Received by OSTI
APR 0 7 1986

CONF-8511172--4

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CONF-8511172--4

VACUUM DRILLING OF UNSATURATED TUFFS AT A POTENTIAL RADIOACTIVE-WASTE REPOSITORY, YUCCA MOUNTAIN, NEVADA

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Abstract

A vacuum reverse-air circulation drilling method was used to drill two 17½-inch (44.5-centimeter) diameter test holes to depths of 1,269 feet (387 meters) and 1,887 feet (575 meters) at Yucca Mountain near the Nevada Test Site. The site is being considered by the U.S. Department of Energy for construction of a high-level radioactive-waste repository. One of these two test holes (USW UZ-1) has been equipped with instrumentation to obtain a long-term record of pressure and moisture potential data; the other test hole (USW UZ-6) will be similarly instrumented in the near future. These investigations are being conducted as part of the Nevada Nuclear Waste Storage Investigations Project of the U.S. Department of Energy.

The test holes were drilled using a 5½-inch (14-centimeter) by 8 5/8-inch (22-centimeter) dual-string reverse-vacuum assembly. A vacuum, induced at the land surface, removed the drill cuttings through the inner string. Compressed air was injected into the dual-string annulus to cool the bit and to keep the bit and inner string clean. A tracer gas, sulfur hexafluoride (SF_6), was added to the compressed air for a later determination of atmospheric contamination that might have occurred during the drilling. After reaching the surface, the drill cuttings were routed to a dry separator for sample collection. Then return air and dust from the cuttings were routed to a wet separator where the dust was removed by a water spray, and the remaining air was exhausted through the vacuum unit (blower) to the atmosphere.

Advantages of using vacuum reverse-air circulation for drilling are: (1) Capability of obtaining continuous uncontaminated and representative rock samples, thus permitting a moisture profile to be made of the unsaturated volcanic rocks drilled, and (2) positive

identification of any perched-water zones. Disadvantages of using this drilling method are: (1) Need for more equipment and a larger drill site than for other drilling methods, (2) vacuuming action creates unstable hole conditions and causes frequent caving, and (3) methods need to be developed to obtain satisfactory cores.

Introduction

Vacuum drilling, or more specifically, vacuum reverse-air circulation, was first used in 1967 at the Nevada Test Site to drill an emplacement hole for underground nuclear testing. Since then, 10 emplacement holes and 2 test holes have been drilled using this method. Two years ago, the U.S. Geological Survey started using vacuum drilling in their hydrologic studies of unsaturated tuff at Yucca Mountain near the Nevada Test Site, one of the potential sites being considered as a repository for storage of high-level radioactive wastes. This investigation is part of the Nevada Nuclear Waste Storage Investigations (NNWSI) Project and is conducted in cooperation with the U.S. Department of Energy, Nevada Operations Office, under Interagency Agreement DE-AI08-78ET44802.

The primary objectives in drilling these large diameter test holes were to: (1) Obtain a vertical moisture-content profile of the rocks drilled, (2) check for the presence of perched-water zones, and (3) emplace hydrologic instruments at selected depths so that a long-term record of pressure and moisture-potential data could be collected. The unsaturated section in the Yucca Mountain area consists of nonwelded to densely welded tuff ranging in thickness from 1,500 to 2,500 feet (460 to 760 meters). The two test holes drilled in these unsaturated rocks are the major topic of this paper; location of these test holes is shown in Figure 1.

This unique method of drilling unsaturated rocks permits the detection of perched water or moist zones as soon as they are penetrated and prevents contamination of the unsaturated rocks with drilling liquids. In waste storage, knowledge of the chemistry of native pore water is important in designing canisters to contain radioactive wastes for long periods. Another essential reason for collecting hydrologic data from boreholes drilled in unsaturated rocks is determining whether in situ borehole conditions still exist after completion of a test hole. One way of doing this is to determine the presence or absence of atmospheric gas in the rocks adjacent to the borehole. Any atmospheric gas induced during the drilling process can later be detected if a tracer gas, such as sulfur hexafluoride (SF_6), is injected into the borehole during drilling. In order to obtain an accurate age determination of water from rocks, it is essential that they not be contaminated by present-day atmospheric gases such as carbon dioxide. Prior to instrumenting, the air in the test hole is vacuumed until all the tracer gas has been removed, assuring that only in situ gases are filling the rock pores.

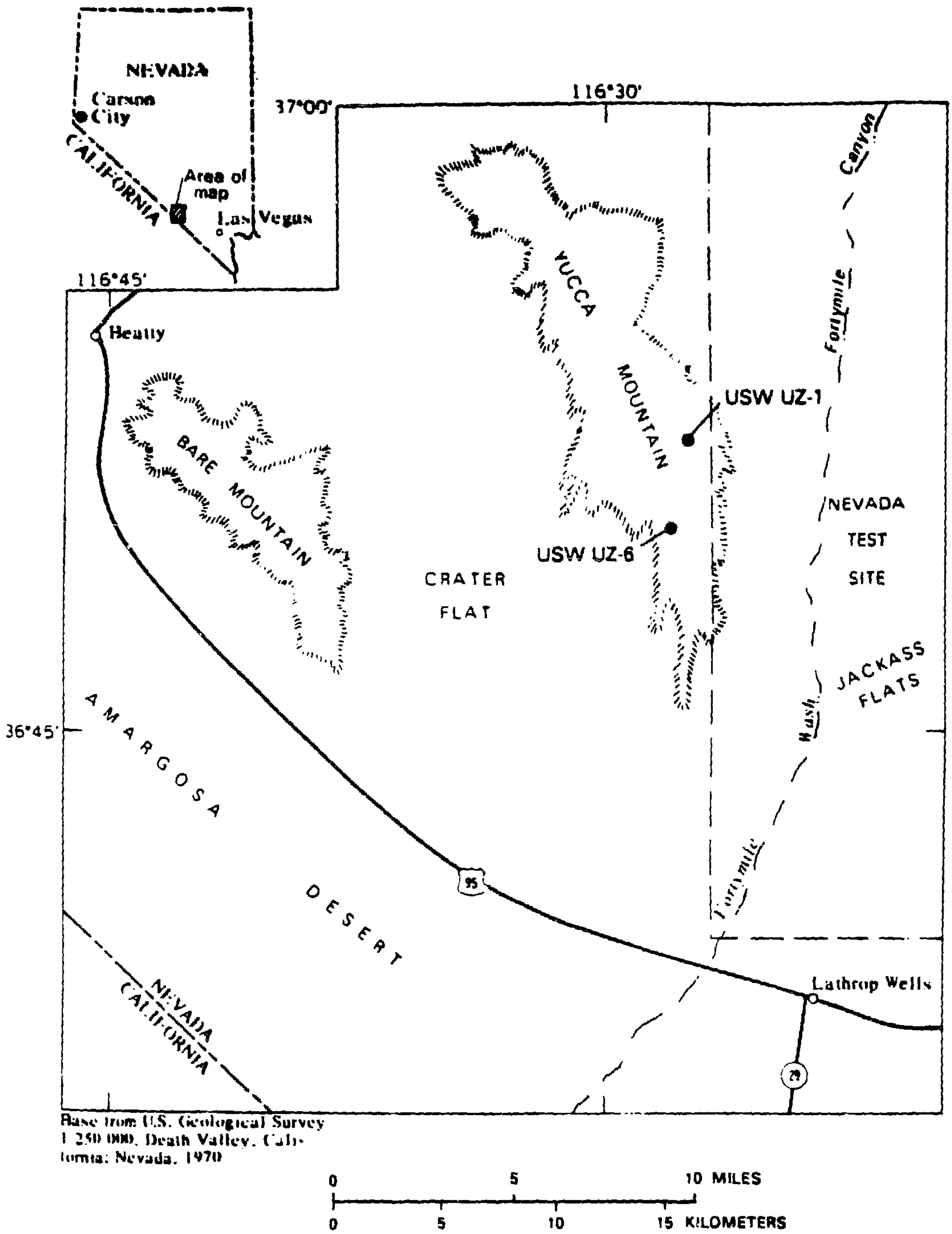

Figure 1. Location of test holes USW UZ-1 and USW UZ-6.

Drilling Procedures

The two test holes completed at Yucca Mountain for hydrologic studies of unsaturated tuff were drilled using a dual-string pipe with a 17½-inch (44.5-centimeter) modified rock bit. The inner string was 5½ inches (14 centimeters), and the outer string was 8 5/8 inches (22 centimeters) in diameter. A vacuum unit or blower located on the land surface created a suction in the inner string of the drill pipe that moved the drill cuttings from the bottom of the drill hole to the surface. From the inner string, the drill cuttings were routed via the kelly hose to a dry separator for sample collection. The dry separator contains two chambers that could be separated by a hydraulic slide gate, which prevents vacuum loss in the system. Drilling and sample collection can then be done simultaneously. When closed, the slide gate allows drill cuttings to accumulate in the upper compartment of the dry separator while drill cuttings are being collected from the lower compartment of the dry separator. A schematic diagram showing the arrangement of the separators and vacuum unit is given in Figure 2. After collecting samples for lithologic and hydrologic analysis, the remaining drill cuttings were vibrated out of the lower chamber of the dry separator and removed from this collecting point by a conveyor belt.

The dust particles that did not settle out in the dry separator were vacuumed to a wet separator where the dust was removed by a water spray, and the remaining clean vacuumed air was exhausted to the atmosphere through the vacuum unit and exhaust muffler. The water spray removed almost all the dust before it passed through the vacuum unit and exhaust muffler to the atmosphere.

One of the major advantages of using this method in drilling unsaturated rocks is that moist zones can be determined immediately from the returned drill cuttings during drilling. Another advantage of using vacuum drilling is that it requires no drilling liquids, so the natural state of rock liquids is minimally disturbed. In addition, natural hydrologic properties of the rock are not altered significantly by invasion of drilling liquids and can be determined more accurately in the laboratory.

Vacuum drilling has proven to be effective when used with 13 3/8-inch (34-centimeter) diameter drill pipe for drilling boreholes varying in diameter from 17½ to 104 inches (44.5 to 366 centimeters). Coring was attempted in the first test hole (USW UZ-1) but was unsuccessful because of the use of an inappropriate coring bit. In addition, the cores were heated to a high temperature by the dry coring; therefore, the moisture contents determined by laboratory analysis were considered erroneous. One problem in vacuum drilling is the slower drilling rate when rock moisture is greater than 5 percent by weight. In moist zones, plugging of the drill bit and encrustation of the inner string and kelly hose with a mud cake eventually restricts the flow of drill cuttings to the surface. When plugging occurs, drilling needs to stop or the drill bit will be buried in drill cuttings, and eventually it will become stuck. Drilling can be resumed only after the bit, inner string, and kelly hose are cleaned and dried by blowing dry compressed air through them.

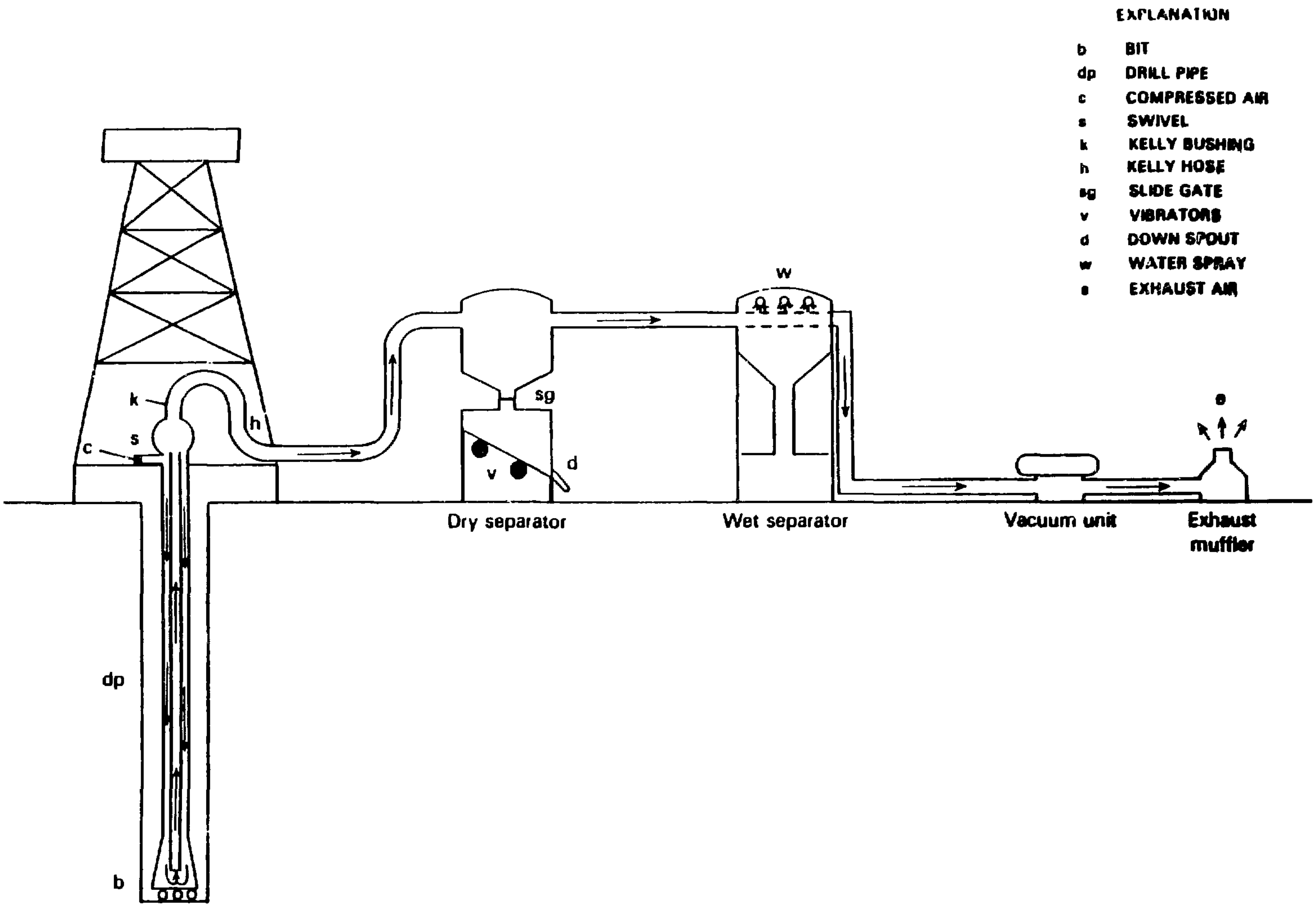

Figure 2. Schematic diagram of separators, vacuum unit, and exhaust muffler.

One solution to the plugging problem can be made if maintaining drilling rate is more important than collecting representative moisture samples. In this case, a measured quantity, less than 2 gallons (7.6 liters) per minute, of clean water can be injected through the outer string of drill pipe while drilling. A tracer of known concentration, such as lithium bromide or lithium chloride, when added to this drilling water will help determine approximately how much formation water has been encountered by periodically checking the concentration of this drilling water as it returns from the borehole. However, by using even this small quantity of drilling water, the ability to detect moist and perched-water zones will be limited. Two critical factors when adding water while drilling are: (1) Water needs to be shut off when drilling is not actually being done, and (2) quantity of water being added needs to be decreased when rock is very hard and the penetration rate is slow. If a head of water occurs above the drill bit, the bit will become submerged, and drill cuttings cannot be removed from the borehole by the vacuum. When this occurs, water in the borehole needs to be pumped out before drilling can be resumed.

Drilling of Test Hole USW UZ-1

The first large diameter test hole using vacuum drilling to collect hydrologic data from the unsaturated zone in the Yucca Mountain area was USW UZ-1. This test hole was drilled to a total depth of 1,269 feet (387 meters). Drilling was discontinued at this depth, because a large volume of water was encountered, and the water level could not be lowered significantly. Thus, the entire unsaturated section, which is about 1,540 feet (470 meters) thick at this location, was not penetrated. There are two possible explanations for the presence of this water:

1. All of this water may be contamination from a geologic test hole (USW G-1) located 1,000 feet (305 meters) to the southeast of test hole USW UZ-1. Approximately 2,300,000 gallons (8,700,000 liters) of polymer drilling fluid were lost in the drilling and coring of USW G-1. A chemical analysis of the water from USW UZ-1 indicated that the polymer was identical to that found in USW G-1. A major fracture zone probably exists between these two test holes that may have provided hydrologic connection between the two holes;

2. A naturally occurring perched-water zone also may have been encountered at this depth; this zone definitely is contaminated with drilling polymer that was used to drill USW G-1.

With the possible exception of perched water in the bottom of this test hole, no perched-water zones were encountered in the upper part. A profile of the geologic units penetrated and the moisture content (by weight) of these rocks are shown in Figure 3. The moisture-content profile of this test hole ranged from 1 to 22 percent by weight. The first 58 feet (17.7 meters) of this hole was drilled in the alluvium using 1,208 gallons (4,573 liters) of water tagged with a lithium bromide tracer, added at the rate of 1.5 to 2 gallons (5.7 to 7.6 liters)

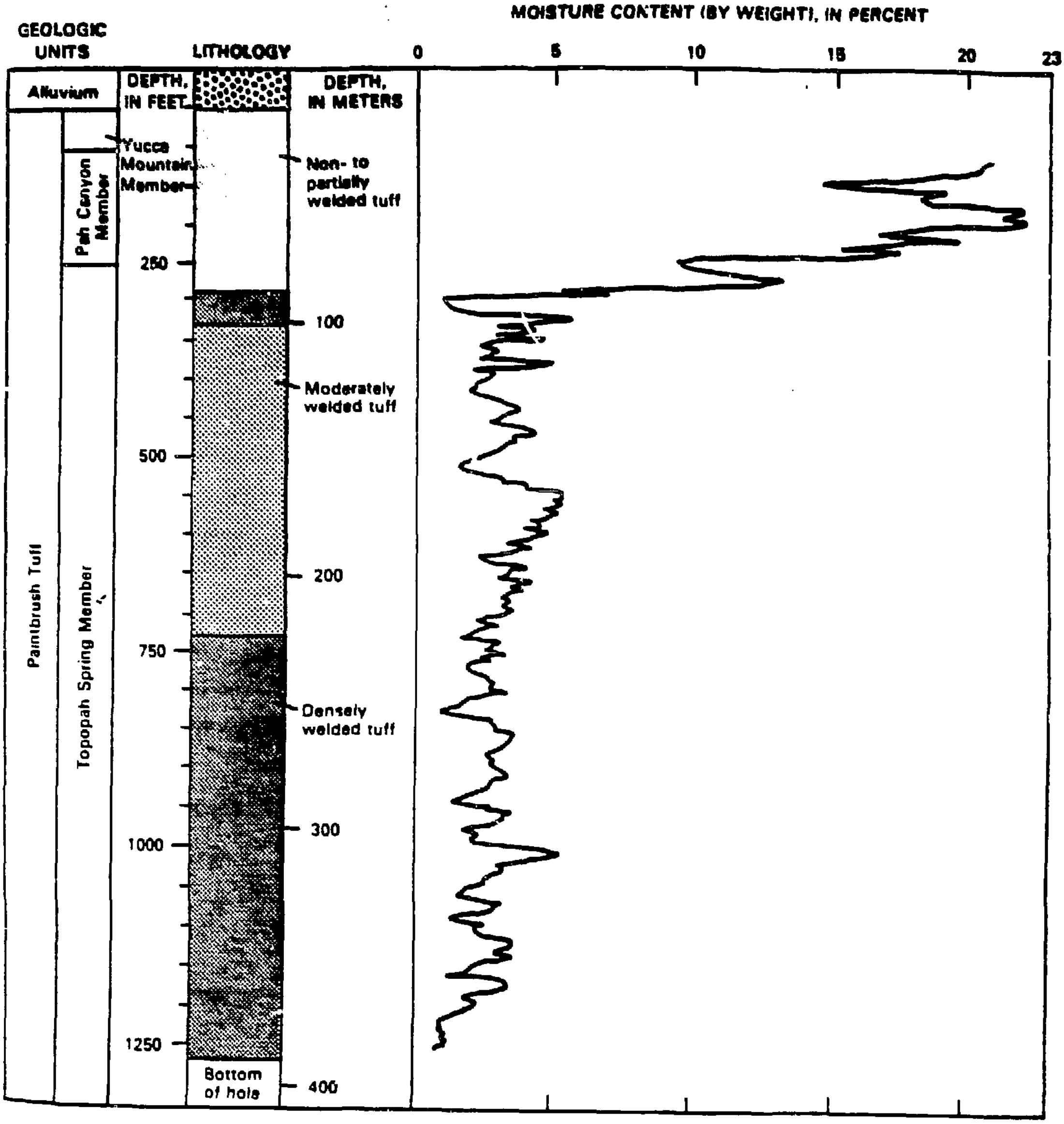

Figure 3. Geologic units, lithology, and moisture content of rocks penetrated in test hole USW UZ-1.

per minute. The addition of water was discontinued below this depth, because a balance could not be maintained between rate of penetration and minimum quantity of water needed to cool the bit. Four hundred gallons (1,514 liters) of water were pumped out of the hole by a diaphragm pump that was lowered downhole; thus, 808 gallons (3,059 liters) of water were left in the borehole. Drill-cutting and instrumentation data indicate that this drilling water probably did not seep below 250 feet (76 meters). Drill cuttings from selected depths were submitted to the laboratory for lithium leaching. Laboratory results indicate that the lithium concentration was 13 micrograms per gram to a depth of 101 feet (31 meters) but showed a background level of lithium less than 10 micrograms per gram below 250 feet (76 meters). Hydrologic-instrumentation data obtained after drilling USW UZ-1 show a relatively low matric potential below a depth of 83 feet (25.3 meters) (Montazer et al. 1985, this proceedings). Below this depth, the rock-moisture content is considered to be representative of rocks underlying a wash that probably receives periodic recharge from surface-water runoff and flooding. This test hole has been instrumented with pressure transducers, psychrometers, and heat-dissipation probes so that a long-term record of atmospheric-pressure and moisture-potential changes can be monitored for selected depths (Montazer et al. 1985, this proceedings; Thamir and McBride, 1985, this proceedings).

Drilling of Test Hole USW UZ-6

The second test hole for collecting hydrologic data from the unsaturated zone was drilled without any drilling water to a total depth of 1,887 feet (575 meters); it will be instrumented next year with pressure transducers, psychrometers, and heat-dissipation probes. The initial plan was to drill through the entire unsaturated section, which is about 2,550 feet (777 meters) thick at this location. However, drilling was stopped because of an overrun of drilling time caused by numerous hole cavings and excessive breakage of the drill-pipe inner string. Continual caving occurred to a depth of 1,000 feet (305 meters) because of the numerous fractures in the densely welded tuffs in the lower part of the Tiva Canyon Member and in the upper one-half of the Topopah Spring Member of the Miocene Paintbrush Tuff. In the drilling of USW UZ-6, the deepest unsaturated-zone test hole, no free water was encountered; however, the kelly hose became plugged and required cleaning several times while drilling through a 60-foot (18-meter) moist, nonwelded to partially welded tuffaceous zone at the geologic contact between the Tiva Canyon Member and the Topopah Spring Member of the Miocene Paintbrush Tuff. Laboratory analysis indicated that this zone had a moisture content ranging from 5 to 18 percent by weight. Similar drilling problems occurred near the bottom of this test hole from 1,400 feet (427 meters) to total depth in nonwelded to partially welded tuff of the tuffaceous beds of Calico Hills and the Prow Pass Member of the Crater Flat Tuff, both of Miocene age. The moisture content in these discontinuous zones generally was less than 5 percent by weight. The geologic units penetrated and the moisture content of these rocks are shown in Figure 4.

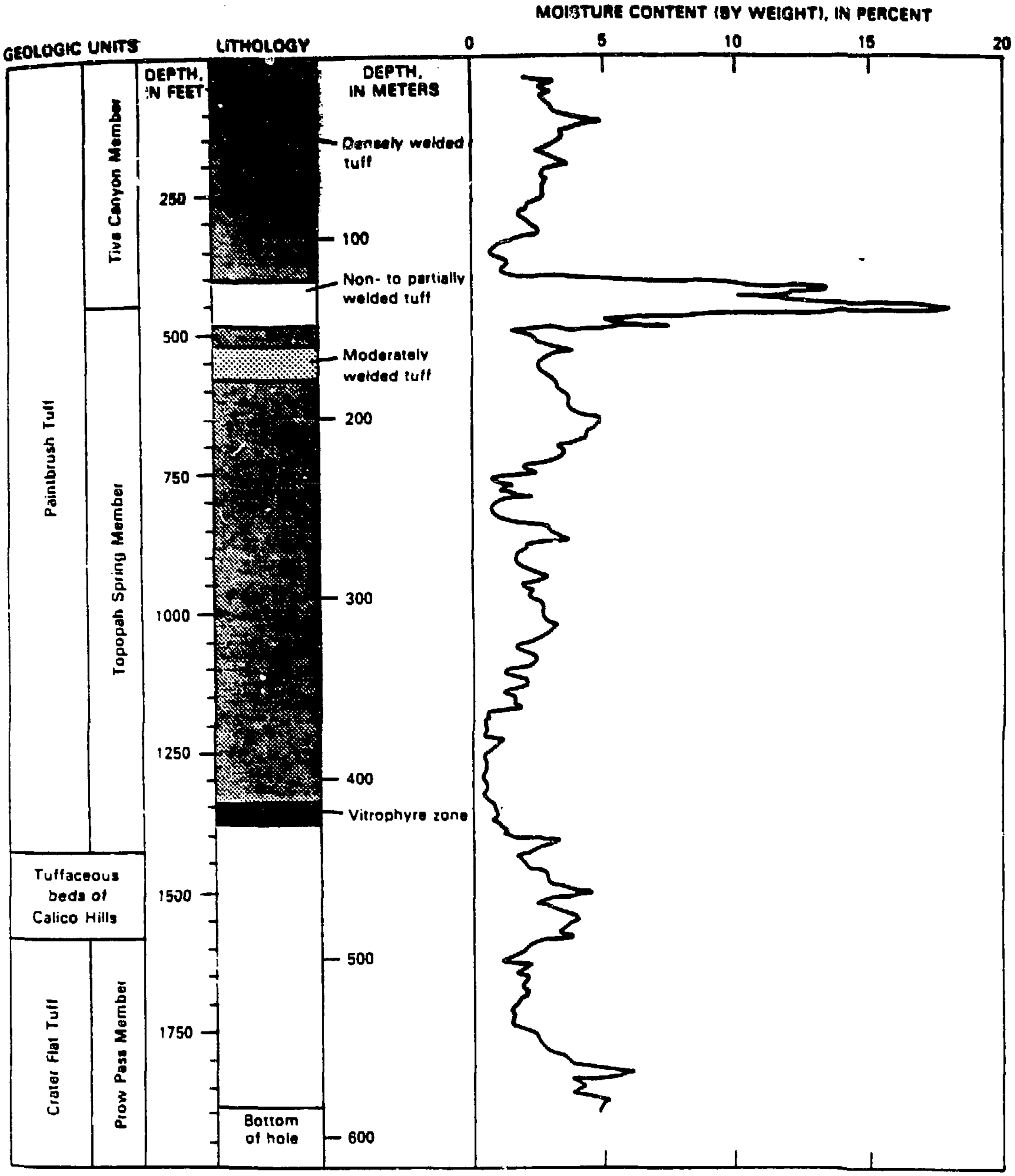

Figure 4. Geologic units, lithology, and moisture content of rocks penetrated in test hole USW UZ-6.

Conclusions

The reverse-vacuum drilling method is well suited for collecting hydrologic data from unsaturated rocks because it permits the drilling of rocks without appreciably changing their moisture content; the rock pores are not contaminated with any drilling fluids, and laboratory determinations of moisture content and hydrologic properties can be more accurately determined. In addition, this drilling method permits the immediate detection of moist or perched-water zones.

Major disadvantages of using the vacuum-reverse-air drilling method are that it requires more equipment and space than conventional rotary-drilling rigs. Drilling problems, such as caving of the borehole also are quite common because no liquids are in the borehole to exert hydrostatic pressure on the walls of the hole, and the vacuuming action creates an inward suction of loose rocks. Extensively fractured zones create the largest drilling problems, and considerable time is required to remove caved material from the borehole.

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Biographical Sketch

Merrick Whitfield received his bachelor of science degree in geology from Baylor University in 1959 and his master of science degree in geology from Louisiana Tech University in 1962. He was employed for 2 years by the Virginia Geological Survey prior to being employed by the U.S. Geological Survey. He spent his first 12 years as a Survey hydrologist in Louisiana working on regional aquifer studies related to the availability and quality of water from aquifers of Quaternary and Tertiary age and to the occurrence of saltwater zones associated with oil-well disposal pits. In 1978, he transferred to Denver where he has been working as a hydrologist involved in determining the potential of bedded salt in Utah and Colorado and tuff in Nevada for the storage of radioactive wastes. His address is: U.S. Geological Survey, Box 25046, MS 416, Denver Federal Center, Denver, CO 80225.