tuff, and were smallest for bedded and ash-fall tuffs and partially welded to nonwelded ash-flow tuffs from the Paintbrush Tuff.

Values of grain density of rotary cores generally were nearly uniform throughout the various lithologic units. The mean and median values of grain-density measurements of rotary cores were almost identical for the Tiva Canyon and Topopah Spring Members and the bedded tuff.

INTRODUCTION

The U.S. Geological Survey is investigating Yucca Mountain, Nev. (fig. 1), to evaluate the hydrological and geological suitability of this site for the potential storage of high-level radioactive wastes in an underground mined repository (Waddell, 1982; Roseboom, 1983; Montazer and Wilson, 1984; Squires and Young, 1984; Waddell and others, 1984). This investigation is a part of the Yucca Mountain Project that is being done in cooperation with the U.S. Department of Energy (DOE), Nevada Operations Office, under Interagency Agreement DE-AI08-78ET44802. The investigation is being done in accordance with the Yucca Mountain Project-U.S. Geological Survey Quality Assurance (QA) Program. Test drilling has been a principal method of investigation (Bentley and others, 1983; Thordarson and others, 1984).

Test hole USW UZ-13 was the fourth test hole in a series of shallow (total depth less than 150 m) unsaturated-zone test holes that are being drilled on and in the vicinity of Yucca Mountain in different geologic and unsaturated hydrologic environments. Test holes UE-25 UZ #4 and UE-25 UZ #5 were the first in this series of test holes, and test hole USW UZ-7 was the third. The main objectives of the shallow test-hole series of investigations are: (1) To determine the flux of water moving through the nonwelded and bedded tuffs in the upper 150 m of unsaturated rock; (2) to determine the vertical distribution of water content, water potential, and other relevant in-situ hydrologic characteristics and conditions of the rock units penetrated; and (3) to monitor changes through time in relevant, in-situ hydrologic characteristics of the rock units penetrated.

The drilling and coring of test hole USW UZ-13 was done primarily to meet objective 2. The hydrologic characteristics measured in minimally disturbed rotary cores obtained from test hole USW UZ-13 will enable the calculation of flux in the penetrated nonwelded and bedded and ash-fall tuffs (objective 1). Work is planned to instrument test hole USW UZ-13 by installing moisture-sensing probes downhole to measure temporal changes in hydrologic characteristics and conditions (objective 3).

Test hole USW UZ-13 is located in Nye County, Nev., near the southeastern corner of Nellis Air Force Range about 140 km northwest of Las Vegas, Nev., in the southern part of the State (fig. 1). The site of the test hole (fig. 2) is on the main north-south oriented ridge of Yucca Mountain, northwest of Jackass Flats (fig. 1) near the southwestern corner of the Nevada Test Site (NTS). The Nevada State Central Zone Coordinates of the test-hole site are N. 229,195.3 m and E. 170,227.4 m. Altitude of the land surface of the test-hole site is 1,468 m above sea level. The location and altitude of this test-hole site were determined by Holmes & Narver, Inc.[1] (written commun., 1985), Mercury, Nev.

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[1]Use of firm or trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

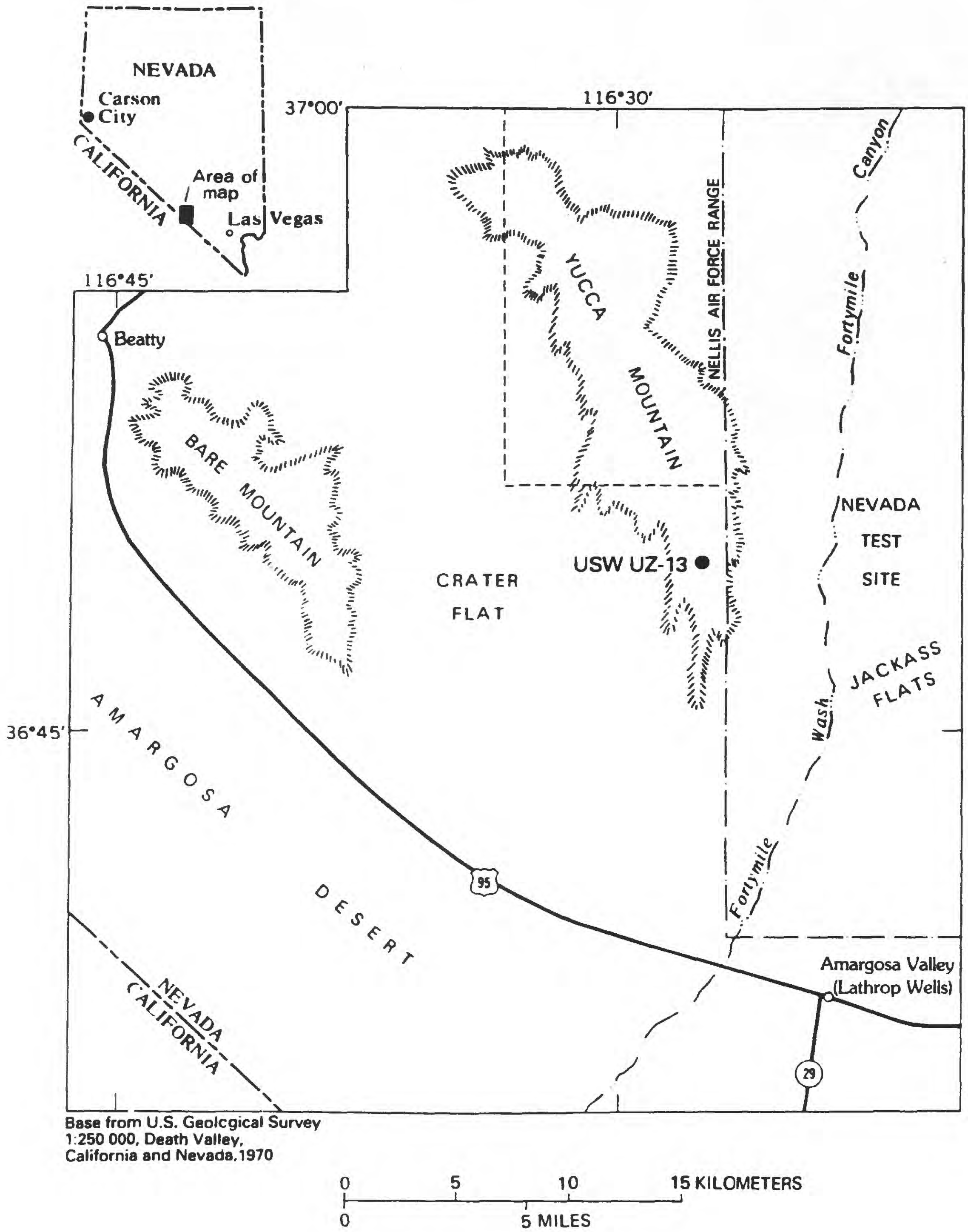

Figure 1.--Location of test hole USW UZ-13.

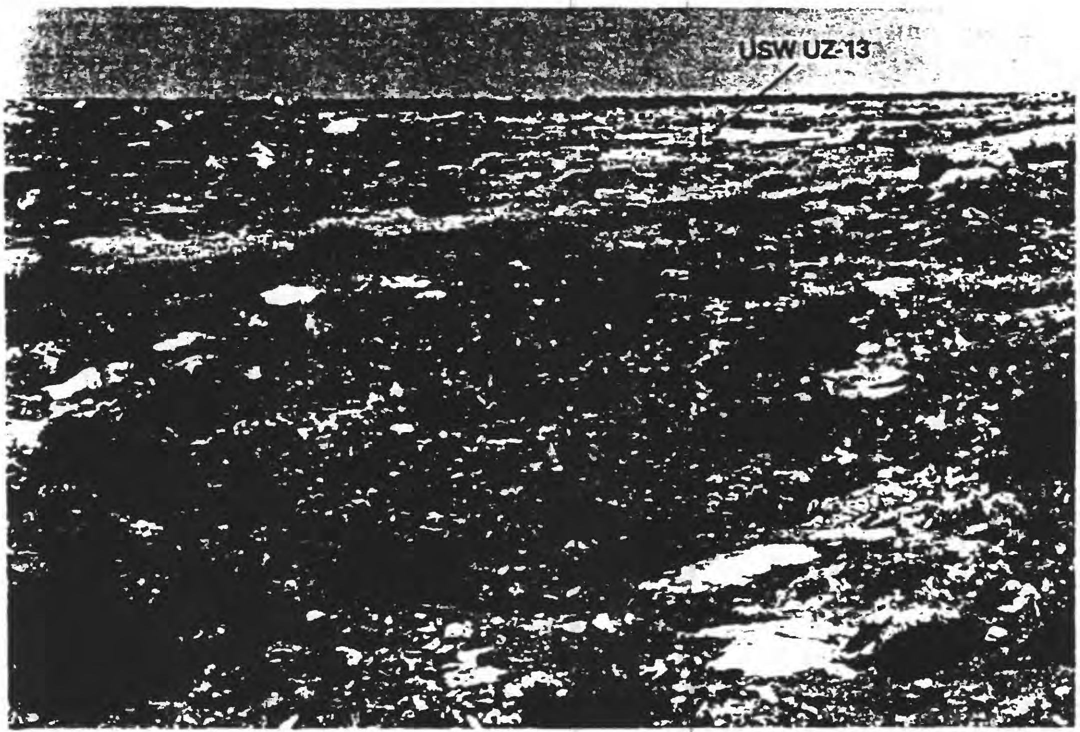

Figure 2.--Drilling site of test hole USW UZ-13.

Purpose and Scope

This report presents data obtained from test hole USW UZ-13, including a lithologic description of the drill-bit cuttings and rotary cores; measurements of the gravimetric water-content values and water-potential values of drill-bit cuttings and of rotary cores; measurements of bulk-density and grain-density values of rotary cores. The report also describes the methods used in drilling and coring the test hole and in collecting, handling, and testing of samples from the test hole. The geophysical logging of the test hole was not completed at the time of this report (1985); however, borehole-television and neutron-moisture logs are available from the U.S. Geological Survey Hydrologic Research Facility office at the NTS.

Methods

This section discribes the methods used to obtain drill-bit cuttings and core samples from test hole USW UZ-13. The testing procedures used on the samples are described in the section "Sample-Testing Procedures and Results."

Drilling and Casing

Drilling of test hole USW UZ-13 started on January 24, 1985, and a total depth of 130.91 m was reached on April 18, 1985. The test hole was drilled using a Joy core rig and the Odex 115 drilling system; air was used as the drilling fluid. This drilling method has been described in detail by Hammermeister and others (1986); therefore, only a brief description is included here. The Odex 115 drilling system is a method that minimally disturbs the in-situ water content of coarse drill-bit cuttings, cores, and borehole wall rock. This method uses a downhole percussion hammer to drill and ream at the bottom joint of the casing. A pilot bit in conjunction with an eccentric reamer drills a hole slightly larger than the outside diameter of the casing. The percussion hammer forces the casing down the borehole by impacting on a shoe attached to the bottom joint of the casing. Thus, the casing is advanced downward as the borehole is drilled deeper. Drill-bit cuttings are brought to the land surface through the casing, thereby minimizing the disturbance to the borehole wall rock. The casing is moved downhole until the desired depth for rotary coring is reached. The desired interval is cored, and the core is collected; then, the cored interval is enlarged (reamed) and the casing is moved to the bottom of the cored interval. This drilling, coring, reaming, and casing sequence is repeated until the total depth of the test hole is reached.

The diameter of the borehole is 152 mm from a depth of 0 to 125 m and 100 mm from a depth of 125 to 130.91 m. Initially, the borehole was cased to a depth of 125.12 m using 1.52-m-long casing sections having a 140-mm outside diameter and a 127-mm inside diameter. When drilling and coring were completed, the casing was removed except for the interval from 0 to 100.58 m. This casing, except for a small piece of stickup casing, will also be removed when the borehole is stemmed and instrumented. A detailed history of the drilling and coring of test hole USW UZ-13 is contained in the Hole History Data file of the engineering firm, Fenix & Scisson, Inc., Las Vegas, Nev. (written commun., 1986).

Rotary Coring

One coring method was used for test hole USW UZ-13. Because there were no unconsolidated deposits (alluvium), drive coring was not needed. In the consolidated deposits (volcanic tuffs), rotary coring was used. Rotary coring using air as the drilling fluid was done using a 1.52-m-long, triple-tube, HWD4-size wireline core barrel modified by Norten Christensen, Inc., Salt Lake City, Utah, for air coring. This air method of rotary coring is described in detail by Hammermeister and others (1986). These authors also reported that this method of coring does not substantially disturb the water content of the core sample or of the borehole wall rock. In relatively soft, poorly consolidated, nonwelded ash-fall tuffs, a tungsten-carbide, stagger-tooth, pilot-type, face-discharge bit was used. In hard, densely welded ash-flow tuffs, a surface-set diamond bit was used. The diameter of the rotary core is 61 mm.

Sample Collection and Handling

During the sample collection and handling operations described in this section for drill-bit cuttings and rotary cores, every effort was made to minimize water evaporation from the rock samples. A method was followed for identification, transport, and handling of drill-bit cuttings, samples, and core from unsaturated-zone boreholes (C.M. McBride, U.S. Geological Survey, written commun., 1984). This method was designed to minimize disturbance to the water content of the drill-bit cuttings and rotary cores from the time these samples are removed from the borehole to the time water-content and water-potential measurements and other water-dependent measurements are made.

Drill-bit cuttings

Fresh drill-bit cuttings were diverted from the borehole through a flexible hose to a nearby dry cyclone separator. As drilling progressed, samples of drill-bit cuttings were collected from the bottom of the cyclone separator through a gate valve that was opened by a hand lever after an interval of 0.61 m had been drilled. The drill-bit cuttings then fell into several collection vessels. A 0.47-L paper carton was filled first; the samples were used for describing the lithology of the interval drilled and for archiving samples in the U.S. Geological Survey Core Library in Mercury, Nev. Next, one or two 0.95-L glass jars were filled and capped using airtight lids. These samples were used for laboratory measurement of water content and water potential. When the collection of samples was completed, the drill-bit cuttings that remained in the separator were discarded on the land surface. If the drill-bit cuttings were moist and stuck to the inside walls of the separator and gate valve, a large hammer was used to knock the drill-bit cuttings from the inside walls and through the gate valve, thereby completely emptying the cyclone separator in preparation for collection of the sample of the next 0.61-m interval drilled. Drilling usually did not stop during these sampling activities. Drill-bit cuttings were collected from the land surface to a depth of 125.12 m.

After the collection of drill-bit cuttings was completed, the cuttings in glass jars usually were taken immediately to the onsite laboratory for processing. If drill-bit cuttings could not be taken immediately to the onsite laboratory, the glass jars were stored temporarily in a large water cooler to minimize condensation inside the jar caused by the heating and cooling of the drill-bit cuttings by ambient-temperature fluctuations and solar radiation.

Once inside the onsite laboratory, the glass jars containing the drill-bit cuttings were placed inside a humidified glove box to minimize evaporation from the samples during subsequent sample preparation. The samples of coarse drill-bit cuttings then were seived through a screen that had openings of about 5.0 mm to separate the drill-bit cuttings into coarse- and fine-sized fractions. Unsieved drill-bit cuttings were called composite-sized fractions. Coarse drill-bit cuttings were collected from the top of the screen, and fine drill-bit cuttings were collected from below the screen. Part of the coarse-sized fraction was put in a 420-mL moisture can for gravimetric water-content measurements. Measurements of gravimetric water content of samples in moisture cans were started immediately in the onsite laboratory. Part of the coarse-sized fraction was placed in a 113-mL glass jar for temporary storage until water-potential measurements could be done. The air-tight lid on the 113-mL jar was taped and sealed with wax to minimize evaporation losses from the drill-bit cuttings during storage. Coarse drill-bit cuttings were collected from welded, nonwelded, and bedded tuffs in the test hole.

Previous investigations of the shallow unsaturated-zone hydrology of Yucca Mountain in which the same drilling, casing, and coring methods were used have indicated that the water content of rotary-core samples correlates more accurately with the water content of coarse drill-bit cuttings than with any other size of drill-bit cuttings (C.L. Loskot and D.P. Hammermeister, U.S. Geological Survey, written commun., 1986). A good correlation or degree of relation (linear-regression coefficient of determination 0.80) was obtained from the water content of composite rotary cores and the water content of coarse drill-bit cuttings from nonwelded and bedded ash-fall tuffs in test-hole UE-25 UZ #4 (C.L. Loskot and D.P. Hammermeister, written commun., 1986).

C.L. Loskot and D.P. Hammermeister (written commun., 1986) also reported that the borehole wall rock tended to dry out when exposed to circulating air for long time periods during continuous core runs. This disturbed rind of borehole wall rock was removed when the borehole was enlarged and cased using the Odex 115 drilling system. In test hole USW UZ-13, continuous rotary-core intervals purposely were kept short to minimize the drying of the borehole wall rock before reaming. Coarse drill-bit cuttings have the smallest surface area per unit of volume of any sized fraction and have the smallest chance for the water content to be changed by the drilling air. On the basis of this fact and on information from previous investigations at Yucca Mountain, coarse drill-bit cuttings were the primary particle-size fraction collected from most of the rock units in test hole USW UZ-13 for water-content and water-potential measurements.

Rotary core

A 1.52-m long, triple-tube core barrel, which has a split tube inside an inner tube, was used to obtain a 64-mm-diameter rotary core. An oversized carbide-tipped drag bit or a diamond-tipped bit was used with air to drill the core. After each coring operation, the split tube containing core was removed from the core barrel at the drill site, immediately taken to the onsite laboratory, and placed in a humidified glove box for processing. The first step included an examination and description of the natural fractures in the core, followed by a preliminary description of lithology. The next step included the removal of several core segments from the split tube for laboratory analysis. For a split tube full of core, segments about 76-mm long were removed from the bottom and from about 760 mm above the bottom of the split tube for water-potential and gravimetric water-content measurements. Additionally, two 76-mm-long and two 152-mm-long core segments also were obtained from the bottom and midsections of the split tube. Of these segments, the shorter segments were to be used for future matric-potential measurements and the longer segments for future physical property and permeability-related measurements. These segments and any other remaining core segments were placed in several split polyvinyl-chloride (PVC) liners (64-mm inside diameter), capped, taped, waxed, labeled, and stored in an air-conditioned environment until laboratory tests could be done. For a less than full split tube, the segment sizes and number collected depended on the length of core recovered. For example, if the split tube was only one-half filled, then only one set of segments was collected.

The rotary-core record for test hole USW UZ-13 is summarized in table 1. Rotary cores were collected continuously from bedded and ash-fall tuffs and partially welded to nonwelded ash-flow tuffs and were collected selectively from moderately and densely welded ash-flow tuffs. Thirty-three cores were collected. A total of 27.03 m of rock was cored, of which 26.54 m or 98 percent was recovered. Thirty core runs had 100-percent or more core recovery. Seven core recoveries were longer than the length of the core barrel (1.52 m). This additional core was recovered as it projected out of the open bottom end of the core barrel. Extra core can occur during continuous coring, as the cored rock does not always break off at the end of the cored interval. It may break off above the total depth of coring, and a stub of core remains in the hole as the core barrel is brought to the land surface. This core stub plus the next cored interval of rock is recovered after the next core run.

LITHOLOGY

A lithologic log of rocks that were penetrated during the drilling of test hole USW UZ-13 was made from a description of samples of drill-bit cuttings and rotary cores and is listed in table 2. The rocks penetrated are of volcanic origin and of Tertiary age. Two major moderately to densely welded and partially welded to nonwelded ash-flow tuffs are the predominant rock type penetrated in test hole USW UZ-13. Bedded, reworked, slightly indurated, vitric, and slightly sorted ash-fall tuffs are present between these two major ash-flow tuffs. The ash-flow and ash-fall tuffs have various degrees of welding and induration, as described in table 2.

SAMPLE-TESTING PROCEDURES AND RESULTS

Drill-bit cuttings and rotary cores were collected for four types of laboratory tests: water-content, water-potential, bulk-density, and grain-density measurements. These laboratory tests were done at the Nevada Test Site in U.S. Geological Survey laboratories near the drill site for water content and at Test Cell C for water potential and Holmes & Narver Materials Testing Laboratory in Mercury, Nev. for bulk and grain density. The results of these tests are summarized in tables in this report.

Water-Content Measurements

Gravimetric water-content measurements were done in the U.S. Geological Survey onsite laboratory using standard gravimetric oven-drying methods as described in a method for monitoring moisture content of drill-bit cuttings from the unsaturated zone (Gardner, 1965), and as described in a method for hydrologic-laboratory testing of core and drilling-cutting samples from unsaturated-zone test holes (C.M. McBride, written commun., 1985). The results of gravimetric water-content measurements of samples of coarse drill-bit cuttings and rotary cores are summarized in tables 3 and 4 and are shown in figure 3. In coarse drill-bit cuttings, the water-content measurements ranged from 0.006 g/g in a sample from a depth of 89.31 m to 0.135 g/g in a sample from 113.69 m (table 3). In rotary cores, the gravimetric water-content measurements ranged from 0.014 g/g in a sample from a depth of 6.71 to 6.83 m to 0.205 g/g in a sample from 113.32 to 113.39 m (table 4).

Table 1.--*Rotary-core record for test hole USW UZ-13*

[A, gravimetric water-content and water-potential measurements; B, matric-potential measurements; C, D, E, physical property and permeability-related measurements; --, no data]

Core number	Depth interval (meters)	Core length (meters)	Core recovered (meters)	Laboratory tests
1	3.66 to 4.12	0.46	0.46	A C E
2	6.71 to 7.32	.61	.37	A C E
3	9.75 to 9.91	.16	.00	--
4	12.80 to 13.10	.30	.30	A C
5	15.85 to 16.15	.30	.30	A C E
6	18.90 to 19.20	.30	.30	A C E
7	21.95 to 22.11	.16	.16	C E
8	28.04 to 28.34	.30	.30	A C E
9	34.14 to 34.44	.30	.30	A C E
10	40.23 to 40.32	.09	.00	--
11	44.81 to 44.90	.09	.09	A
12	51.82 to 52.12	.30	.30	A C E
13	102.11 to 102.26	.15	.15	E
14	102.26 to 102.87	.61	.61	A B C D E
15	105.16 to 106.37	1.32	1.32	A B C D E
16	106.47 to 106.59	.12	.12	E
17	106.59 to 108.11	1.52	1.52	A B C D E
18	108.11 to 109.48	1.37	1.37	A B C D E
19	109.48 to 110.76	1.28	1.28	A B C D E
20	110.76 to 111.74	.98	.98	A B C D E
21	111.74 to 113.33	1.59	1.59	A B C D E
22	113.33 to 114.92	1.59	1.59	A B C D E
23	114.92 to 116.50	1.58	1.58	A B C D E
24	116.50 to 118.08	1.58	1.58	A B C D E
25	118.08 to 119.60	1.52	1.52	A B C D E
26	119.60 to 121.13	1.53	1.53	A B C D E
27	121.13 to 121.74	.61	.61	A B C E
28	121.74 to 121.92	.18	.18	E
29	124.97 to 126.52	1.55	1.55	A B C D E
30	126.52 to 127.10	.58	.58	A B C D E
31	127.10 to 128.69	1.59	1.59	A B C D E
32	128.69 to 130.18	1.49	1.49	A B C D E
33	130.18 to 131.10	.92	.92	A B C D E

Table 2.--*Lithologic log for test hole USW UZ-13*

[Modified from a condensed log by R.W. Spengler, U.S. Geological Survey, written commun., 1985]

Stratigraphy and lithologic description	Thickness of interval (meters)	Depth of interval (meters)
Paintbrush Tuff of Tertiary age		
Tiva Canyon Member (0 to 107.90 meters)		
Tuff, ash-flow, densely welded, devitrified	100.28	0.00 to 100.28
Tuff, ash-flow, partially welded to nonwelded, vitric	7.62	100.28 to 107.90
Bedded tuff (unnamed, 107.90 to 114.00 meters)		
Tuff, ash-fall, slightly consolidated, moderately to slightly sorted, fine to medium grained, vitric	.61	107.90 to 108.51
Tuff, reworked, slightly to well cemented with carbonate, slightly sorted, vitric	1.22	108.51 to 109.73
Tuff, reworked, slightly indurated, slightly sorted, vitric	.91	109.73 to 110.64
Tuff, ash-fall, slightly indurated, slightly sorted, vitric	.92	110.64 to 111.56
Tuff, reworked, slightly indurated, vitric	.30	111.56 to 111.86
Tuff, ash-fall, slightly indurated, slightly sorted, vitric	2.14	111.86 to 114.00
Topopah Spring Member (114.00 to 130.91 meters)		
Tuff, ash-fall(?), slightly indurated, slightly sorted, vitric	4.90	114.00 to 118.90
Tuff, ash-fall, slightly to moderately indurated [fused(?)], vitric	2.41	118.90 to 121.31
Tuff, ash-flow, moderately welded, vitric	1.83	121.31 to 123.14
Tuff, ash-flow, densely welded, vitrophyre	1.52	123.14 to 124.66
Tuff, ash-flow, densely welded, devitrified	.61	124.66 to 125.27
Tuff, ash-flow, moderately welded, vapor-phase crystallization	5.64	125.27 to 130.91
	Total depth	130.91 meters

Table 3.--*Results of laboratory analyses for gravimetric water content and water potential of coarse drill-bit cuttings from test hole USW UZ-13*

[--, no data]

Depth (meters)	Gravimetric water content (gram per gram)	Water potential (kilopascals)
0.91	0.076	-730
1.52	.075	-660
1.98	.081	-850
2.29	.072	-1,500
2.74	.072	-640
3.35	.071	-490
3.96	.052	-370
4.57	.073	-350
5.03	.079	-440
5.33	.051	-330
5.79	.040	-390
6.40	.048	-650
7.01	.035	-1,000
7.62	.043	-650
8.08	.032	-620
8.38	.036	-640
8.84	.049	-710
9.45	.090	-290
10.06	.058	-360
11.89	.042	-500
12.50	.065	-230
13.11	.051	-470
13.87	--	-890
14.48	.047	-690
14.94	.059	-560
15.54	.061	-510
16.15	.055	-580
16.76	.058	-480
17.22	.059	-450
17.53	.056	-550
17.98	.060	-570
18.59	.061	-710
19.20	.058	-520
19.81	.059	-530
20.27	.058	-440

Table 3.--*Results of laboratory analyses for gravimetric water content and water potential of coarse drill-bit cuttings from test hole USW UZ-13*--Continued

Depth (meters)	Gravimetric water content (gram per gram)	Water potential (kilopascals)
20.57	0.055	-520
21.03	.053	-510
21.64	.055	-580
22.25	.057	-510
22.86	.057	-740
23.32	.049	-800
23.62	.053	-650
24.08	.050	-690
24.69	.045	-770
25.30	.047	-620
25.91	.047	-580
26.37	.045	-620
26.67	.046	-620
27.13	.044	-650
27.74	.039	-620
28.35	.033	-700
28.96	.034	-830
29.41	.032	-760
29.72	.033	-720
30.18	.034	-730
30.78	.040	-680
31.39	.038	-640
32.00	.037	-1,100
32.46	.040	-800
32.77	.040	-890
33.22	.037	-880
33.83	.037	-1,000
34.44	.038	-900
35.05	.036	-1,100
35.51	.037	-1,000
35.81	.051	-640
36.27	.045	-680
36.88	.048	-610
37.49	.040	-810
38.10	.033	-1,300
38.56	.027	-1,700
38.86	.028	-1,000
39.32	.026	-2,700
39.93	.027	-2,200
40.54	.028	-2,800

Table 3.--*Results of laboratory analyses for gravimetric water content and water potential of coarse drill-bit cuttings from test hole USW UZ-13*--Continued

Depth (meters)	Gravimetric water content (gram per gram)	Water potential (kilopascals)
41.15	0.029	-1,800
41.61	.030	-2,700
41.91	.026	-2,900
42.37	.028	-3,800
42.98	.031	-2,300
43.59	.027	-4,200
44.04	.025	-3,100
44.35	.027	-3,200
44.65	.031	-3,000
44.96	.025	-4,300
45.41	.026	-3,400
46.02	.025	-2,000
46.63	.024	-4,900
47.24	.028	-1,900
47.85	.029	-2,700
48.46	.028	-3,400
49.07	.026	-5,700
49.68	.027	-3,300
50.29	.019	-6,600
50.90	.021	-6,300
51.51	.024	-3,700
52.12	.027	-2,000
52.73	.026	-4,900
53.34	.024	-5,200
53.95	.025	-4,500
54.56	.022	-6,300
55.17	.026	-3,300
55.78	.023	-4,300
56.39	.020	-5,500
57.00	.022	-4,000
57.61	.020	-8,000
58.22	.020	-5,900
58.83	.018	-7,900
59.44	.022	-5,800
60.05	.024	-5,400
60.66	.022	-6,900
61.26	.028	-1,300
61.87	.026	-3,600
62.48	.027	-1,200
63.09	.029	-1,400

Table 3.--*Results of laboratory analyses for gravimetric water content and water potential of coarse drill-bit cuttings from test hole USW UZ-13*--Continued

Depth (meters)	Gravimetric water content (gram per gram)	Water potential (kilopascals)
63.70	0.027	-1,100
64.31	.025	-2,100
64.92	.018	-7,300
65.53	.015	-10,000
66.14	.016	-10,000
66.75	.015	-9,300
67.36	.017	-7,200
67.97	.007	-4,700
68.58	.015	-6,300
69.19	.015	-11,000
69.80	.015	-10,000
70.41	.017	-8,600
71.02	.018	-8,400
71.63	.016	-10,000
72.23	.019	-8,700
72.85	.019	-6,400
73.46	.019	-7,100
74.07	.017	-7,400
74.68	.017	-6,200
75.29	.016	-8,200
75.90	.016	-8,000
76.50	.018	-8,600
77.11	.015	-13,000
77.72	.021	-5,400
78.33	.020	-4,200
78.94	.021	-7,800
79.55	.019	-8,900
80.16	.013	-11,000
80.77	.019	-7,800
81.38	.020	-8,600
81.99	.018	-8,600
82.60	.019	-9,400
83.21	.010	-16,000
83.82	.011	-2,100
84.28	.019	-9,600
84.58	.012	-12,000
85.04	.016	-18,000
85.65	.011	-39,000
86.26	.018	-16,000
86.87	.022	-13,000

Table 3.--*Results of laboratory analyses for gravimetric water content and water potential of coarse drill-bit cuttings from test hole USW UZ-13*--Continued

Depth (meters)	Gravimetric water content (gram per gram)	Water potential (kilopascals)
87.48	0.024	-8,900
87.78	.027	--
88.09	.026	-15,000
88.70	--	-6,900
89.31	.006	-55,000
89.92	.012	-50,000
90.53	--	-37,000
91.14	.018	-21,000
91.74	.022	-13,000
92.35	.021	-10,000
92.96	.016	-19,000
93.57	.016	-28,000
93.88	.018	-16,000
94.79	.019	-26,000
95.40	.022	-13,000
96.01	.025	-16,000
96.62	.020	-17,000
97.23	.023	-20,000
97.84	.021	-14,000
98.45	.022	-15,000
99.06	.035	-2,400
99.67	.025	-23,000
100.28	.040	-26,000
100.89	.040	-22,000
101.50	.046	-22,000
101.96	.046	-18,000
102.26	.041	-13,000
102.72	.040	-13,000
103.33	.046	-8,700
103.94	.059	-5,800
104.55	.059	-1,900
105.00	.086	-740
105.31	.058	-2,400
105.77	.060	-7,700
106.38	.065	-7,700
106.98	.052	-15,000
107.59	.079	-8,100
108.20	--	-10,000
108.81	.045	-15,000
109.42	.038	-14,000

Table 3.--*Results of laboratory analyses for gravimetric water content and water potential of coarse drill-bit cuttings from test hole USW UZ-13*--Continued

Depth (meters)	Gravimetric water content (gram per gram)	Water potential (kilopascals)
110.03	--	-4,500
110.64	--	-12,000
111.25	0.068	-2,400
111.86	.102	-710
112.47	--	-680
112.93	.115	-610
113.23	.109	-540
113.69	.135	-480
114.30	.119	-600
114.91	.120	-620
115.52	.118	-540
116.13	.118	-510
116.74	.111	-630
117.35	.104	-480
117.96	.099	-810
118.57	.082	-960
119.18	.081	-920
119.79	.053	-690
120.40	.066	-650
121.01	.075	-710
121.61	.067	-550
122.22	.073	-600
122.83	--	-5,700
123.44	--	-10,000
124.05	--	-7,300
124.66	.009	-12,000
125.12	--	-19,000

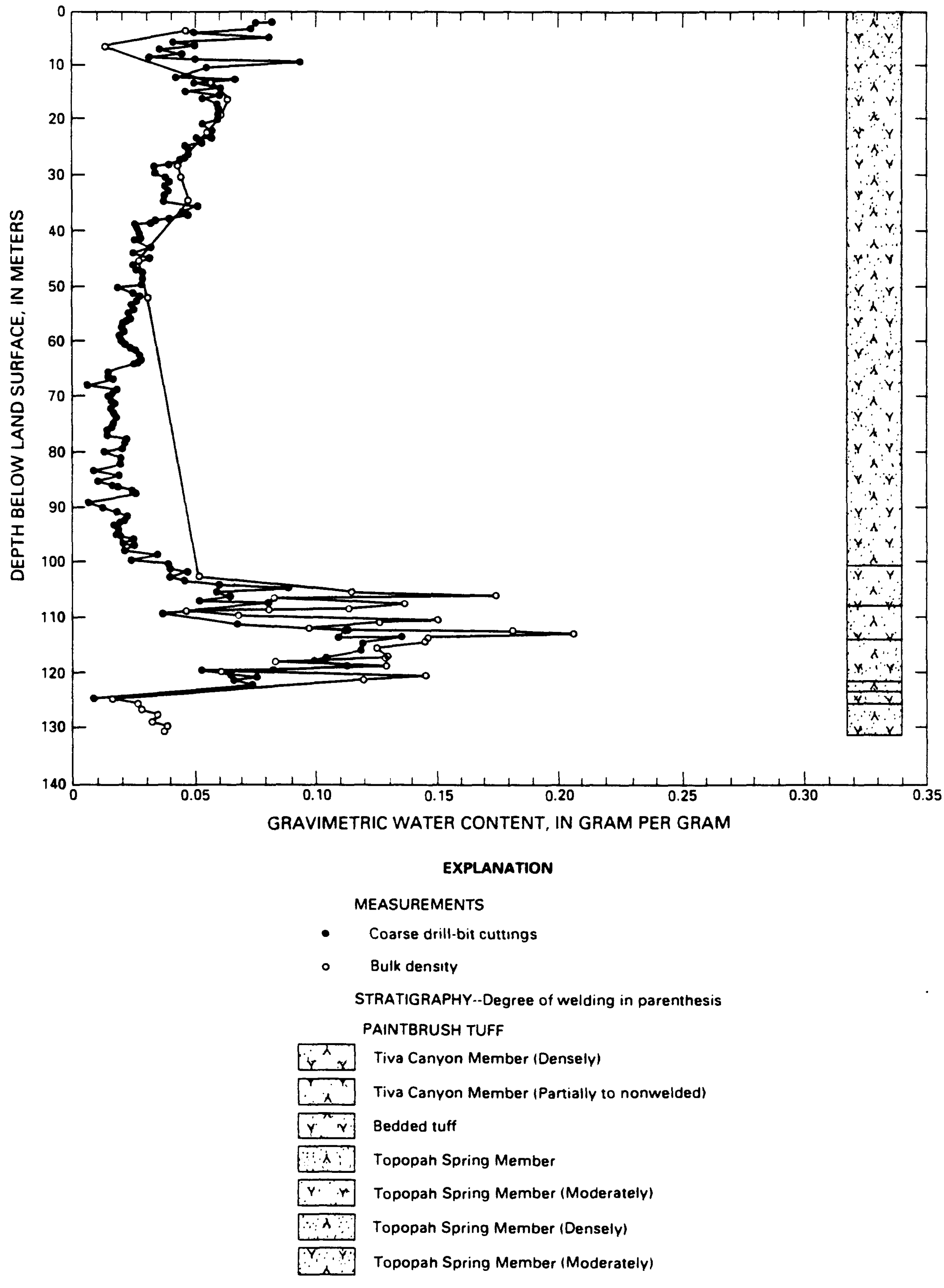

Figure 3.--Gravimetric water-content measurements, stratigraphy, and welding of coarse drill-bit cuttings and rotary cores from test hole USW UZ-13.

Table 4.--*Results of laboratory analyses for gravimetric water content and water potential of rotary cores from test hole USW UZ-13*

[--, no data]

Depth interval (meters)	Gravimetric water content (gram per gram)	Water potential (kilopascals)
3.66 to 3.73	0.047	-1,400
6.71 to 6.83	.014	-730
12.80 to 12.89	.057	-550
15.85 to 15.91	.065	-600
18.90 to 19.20	--	-730
19.13 to 19.20	.062	--
22.10 to 22.13	--	-700
28.04 to 28.13	.044	-790
34.31 to 34.40	.049	-580
44.80 to 44.90	.027	-830
51.94 to 52.04	.031	-3,200
102.69 to 102.75	.053	-1,100
105.37 to 105.46	.115	-630
106.31 to 106.41	.175	-550
106.65 to 106.71	.083	-600
107.29 to 107.38	.137	-590
108.35 to 108.45	.114	-470
108.81 to 108.87	.048	-3,400
109.48 to 109.55	.060	-1,500
110.40 to 110.46	.151	-330
110.86 to 110.95	.128	-240
111.65 to 111.74	.097	-320
112.04 to 112.14	.113	-250
112.65 to 112.78	.181	-330
113.32 to 113.39	.205	-260
114.00 to 114.09	.146	-320
114.91 to 115.00	.145	-340
115.79 to 115.88	.125	-360
116.49 to 116.59	.127	-370
117.50 to 117.59	.129	-360
118.17 to 118.29	.084	-470
118.84 to 188.90	.129	-400
119.60 to 119.69	.062	-460
120.73 to 120.82	.145	-300
121.37 to 121.46	.120	-340
125.21 to 125.27	.017	-1,900
125.79 to 125.85	.028	-770
126.77 to 126.86	.029	-800
127.10 to 127.16	.030	-820
127.92 to 127.99	.035	-760
129.02 to 129.11	.033	-710
130.00 to 130.06	.040	-580
130.82 to 130.91	.037	-770

Generally, especially for deeper sample depths, the gravimetric water-content measurements of rotary cores were larger than the same measurements of coarse drill-bit cuttings (fig. 3). Linear-regression analysis indicated a good correlation (coefficient of determination, $r^2 = 0.819$ in table 5) between the water content of coarse drill-bit cuttings and that of rotary cores. A comparison of gravimetric water content between coarse drill-bit cuttings and rotary cores obtained from the same depth showed differences as large as 0.110 g/g and as small as 0.001 g/g; generally, the differences were less than 0.030 g/g for most measurements. These differences are thought to be due to the drying of the borehole wall rock during coring and to the drying that occurred when the thin (about 25 mm) rind of borehole wall rock was removed from the borehole wall during the reaming process.

A comparison of the gravimetric water content of rotary cores indicated that the water content is largest for bedded and reworked tuffs and ash-fall tuffs from the bedded tuff; it is smallest for densely welded ash-flow tuffs from the Tiva Canyon Member and almost as small from the Topopah Spring Member of the Paintbrush Tuff. For the Tiva Canyon Member, the water content ranged from 0.014 to 0.175 g/g. For the bedded tuff, the water content ranged from 0.048 to 0.205 g/g (table 4). For the Topopah Spring Member, the water content ranged from 0.017 to 0.146 g/g.

The gravimetric water content of volcanic tuffs probably is directly related to the degree of welding. The relations of the gravimetric water content of coarse drill-bit cuttings and rotary cores from test hole USW UZ-13 to the lithology and degree of welding are summarized in tables 6 and 7. Although the water content of rotary cores was the least disturbed during drilling process and should be, therefore, more representative of the in-situ hydrologic conditions, coarse drill-bit cuttings also were analyzed. A more complete sampling record for drill-bit cuttings was available, whereas several gaps existed in the sampling record for rotary cores.

Table 5.--*Summary of linear-regression analysis of gravimetric water content of coarse drill-bit cuttings and rotary cores from test hole USW UZ-13*

[Y = a + bX; dependent variable, Y; gravimetric water content of rotary cores from welded, partially welded to nonwelded, and bedded tuffs; independent variable, X; gravimetric water content of coarse drill-bit cuttings from welded, partially welded to nonwelded, and bedded tuffs]

Number of data points, n	Coefficient of determination, r^2	Intercept, a	Slope, b
35	0.819	0.006	1.261

Table 6.--*Summary of gravimetric water-content and water-potential measurements of coarse drill-bit cuttings from different lithologic units penetrated in test hole USW UZ-13, and degree of welding*

[--, no data]

Lithologic unit	Gravimetric water content (gram per gram)			Water potential (kilopascals)			Degree of welding
	Range	Mean	Median	Range	Mean	Median	
Paintbrush Tuff							
Tiva Canyon	0.006 to 0.090	0.033	0.027	-230 to -55,000	-5,900	-2,800	Densely welded
Member	0.040 to 0.086	.056	.055	-740 to -22,000	-10,000	-8,400	Partially welded to nonwelded
Bedded tuff	0.038 to 0.135	.087	.102	-480 to -15,000	-5,500	-2,400	Not applicable
Topopah	0.053 to 0.120	.096	.102	-480 to -960	-680	-640	Not applicable
Spring	0.067 to 0.073	.070	.070	-550 to -5,700	-2,300	-600	Moderately welded
Member	[1]0.009	--	--	-7,300 to -19,000	-12,000	-11,000	Densely welded
	-- --	--	--	-- --	--	--	Moderately welded

[1]One sample.

Table 7.--*Summary of gravimetric water-content and water-potential measurements of rotary cores from different lithologic units penetrated in test hole USW UZ-13, and degree of welding*

[--, no data]

Lithologic unit	Gravimetric water content (gram per gram)			Water potential (kilopascals)			Degree of welding
	Range	Mean	Median	Range	Mean	Median	
Paintbrush Tuff							
Tiva Canyon	0.014 to 0.065	0.044	0.047	-550 to -3,200	-1,000	-730	Densely welded
Member	0.053 to 0.175	.113	.115	-550 to -1,100	-690	-600	Partially welded to nonwelded
Bedded tuff	0.048 to 0.205	.122	.114	-240 to -3,400	-790	-330	Not applicable
Topopah	0.062 to 0.146	.121	.129	-300 to -470	-380	-360	Not applicable
Spring	[1]0.120	--	--	[1]-340	--	--	Moderately welded
Member	[1]0.017	--	--	[1]-1,900	--	--	Densely welded
	0.028 to 0.040	.033	.033	-580 to -820	-740	-770	Moderately welded

[1]One sample.

The densely welded ash-flow tuffs have the smallest water content, and the bedded and reworked tuffs and ash-fall tuffs have the largest water content. The largest value (0.205 g/g) is for the ash-fall tuffs of the bedded tuff (table 7), and the smallest value (0.006 g/g) is for densely welded ash-flow tuffs from the Tiva Canyon Member (table 6). Intermediate values of water content were measured for partially welded to nonwelded ash-flow tuffs from the Tiva Canyon Member and for the moderately welded ash-flow tuffs from the Topopah Spring Member of the Paintbrush Tuff.

A comparison was made of gravimetric water content of coarse drill-bit cuttings from the different lithologic units in test hole USW UZ-13 (table 6). The water content was largest (0.135 g/g) for bedded and ash-fall tuffs (fig. 3) and almost as large (0.120 g/g) for ash-fall tuffs from the Topopah Spring Member of the Paintbrush Tuff. The water content was smallest (0.006 g/g) for densely welded ash-flow tuffs from the Tiva Canyon Member and almost as small (0.009 g/g) for densely welded ash-flow tuffs from the Topopah Spring Member of the Paintbrush Tuff.

Water-Potential Measurements

Water-potential measurements were made in accordance with methods describing hydrologic laboratory testing of core and drilling-cutting samples from unsaturated-zone test holes (C.M. McBride, written commun., 1985). Water potential (Rawlins, 1966; Brown, 1970; Phene and others, 1971) is the sum of the matric and osmotic potentials. The water potential was measured during this investigation using an SC-10 thermocouple psychrometer and an NT-3 nanovoltmeter (Decagon Devices, Pullman, Wash.). The SC-10 consists of a stationary thermocouple psychrometer and 10 sample chambers that can be rotated to the thermocouple psychrometer. The Richards method (Richards, 1942; Richards and Ogata, 1958) was used to condense water on the thermocouple junction for the measurements described here. Calibration solutions were measured concurrently with the actual rock samples to compensate for the zero drift of the amplifier of the nanovoltmeter. Generally, three of the sample chambers contained calibration solutions equivalent to known water potentials; six of the sample chambers contained samples of drill-bit cuttings or rotary cores or both; and the remaining chamber contained distilled water. Thermocouple output (voltage) was measured first for the known calibration standards, second for the output from the rock samples, and third for the output from the calibration standards again. The average of the before-and-after outputs for each calibration standard was used to determine the calibration curve. Calibration curves of water potential versus output were nearly linear from about -100 to -7,000 kPa for water potential measured. Regression coefficients ranged from 0.993 to 1.000; most coefficients were equal to 1.000. The water potential was measured in negative bars (bar = 100 kPa) but was converted to negative kilopascals for this report.

The SC-10 sample chamber was filled with calibration solutions and rock samples in a humidified glove box to minimize evaporation. After filling was completed, at least 0.5 hour passed to enable temperature and vapor to achieve equilibrium before measurements were made. To avoid temperature fluctuations, all measurements were made inside a glove box at room temperature between 20 and 25 °C. All equipment, including the thermocouple junction, was meticulously cleaned after each set of measurements to prevent carryover of salts or dust to the next set of measurements.

The results of water-potential measurements are summarized in tables 3 and 4 and shown in figure 4. Generally, for samples obtained from the same sample depths, the water-potential measurements of coarse drill-bit cuttings were consistently more negative (less water content) than the measurements of rotary cores. The water-potential differences between coarse drill-bit cuttings and rotary cores from the same depths were as large as -17,000 kPa and as small as -55 kPa; generally, the differences were less than -500 kPa for most measurements. The differences in water potential between cuttings and cores (fig. 4) are greater than the differences in water content (fig. 3). These differences probably were caused by some drying of the drill-bit cuttings during transfer from the drill bit to the cyclone separator, for various reasons. Linear-regression analysis indicated a poor correlation (coefficient of determination, $r^2 = 0.467$ in table 8) between the water-potential measurements of coarse drill-bit cuttings and rotary cores. Water potential is dependent on water content and, in many instances, a small change of water content caused by drying can result in a large change of water potential. This phenomenon is discussed in more detail by Hammermeister and others (1986).

A comparison was made of the water potential of coarse drill-bit cuttings and rotary cores from the various lithologic units in test hole USW UZ-13 (fig. 4 and tables 6 and 7); the comparison indicated that trends of the water-potential data are similar to trends of gravimetric water-content data. Water potential of rock is dependent (nonlinear) on water content. The largest negative values were obtained from coarse drill-bit cuttings for densely welded ash-flow tuffs (table 6); the smallest negative values were measured from rotary cores for bedded and ash-fall tuffs (table 7); and the intermediate negative values were measured from rotary cores from partially welded to nonwelded ash-flow tuffs. For coarse drill-bit cuttings, the water potential was more negative for the Tiva Canyon Member of the Paintbrush Tuff than for the bedded tuff and the Topopah Spring Member of the Paintbrush Tuff. For rotary cores from the Tiva Canyon Member, the water potential ranged from -550 to -3,200 kPa (table 7). For the bedded tuff, the water potential of rotary cores ranged from -240 to -3,400 kPa. For the Topopah Spring Member, the water potential of rotary cores ranged from -300 to -1,900 kPa.

Water potential of tuffs, like gravimetric water content, probably is directly related to the degree of welding. Although rotary-core data are the most representative for the rock units penetrated, coarse drill-bit-cutting data were analyzed because a more complete sampling record was available. The densely welded ash-flow tuffs from the Tiva Canyon and the Topopah Spring Members of the Paintbrush Tuff are the driest and have the most negative water potential. The bedded tuff and the ash-fall tuffs from the Topopah Spring Member and the partially welded to nonwelded ash-flow tuffs from the Tiva Canyon Member of the Paintbrush Tuff are the wettest and have the least negative water potential.

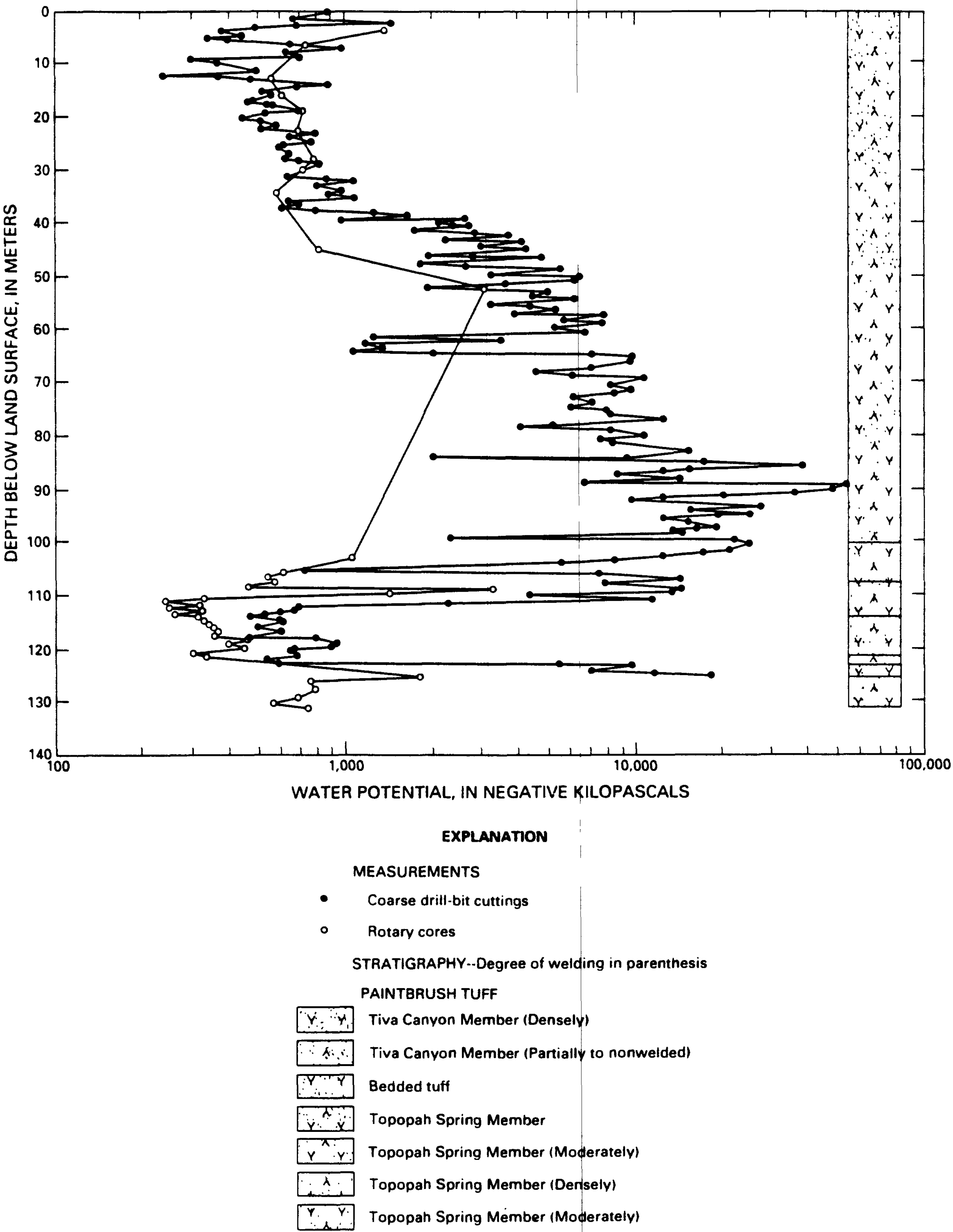

Figure 4.--Water-potential measurements, stratigraphy, and welding of coarse drill-bit cuttings and rotary cores from test hole USW UZ-13.

Table 8.--*Summary of linear-regression analysis of water potential of coarse drill-bit cuttings and rotary cores from test hole USW UZ-13*

[Y = a + bX; dependent variable, Y; gravimetric water content of rotary cores from welded, partially welded to nonwelded, and bedded tuffs; independent variable, X; gravimetric water content of coarse drill-bit cuttings from welded, partially welded to nonwelded, and bedded tuffs]

Number of data points, n	Coefficient of determination, r^2	Intercept, a	Slope, b
35	0.467	-4.89	0.064

Bulk-Density and Grain-Density Measurements

A comparison was made between the bulk density and the grain density of rotary cores in the various lithologic units drilled in test hole USW UZ-13. Bulk-density and grain-density measurements were made of rotary cores by Holmes & Narver Materials Testing Laboratory. The bulk specific gravity was determined for each sample in accordance with ASTM Procedure D-1188, "Bulk Specific Gravity of Compacted Bituminous Mixtures Using Paraffin Coated Specimens." The bulk density was calculated from the bulk specific gravity and is a natural bulk density. Each sample was then pulverized to pass No. 200 mesh sieve, oven-dried, and tested in accordance with ASTM Procedure D854, "Specific Gravity of Soils." The grain density was calculated from the bulk specific gravity. The results are summarized in tables 9 and 10. The relations between bulk density and grain density and depth are shown in figure 5. Bulk density of rotary cores ranged from 0.91 g/cm^3 at a depth of 117.50 to 117.59 m to 2.38 g/cm^3 at a depth of 6.71 to 6.83 m. Grain density of rotary cores ranged from 2.33 g/cm^3 at a depth of 125.21 to 125.27 m to 2.67 g/cm^3 at 6.71 to 6.83 m.

The bulk density was largest (2.38 g/cm^3) for densely welded ash-flow tuffs from the Tiva Canyon Member at a depth of about 7 m and almost as large (2.31 g/cm^3) for densely welded ash-flow tuffs from the Topopah Spring Member of the Paintbrush Tuff at a depth of 125 m. The bulk density was smallest for ash-fall tuffs from the Topopah Spring Member and for bedded and ash-fall tuffs from the bedded tuff (fig. 5, table 9) of the Paintbrush Tuff.

Table 9.--*Results of laboratory analyses for bulk density and grain density of rotary cores from test hole USW UZ-13*

[Data from Holmes & Narver Materials Testing Laboratory, Mercury, Nev.]

Depth interval (meters)	Bulk density (grams per cubic centimeter)	Grain density (grams per cubic centimeter)
3.66 to 3.73	2.02	2.55
6.71 to 6.83	2.38	2.63
12.80 to 12.89	2.14	2.50
15.85 to 15.91	2.06	2.49
19.13 to 19.20	2.09	2.49
28.04 to 28.13	2.18	2.44
34.31 to 34.40	2.15	2.46
44.81 to 44.90	2.27	2.53
51.91 to 51.98	2.22	2.52
102.69 to 102.75	1.99	2.38
105.37 to 105.46	1.65	2.38
106.31 to 106.41	1.40	2.38
106.65 to 106.71	1.61	2.46
107.29 to 107.38	1.23	2.36
108.36 to 108.45	1.38	2.42
108.81 to 108.87	2.10	2.50
109.48 to 109.54	2.06	2.52
110.40 to 110.46	1.42	2.48
110.86 to 110.95	1.18	2.52
111.65 to 111.74	1.28	2.42
112.04 to 112.14	1.15	2.50
113.32 to 113.39	1.10	2.49
114.00 to 114.09	.96	2.45
114.91 to 115.00	.92	2.51
115.79 to 115.88	1.37	2.47
116.49 to 116.59	.92	2.49
117.50 to 117.59	.91	2.48
118.84 to 118.90	1.11	2.44
119.60 to 119.69	1.32	2.48
120.73 to 120.82	1.04	2.37
121.37 to 121.46	1.59	2.39
125.21 to 125.27	2.31	2.33
125.79 to 125.85	2.10	2.58
126.77 to 126.86	2.02	2.57
127.10 to 127.16	2.08	2.59
127.92 to 127.99	2.08	2.68
129.02 to 129.11	2.12	2.57
130.00 to 130.06	2.05	2.53
130.82 to 130.91	1.95	2.49

Table 10.--*Summary of bulk-density and grain-density measurements of rotary cores in different lithologic units penetrated in test hole USW UZ-13, and degree of welding*

[--, no data]

Lithologic unit	Bulk density (grams per cubic centimeter)			Grain density (grams per cubic centimeter)			Degree of welding
	Range	Mean	Median	Range	Mean	Median	
Paintbrush Tuff							
Tiva Canyon	2.02 to 2.38	2.17	2.15	2.44 to 2.67	2.52	2.50	Densely welded
Member	1.23 to 1.99	1.58	1.61	2.36 to 2.46	2.39	2.38	Partially welded to nonwelded
Bedded tuff	1.10 to 2.10	1.46	1.40	2.42 to 2.52	2.48	2.50	Not applicable
Topopah	0.91 to 1.37	1.07	1.00	2.37 to 2.51	2.46	2.48	Not applicable
Spring	[1]1.59	--	--	[1]2.39	--	--	Moderately welded
Member	[1]2.31	--	--	[1]2.33	--	--	Densely welded
	1.95 to 2.12	2.06	2.08	2.49 to 2.60	2.56	2.57	Moderately welded

[1]One sample.

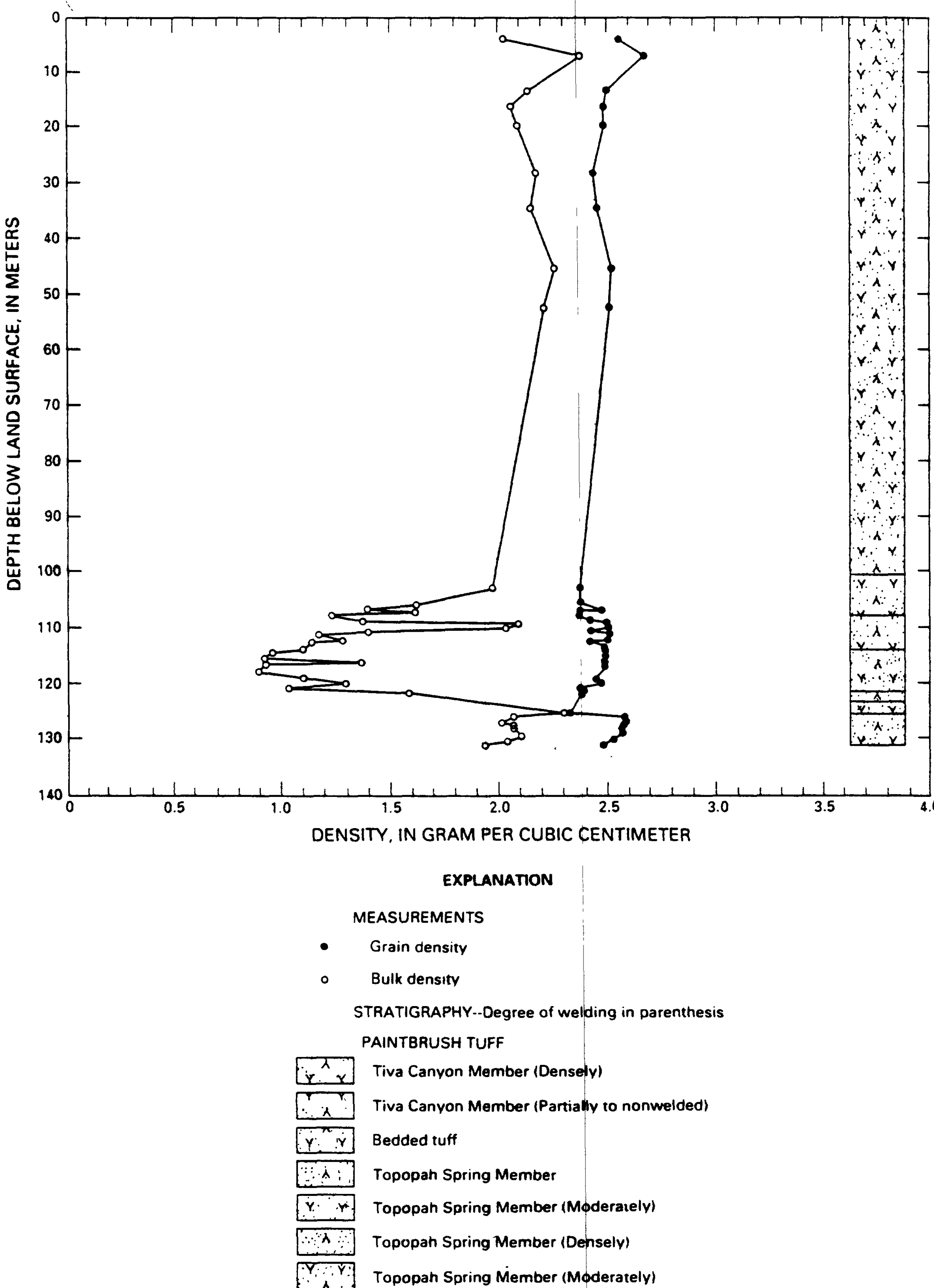

Figure 5.--Bulk-density and grain-density measurements, stratigraphy, and welding of rotary cores from test hole USW UZ-13.

The grain density generally was uniform throughout the various lithologic units, but it was slightly larger for ash-fall tuffs from the Topopah Spring Member and for bedded and ash-fall tuffs from the bedded tuff than for welded ash-flow tuffs from the Tiva Canyon and Topopah Springs Members. The mean and median values of grain-density measurements were almost identical for rotary cores from the Tiva Canyon and Topopah Spring Members and from the bedded tuff (table 10).

SUMMARY

Test hole USW UZ-13 was drilled and rotary cored to a total depth of 130.91 m. The drilling was done using air as a drilling fluid to minimize disturbance to the water content of coarse drill-bit cuttings, rotary cores and borehole wall rock. The unsaturated-zone rock consisted of densely welded and partially welded to nonwelded ash-flow tuffs; bedded ash-fall, bedded reworked, and ash-fall tuffs; slightly to moderately indurated ash-fall tuff; and moderately and densely welded ash-flow tuffs. Bedded and ash-fall tuffs and nonwelded ash-flow tuffs were rotary cored continuously, and moderately and densely welded ash-flow tuffs were rotary cored at selected intervals.

Gravimetric water content and water potential for volcanic tuffs probably are directly related to the degree of welding. The values of gravimetric water content of rotary cores were largest for bedded and reworked tuffs, ash-fall tuffs, and partially welded to nonwelded ash-flow tuffs and were smallest for densely welded ash-flow tuffs. The values of water potential of rotary cores were more negative for densely welded ash-flow tuffs and were less negative for bedded and ash-fall tuffs and partially welded to nonwelded ash-flow tuffs.

The gravimetric water-content and water-potential data indicate that some drying of the coarse drill-bit cuttings did occur during transfer from drill bit to separator. Gravimetric water content generally was larger for rotary cores than for coarse drill-bit cuttings from the same approximate depths. Water potential generally was less negative values (more water content) for rotary cores than for coarse drill-bit cuttings from the same approximate depths.

Physical properties of volcanic tuffs were directly related to the degree of welding. Bulk density of rotary cores was largest for densely welded ash-flow tuffs and was smallest for bedded and ash-fall tuffs and partially welded to nonwelded ash-flow tuffs. Grain density of rotary cores generally was nearly uniform throughout the different lithologic units but was slightly larger for bedded and ash-fall tuffs than for welded ash-flow tuffs.

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