

Drilling, Logging, and Testing Information from Borehole UE-25 UZ#16, Yucca Mountain, Nevada

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CONVERSION FACTORS, VERTICAL DATUM, AND COORDINATES

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
inch	25.40	millimeter (mm)
gallon, U.S., (gal)	3.785	liter (L)
mile (mi)	1.609	kilometer (km)
pound mass (lbm)	0.4536	kilogram (kg)
pound mass per foot (lbm/gal)	1.488	kilogram per meter (kg/m)
pound mass per gallon (lbm/gal)	0.1198	kilogram per liter (kg/L)
pound force per square inch (psi)	6.895	kilopascal (kPa)

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.

Coordinates: Northing and easting coordinates used in this report are based on the North American Datum 1927, Nevada State Plane Central Zone Coordinate System.

Depths: Depths are referenced to ground level after the drilling pad was constructed.

Drilling, Logging, and Testing Information from Borehole UE–25 UZ#16, Yucca Mountain, Nevada

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ABSTRACT

Borehole UE–25 UZ#16 is the first of two boreholes that may be used to determine the subsurface structure at Yucca Mountain by using vertical seismic profiling. This report contains information collected while this borehole was being drilled, logged, and tested from May 27, 1992, to April 22, 1994. It does not contain the vertical seismic profiling data. This report is intended to be used as: (1) a reference for drilling similar boreholes in the same area, (2) a data source on this borehole, and (3) a reference for other information that is available from this borehole. The reference information includes drilling chronology, equipment, parameters, coring methods, penetration rates, completion information, drilling problems, and corrective actions. The data sources include lithology, fracture logs, a list of available borehole logs, and depths at which water was recorded. Other information is listed in an appendix that includes studies done after April 22, 1994.

INTRODUCTION

Borehole UE–25 UZ#16, hereinafter referred to as UZ#16, is the first of two boreholes that may be used for vertical seismic profiling (VSP) to support site characterization of the unsaturated zone (UZ) at Yucca Mountain in southern Nevada (fig. 1). Vertical seismic profiling measurements will be made after a string of geophones is cemented into the borehole.

Borehole Location

The location for this borehole was selected on the basis of the following:

(1) Initially, an approximate location was determined where key structural features may be mapped using VSP. The key features were the Ghost Dance fault and the imbricate fault structure (Scott and Bonk, 1984). Both features are along the eastern flank of Yucca Mountain.

(2) A two-dimensional computer and physical model simulation (Cunningham, 1988) was conducted to determine the approximate location. The simulations were made on an east-west cross section of Yucca Mountain that went through borehole USW UZ–6. The coordinates of UZ–6 are lat 36°50'14"N., long 116°28'03"W., which is located on the crest of Yucca Mountain. Surface-to-borehole seismic ray path propagations were simulated to determine a borehole location that would maximize the chance of delineating and imaging the key structural features. The model components used in the ray path simulation were constructed from information contained in the preliminary geologic report of Yucca Mountain by Scott and Bonk (1984).

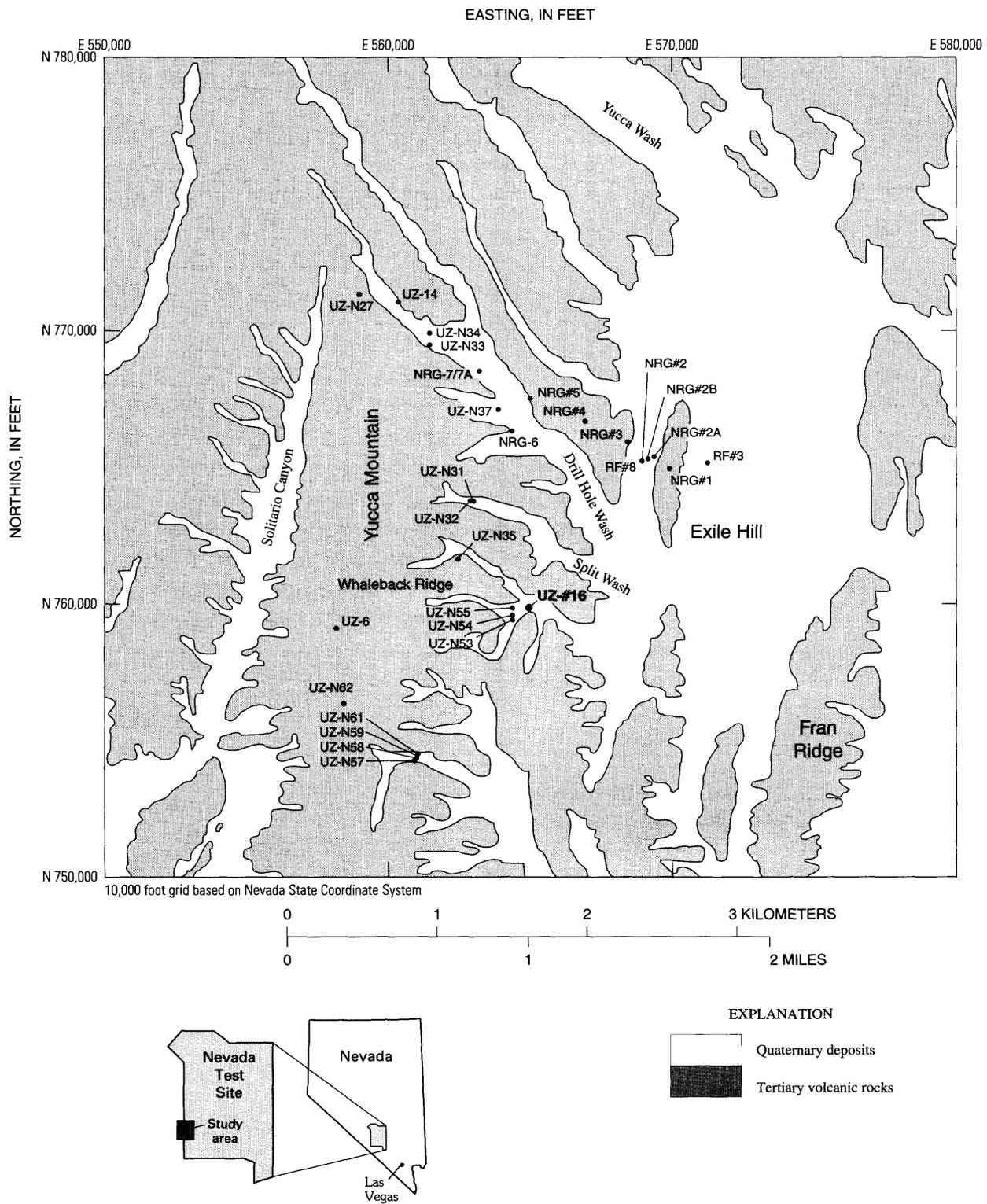


Figure 1. Location of borehole UE-25 UZ#16 in Nevada. Yucca Mountain and other boreholes are also shown for reference.

2 Drilling, Logging, and Testing Information from Borehole UE-25 UZ#16, Yucca Mountain, Nevada

(3) Finally, the borehole was located at the intersection of two drainages along the western margin of the imbricate fault structure of Scott and Bonk (1984) (fig. 1). The location was chosen to have favorable terrain for transportation and to minimize the cost for constructing the drilling pad.

Detailed specifications of the borehole location are as follows:

Borehole Name:	UE-25 UZ#16
County and State:	Nye County, Nevada
Northing:	760,535.17 ft
Easting:	564,857.52 ft
Latitude:	36°50'21.44" N
Longitude:	116°26'42.09" W
Elevation at Drilling Pad:	4,000.64 ft

Purpose and Scope

This report is intended to be used as: (a) a reference for drilling similar boreholes in the same area; (b) a data source for possible future studies on this borehole; and (c) a reference for information that is available from this borehole. It contains information collected while borehole UZ#16 was drilled, logged, and tested (March 27, 1992, to April 22, 1994).

Two sets of data were to be collected from this borehole: (1) pre-placement, and (2) post-placement of geophones. Data collected prior to placing the geophones were (a) lithology and fault locations (from the cores, cuttings, and fracture logs); (b) fracture locations (from the cores); (c) hydrochemical characteristics of the ground water (from cores, down-hole water samples, and geochemical logs); (d) geophysical data (from borehole logs); (e) depths of ground-water occurrences (from cores and down-hole water level measurements); (f) hydrologic properties of the matrix (from core measurements); and (g) air-permeability measurements (from down-hole measurements). All the above-mentioned data sets except the last two will be discussed and/or referenced in this report. Data that were collected after placing the geophones are (a) vertical seismic profile (from geophones); (b) fluctuations in the level of ground water (from down-hole measurements through a central tubing); and (c) hydrochemical characteristics of the ground water (from down-hole water samples). None of the data sets collected after placing the geophones will be discussed in this report.

Information in this report is organized as follows: (a) a description of the drilling, logging, and testing operations which includes chronology, equipment, drilling parameters, coring methods, penetration and recovery rates, borehole completion information, and drilling problems and corrective actions; (b) a list of data available from this borehole which includes lithology, fracture logs, borehole logs, and water occurrences; and (c) a list of other information sources that are available from this borehole is presented in appendix.

QUALITY-ASSURANCE INFORMATION AND DATA RECORDS

Work on this borehole was conducted under a documented quality-assurance program and was approved by the U.S. Department of Energy (DOE) on January 29, 1991. The sources of data used in this report are reported in appendix 1 with the appropriate data tracking numbers.

DRILLING

Initial Plan and Changes

The initial plan was to continuously dry-core this borehole with a 4.38-inch OD, 2.4-inch ID coring bit. After every four core runs, the borehole was to be reamed with a 12.25-inch OD, 4.5-inch ID open-center reaming bit. The targeted depth was 1,663 ft (or 40 ft below the water table, whichever was greater). A 16-inch OD surface casing for wall support was planned at a depth of approximately 5 ft below the alluvium/colluvium tuff contact. The rest of the borehole was to be left open. The borehole was to be drilled dry to preserve in place geochemical and physical conditions.

Two main events took place during the drilling operation: (1) change of drilling equipment and method to prevent excessive borehole deviation; and (2) encounter of ground water close to the bottom of the borehole.

Chronology and Equipment

Drilling chronology and borehole information were as follows:

Spud Date:	May 27, 1992
Completion Date:	March 11, 1993
Elevation at Drilling Pad:	4,000.64 ft
Total Measured Depth:	1,686.16 ft
Potentiometric Surface Level:	1,605 ft
Number of Shifts to Complete Borehole:	191 shifts (8-hr shifts; one shift a day)
Average Penetration Rate:	8.3 ft/shift

The whole borehole was continuously cored with some exceptions that will be discussed in the section "Core Specifications and Recoveries." The true vertical depth is about 1 ft less than the measured depth due to borehole deviation. The estimated penetration rate before drilling started was 10 ft/shift. Drilling was not terminated until it was certain the saturated zone was penetrated, as originally desired. The final depth was 81 ft below the potentiometric surface level. Two years after the borehole was completed, the depth of the bottom was measured at 1,625 ft, which was caused by caving (see section on "Stability of Borehole" for more details).

Drilling equipment and parameters were as follows:

Drilling Rig:	Lang, model LM-300 Load Capacity (at the hook): 300,000 lbs Height with mast erect: 84 ft
Drilling Pipe:	Dual-wall, 9 5/8-inch OD, 6-inch ID, 60 lbs/ft for the outer pipe
Drilling Collar:	Not used; the drilling pipes were used as collars
Circular Velocity of Drilling String:	Not recorded
Weight on Bit:	Not recorded
Drilling Fluid:	Air (filtered and tagged with sulphur hexafluoride)
Circulation Method:	Reverse circulation (see fig. 2)
Injection Rate of Drilling Fluid:	1. Coring: 300 to 900 standard cubic feet per minute (SCFM) 2. Reaming: 600 to 1,500 SCFM
Suction Rate of Drilling Fluid:	1. Coring: 800 to 1,200 SCFM 2. Reaming: 1,000 to 1,500 SCFM

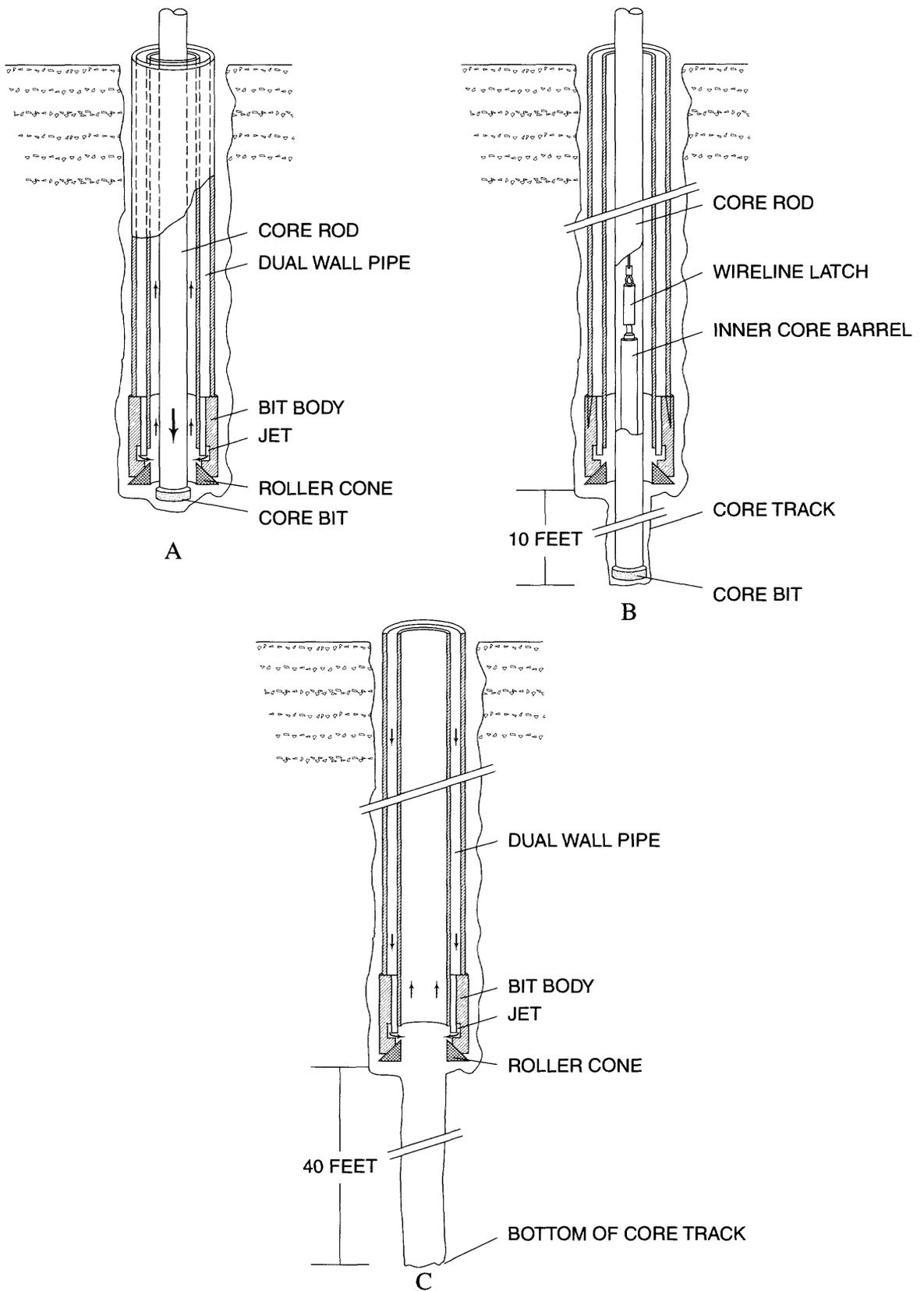


Figure 2. The dual-wall drilling and coring system used to drill borehole UE-25 UZ#16. (a) coring; (b) core retrieval; (c) reaming.

Coring Bit:	1. Surface to 30.30 ft: drive sampler made by Acker to sample the upper part of the alluvium; OD= 3.5 inches; ID= 3.25 inches. 2. 30.30 to 1,686.16 ft: coring bits (made by Christensen and Longyear), OD= 4.380 inches; ID= 2.4 inches.
Coring Rod:	8.8 lb/ft; OD= 3.7 inches; ID= 3.1 inches.
Coring Barrel:	Made by Christensen and Longyear; OD= 3.7 inches; ID= 3.1 inches; liner ID= 2.4 inches.
Reaming Bit:	1. Surface to 53.04 ft: OD= 22 inches. 2. 53.04 to 759.11 ft: open-center bit; OD= 12.25 inches; ID= 4.5 inches. 3. 759.11 to 919.08 ft: alternated between no. 2 above and a tri-cone bit with OD= 12.25 inches. 4. 919.08 to 1,658.91 ft: open-center bit with 3 cones facing in and 3 cones facing out; OD= 12.25 inches; ID= 4.5 inches.
Solids-Removal System:	One cyclone followed by one dust filtration system

Air was used as a drilling fluid; it was tagged with sulphur hexafluoride (SF₆) at 0.75 to 2.5 parts per million by volume (ppm) which was used as a tracer to detect the extent of formation contamination with the drilling fluids. Before entering the drill pipe, the air was passed through a coalescing filter unit to eliminate oil vapors from it. The flowing air pressure at the surface was between 80 and 120 psi with a 2-inch orifice in-line. The circulation method is called "reverse" because the drilling fluid was circulated down through the annulus and exhausted through the central pipe which is opposite to that used in conventional drilling methods. This circulation method was chosen to minimize formation contamination (see section on "Contamination of Formation with Drilling Fluid" for more details). The drilling fluid (air) was not circulated back in the hole; it was exhausted to the atmosphere. Fresh air was always used for injection (see section on "Emission of Dust" for further details). No water or water mist was added to the injected air. The solids-removal system was used for dust control to meet environmental regulations at the drilling site. The cyclone in the solids-removal system also was used to collect sample cuttings.

Core Specifications and Recovery

Cores were obtained from this borehole as follows:

Number of Cores:	1. Surface to 30.30 ft: 18 cores 2. 30.30 to 1,686.16 ft: 314 cores
Size:	1. Surface to 30.30 ft: 3.25 inches in diameter 2. 30.30 to 1,686.16 ft: 2.4 inches in diameter
Orientation:	Not oriented
Advancement per Core Run:	Average = 5.08 ft; minimum = 0.23 ft; maximum = 11.34 ft
Length of Recovered Core:	Average = 4.37 ft; minimum = 0.00 ft; maximum = 10.40 ft
Core Distribution:	1. UZ hydrochemistry study (see appendix 2) 2. Matrix hydrologic properties testing (see appendix 2) 3. The remainder of the core is stored at Sample Management Facility (SMF)
Permanent Storage Place:	SMF
Storage Method:	Labeled and boxed; heavily broken sections were saved in plastic tubes; the rest was kept unwrapped in boxes.

All cores were handled by personnel from the SMF. The whole borehole was cored except the interval from 1,199.58 to 1,201.26 ft (1.68 ft), which was drilled; however, not all the core was available since core recovery rate in some cases was less than 1.0, which is explained later in this section. The core saved at the SMF was used for fracture mapping (see section on "Fracture Logs" for more information). Ream cuttings also were

collected; some samples were used for determining the water age. The rest of the cuttings were stored at the SMF.

Core recovery was as follows:

Total cored length:	1,684.48 ft
Total length of recovered core:	1,451.66 ft
Overall Recovery Rate:	0.86 excluding the drive core between 0 to 30.30 ft (minimum = 0.000; maximum = 2.150)

Core recovery problems are discussed in the section on "Loss of Core." The frequency distribution of the recovery rates is shown in figure 3. Recovery rates over 1.0 were observed for the following reasons:

a. Length measurements of cores retrieved at the surface were not accurate because the cores usually were broken in several places along natural and drilling-induced fractures. For this reason, it was possible to measure core lengths slightly longer than the lengths of their corresponding cored intervals. Assuming core length expansion due to breakage does not exceed 0.05, of the 332 core runs, only 14 cores had recovery rates over 1.05;

b. Of the 14 cores with core recovery rates over 1.05, all except two followed cores with shortages equal to or greater than the extra length measured in the successive core; that is, the bottom parts of previous cores were retrieved by the cores that followed;

c. The core made in the depth interval from 62.88 to 65.89 ft (3.07 ft) on June 17, 1992, had a recovery rate of 2.15 (6.6 ft), or 3.53 ft extra core. This core was started after finishing a ream cycle. The core bit touched the bottom of the borehole at 58.39 ft because of fill material that fell to the bottom after the ream cycle was finished. Part of the recovered core was from the fill material, which caused an increase in the calculated recovery rate.

d. The core made in the depth interval 648.16 to 655.05 ft (6.89 ft) on August 26, 1992, had a recovery rate of 1.10 (7.6 ft), or 0.71 ft extra core. The preceding core was 0.4 ft short. Therefore, the extra length measured from this core was 0.71 - 0.4, or 0.31 ft, which is within the assumed measurement error of 0.05 of the cored length.

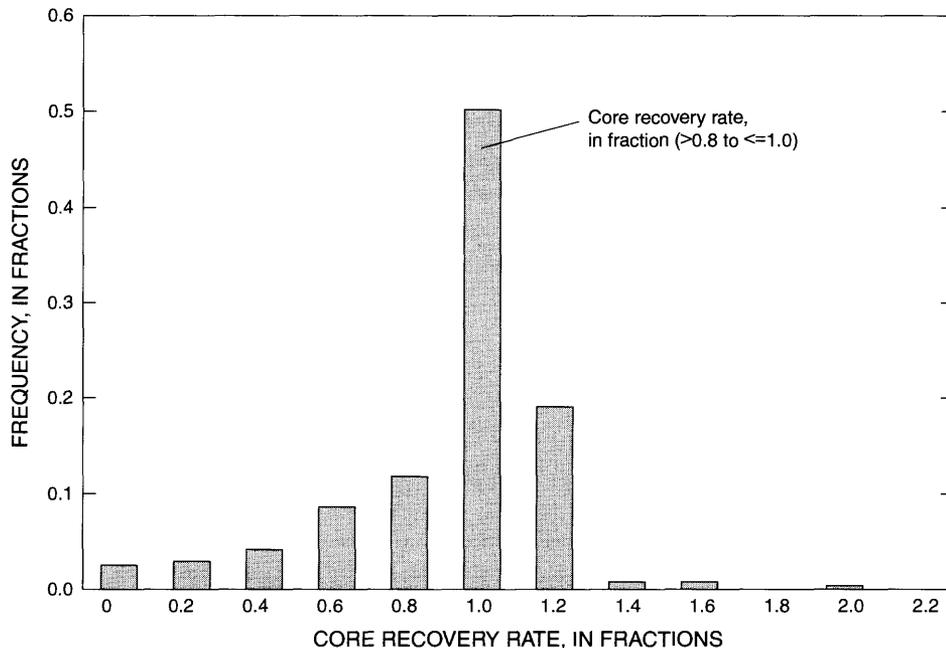


Figure 3. Frequency distribution of core recovery rate in borehole UE-25 UZ#16. Total cored length = 1,684.48 feet; Total length of recovered core = 1,451.66 feet; Mean recovery rate = 0.86.

Borehole Completion

Borehole UZ#16 was completed with a surface casing; the remainder of the borehole was left open. Surface casing and borehole diameter are as follows:

Surface casing: K-55, 75 lb/ft, OD= 16 inches from the surface to a depth of 52.25 ft, cemented with type II cement; wet density ranged from 15.6 to 15.7 lb/gal.

Borehole Diameter:

	Depth interval, in feet	Nominal diameter, ^a in inches
surface	53.04	22.00
49.49	53.04 ^b	14.75
53.04	1,658.91	12.25
1,658.91	1,686.16 ^c	4.38

^a Actual (finished) borehole diameter is discussed in section on "Caliper Logs".

^b This section was drilled in the cement at the bottom of the surface casing.

^c This section was not reamed because it was deeper than the level of the deepest planned VSP geophone.

After the final depth was reached, a weather-proof wellhead was installed. The wellhead was a metal pipe, 48 inches in diameter and 60 inches tall. A metal bottom also was installed and was welded to the surface casing. The top of the wellhead pipe protruded 12 inches above the ground level. The top of the wellhead pipe was equipped with a flange and a removable steel cover that was bolted to the flange. The section of the borehole below the surface casing was kept open in preparation for well logging, permeability measurements, and VSP instrumentation.

Drilling Problems and Corrective Actions

Contamination of Formation with Drilling Fluid

The objective of the drilling method used was to minimize physical and geochemical alterations to the surrounding rock. Conventional drilling techniques were not considered adequate because drilling fluids are applied at positive pressures along the whole length of the borehole. The dual-wall drilling pipe and reverse circulation technique used to drill UZ#16 minimized in-situ alteration of the properties.

1. Except for the bottom part, the dual-wall pipe restricted the drilling fluid (air) flow paths to the inner pipe and annulus of the dual-wall pipe. Only the bottom part was exposed to flowing drilling fluid.

2. With the reverse circulation method, the return flow rate was maintained above the injection flow rate. This combination was expected to have minimized the amount of drilling fluid that may have entered the formation.

3. Impurities, such as water and oil, were filtered out of the air prior to injection. No water or water mist was mixed with the injected air because dry air was adequate to clean the borehole. The air was tagged with a tracer to detect the contamination levels during pumping tests.

Emission of Dust

Because air was used as the drilling fluid, dust was produced at the surface. Environmental regulations at the drilling site dictated that the exhausted air be visibly free of dust particles. A two-stage dust separation system was successfully used.

1. The first stage consisted of one cyclone that collected the large pieces. It also separated the water when water was encountered at the bottom part of the borehole. This cyclone also was used to collect cutting samples when drilling was stopped.

2. The second stage consisted of a baghouse filter that collected most of the dust particles before the air was exhausted to the atmosphere by the vacuum pump.

Stability of Borehole

Borehole wall stability was a concern at UZ#16 for two reasons: (1) the borehole was dry-drilled; drilling mud was not present to support the borehole walls, and (2) the borehole was to be kept open for instrumentation (except the top 53 ft). While drilling, tight sections were redrilled. Below the depth of 919 ft, an open-center reaming bit with three cones facing in and three cones facing out was used. This bit design provided the ability to drill upward and free the drilling string in case the borehole caved in above the bit; this feature was not used because the borehole did not cave in above the bit.

This borehole was drilled to a depth of 1,686.16 ft. Nearly 2 years after its completion and prior to instrumenting the borehole, the bottom was tagged at 1,625 ft. This reduction in depth was caused by cave-in material filling the bottom of the borehole. The VSP instrumentation string was shifted upward to bypass the bottom section.

Loss of Core

The main cause for core loss was thought to be the slippage of naturally unconsolidated or fractured cores past the core catcher when the cores were retrieved. The core catcher was located at the bottom end of the core barrel. Other factors may have affected core loss, such as drilling parameters (weight-on-bit, rotating speed of bit, and bottom-hole cleaning efficiency); however, these parameters were not analyzed because the core recovery rate did not continuously decline; it kept fluctuating as shown in the "Summary of Drilling and Completion" at the end of this section. The overall recovery rate below the surface casing was about 0.86, which was sufficient to make lithologic, fracture, and other studies that required cores.

Deviation of Borehole

A plumb borehole is required to prevent the downhole instrument stations from coming into contact with the walls of the borehole. Excessive contact with the walls during installation may cause two problems:

- (1) A change in the orientation of the geophones as they are lowered into the borehole (the geophones are to be oriented at a particular directions during installation), and (2) Loss of effective coupling between the geophones and the wall rock if voids develop during grout emplacement. The preset limit on deviation was 3 degrees. Bottom-hole measurements were planned every 100 ft; this value was later increased after deviation stabilized.

Between the depths of 536 and 757 ft, the deviation increased from less than 1 degree to over 2 degrees. Although borehole deviation did not reach the preset limit, deviation control was started at the depth of 759 ft using the following measures:

1. Mast of rig was surveyed once each week to ensure it was plumb. When measurable movement stopped, mast surveying was terminated.

2. Bottom-hole reaming assembly was changed. Initially, the open-center reaming bit was replaced with a tri-cone bit attached to an adapter sub between the dual-wall pipe and the bit. This method allowed the cuttings to circulate across the formation face for about 30 inches (between the bit and the intake opening of the dual-wall pipe). Later, both types of bits (open-center and tri-cone) were interchanged until the depth of 919 ft was reached. After 919 ft, the tri-cone bit was used until total depth was reached.

3. Length of core runs was reduced to less than 20 ft.

Results of the deviation measurements are listed in the “Summary of Drilling and Completion” section next to coring and core recovery rates at the end of this section.

Plugging of Drill String

Plugging of the surface exhaust pipes and central part of the dual-wall drill string happened several times. Two types of plugs were observed during this operation: (1) Dry plugs, which usually occurred when unconsolidated or weak sections were reamed and large pieces of rock were drawn into the central pipe of the dual-wall drill string, and (2) Wet plugs, which occurred when wet sections (where ground water was encountered) were reamed. The wet cuttings formed mud rings along the central pipe of the dual-wall drill string. Surface sections were unplugged by disconnecting and cleaning them. Down-hole sections were cleared using two methods: (1) Pounding the plug with a sinker bar several times until the plug was knocked down. This method was used with the dry plugs only; or (2) Drilling the plug with the coring string. This method was used with wet and dry plugs to unplug the central part of the dual-wall pipe.

Objects Lost in the Borehole

Several items fell in borehole UZ#16. Most of the items were retrieved except the following:

1. A plastic bailer
Dimensions: 2 inches in diameter by 4 feet long
Date when lost: Not recorded
2. A battery pack
Type: Rechargeable 12 Vdc, made by PowerSonic, model PS-1265;
it was a gel cell with solid electrolyte
Dimensions: 2.5 inches × 3.5 inches x 6 inches
Date when lost: June 17, 1993
3. An inflatable packer casing
Dimensions: Unknown
Date when lost: October 21, 1993

Attempts to retrieve the above-mentioned items prior to borehole instrumentation were not successful; they were left in the borehole because their presence did not affect borehole instrumentation. The lost items were eventually buried by cave-ins.

Summary of Drilling and Completion

Figure 4 shows a diagrammatic of borehole UZ#16 after its completion. Figure 5 shows the drilling rate per core run, core recovery rate, and down-hole deviation surveys next to a lithologic log. The lithology is from Geslin and others (1995).

LOGGING

With some exceptions, geophysical logs made before the borehole was completed were considered nonquality affecting because they were made to support the drilling operations. Geophysical well logs made after borehole completion were considered quality affecting.

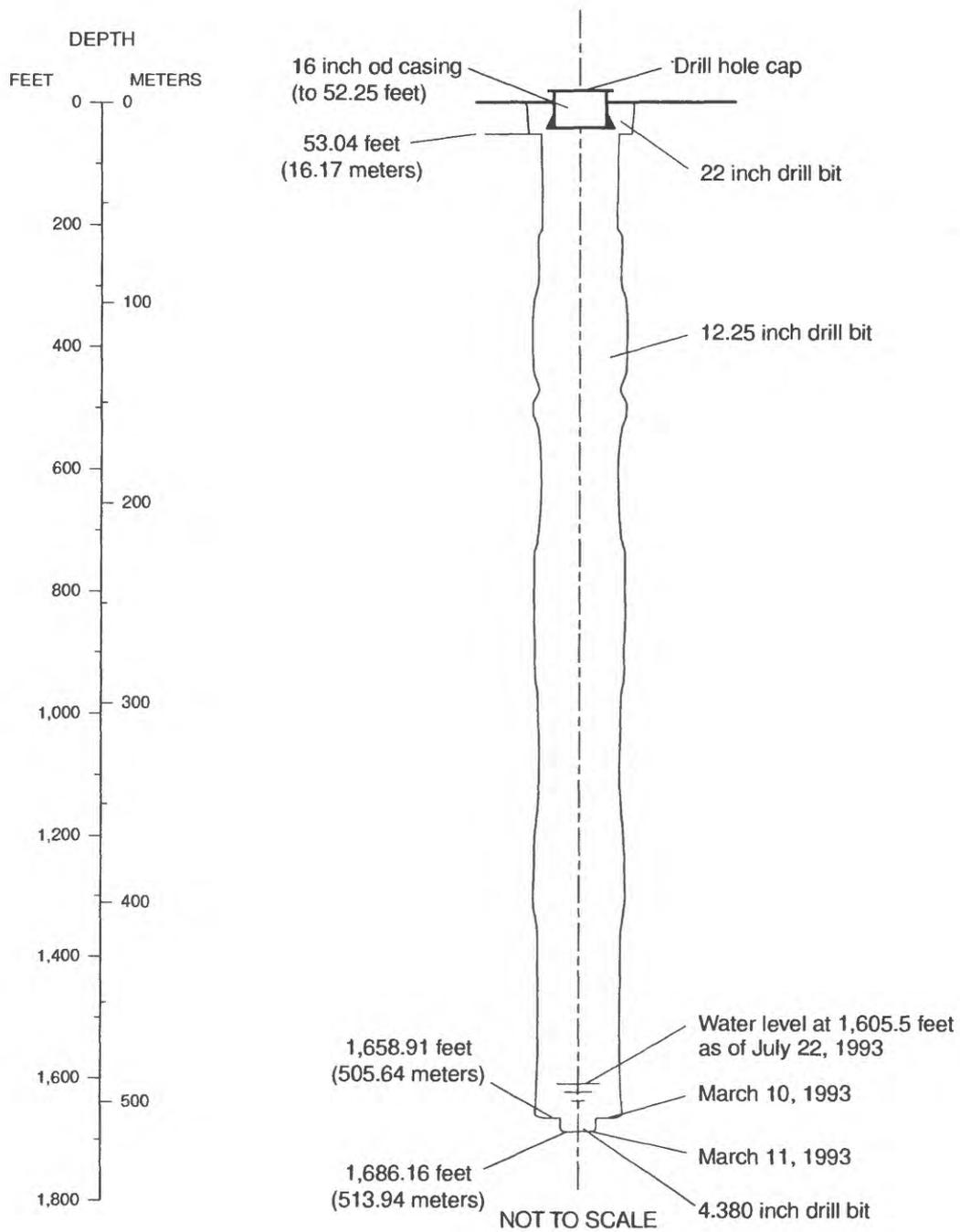


Figure 4. Diagrammatic section of borehole UE-25 UZ#16 after completion.

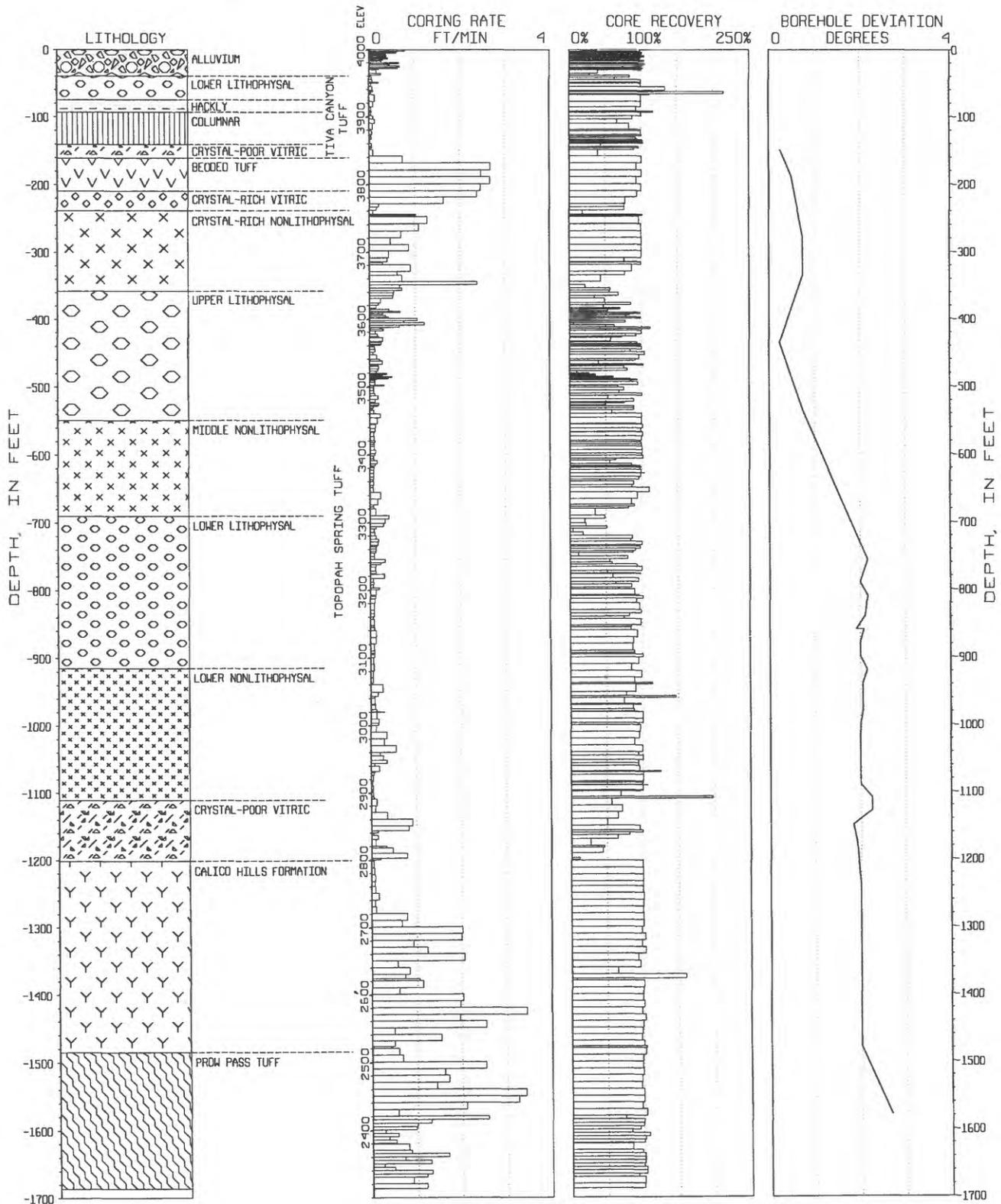


Figure 5. Lithology, drilling rate, core recovery rate, and down-hole deviation measurements in borehole UE-25 UZ#16. Lithology from Geslin and others (1995). [elev: elevation, in feet; ft: foot; min: minute; %: percent].

Lithologic Log

Figure 6 shows a lithologic log of UZ#16 that was modified from Geslin and others (1995, p. 38–39); this reference also lists the lithologic logging methods and criteria used for contact selection.

Fracture Logs

Two fracture logs, a preliminary and a detailed, were made from the recovered core. Both are described, and a comparison of the two is presented.

Preliminary Log

Fracture data were first recorded at the drilling site as soon as the cores were retrieved to the surface and before they were packaged. At the drilling site, priority was given to core preservation, distribution to other participants, and storage (see section on “Core Specification and Recovery”); fracture logging was given a secondary priority during this operation.

Not all core was available for logging because full core recovery was not achieved (see section on “Core Specification and Recovery”). In addition to the lost core, some core was distributed to other participants; however, the distributed core was mostly solid pieces with little or no loose fractures (fractures that did not fall apart when retrieved), although some pieces had intact fractures. The effect of this removal on the calculated fracture frequencies has not been studied yet.

Onsite fracture logs were considered quality affecting after August 20, 1993. Because onsite fracture data from UZ#16 were collected before this date, the data presented in this section were not considered quality affecting when they were collected.

The number of visible fractures (loose and intact) per retrieved core was the only measured parameter. There was no preset limit on the length of fracture trace as the case was in the detailed study (see section on “Detailed Log”). Exceptions in fracture consideration were:

1. Fractures in rubble zones were not individually counted; 2 fractures per 0.1 ft (or 20 fractures per foot) were assumed; and
2. Fractures identified as drilling-induced were not counted; however, drilling-induced fractures that could not be distinguished from natural fractures were counted.

The number of fractures per 5-ft interval was tabulated. Where there was missing core, the number counted in the retrieved core was assigned to the whole 5-ft interval. If all the core was missing in a 5-ft interval, then the number of fractures was labeled as not available (NA).

Table 1 lists the distribution of average fracture frequencies in the different formations in UZ#16. Figure 7 shows the distribution graphically. No adjustments were made for the missing core. Figure 8 shows the core recovery rate and number of counted fractures per 10-foot interval relative to depth.

Zones of welding (W)

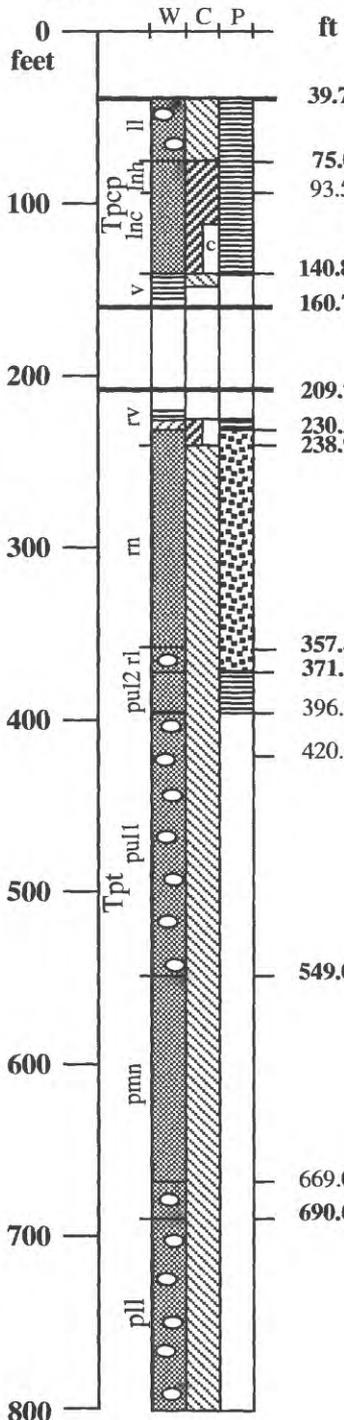
Zones of crystallization (C)

Phenocryst content (P)

- Moderately to Densely (o-lithophysae)
- Partially to Moderately
- Non- to Partially
- Nonwelded

- Devitrified / Devit. + vapor-phase mins.
- Vitric / Vitric + vapor-phase mins.
- Altered (a) / to clay (c) / to zeolite (z)

- greater than 10 percent
- 5 - 10 percent
- less than 5 percent



Alluvium (QTac)

Tiva Canyon Tuff (Tpc) - (Phenocrysts of san and hbl)

Crystal-poor lower lithophysal zone: Lithophysae are 2 to 5 percent of rock, and light gray spots and rims form 5 to 10 percent. Cavities less than 2 mm at 60.7 - 75.0

Crystal-poor lower nonlithophysal zone:

hackly subzone (lnh) (75.0 - 93.5) - hackly fractures on broken surfaces
columnar subzone (lnc) (93.5 - 140.8) - hackly fractures not well developed, closely spaced joints at 93.5, top of clay-filled pumice pseudomorphs at 112.0

Crystal-poor vitric zone: partially welded and devitrified with less than 2 mm vapor-phase filled cavities (140.8 - 153.9), vitric nonwelded (157.5 - 160.8)

Bedded tuffs - Six bedded deposits, each with orange top. Includes Yucca Mountain Tuff (Tpy: 165.9 - 175.0) but no Pah Canyon Tuff in this borehole.

Topopah Spring Tuff (Tpt) -

Crystal-rich vitric zone: post-Topopah Spring Tuff bedded tuff (188.8 - 209.7) with paleosol (?); 1 cm-thick lithic-rich fallout tephra (209.7); nonwelded and moderately welded vitric subzones; vitrophyre subzone (230.3 - 238.9); phenocrysts of feld, bio, minor hbl and cpx

Crystal-rich nonlithophysal zone:

Phenocrysts of feld, bio, with minor hbl and cpx
 Minor amounts of brown pumice down to 413.

Crystal-rich lithophysal zone (rl) (357.8 - 371.0); phenocrysts of feld, bio, with minor hbl and cpx.

Crystal-poor upper lithophysal zone: phenocrysts of feld and bio
lithophysae-poor subzone (pul2) (371.0 - 396.0)
lithophysal zone (pul1) (396.0 - 549.0)
 (In previously published lithologic logs, the crystal-rich and crystal-poor lithophysal zones were probably logged as a single unit.)

Increase in size and amount of brown pumice to 455,
 at 420.0 a brown pumice is 12 cm along core axis.
 Lithophysae are approximately 35x45 cm, have 5 mm-wide light gray rims, and hackly fracture is moderately well developed.

Crystal-poor middle nonlithophysal zone:
 conchoidal breakage is typical along high-angle fractures ;
 vapor-phase minerals fill some fractures

transition subzone with rare lithophysae and change from conchoidal high-angle fractures to small *en echelon* hackly fractures (669.0 - 690.0)

Crystal-poor lower lithophysal zone:
 lithophysae are approximately 15x60 cm, have 15 mm-wide light gray rims, and hackly fracture is moderately well-developed.
 high-angle hackly fractures, many *en echelon* (887.0 - 1054.6)

Figure 6. Lithologic log of borehole UE-25 UZ#16 (modified from Geslin and others, 1995).

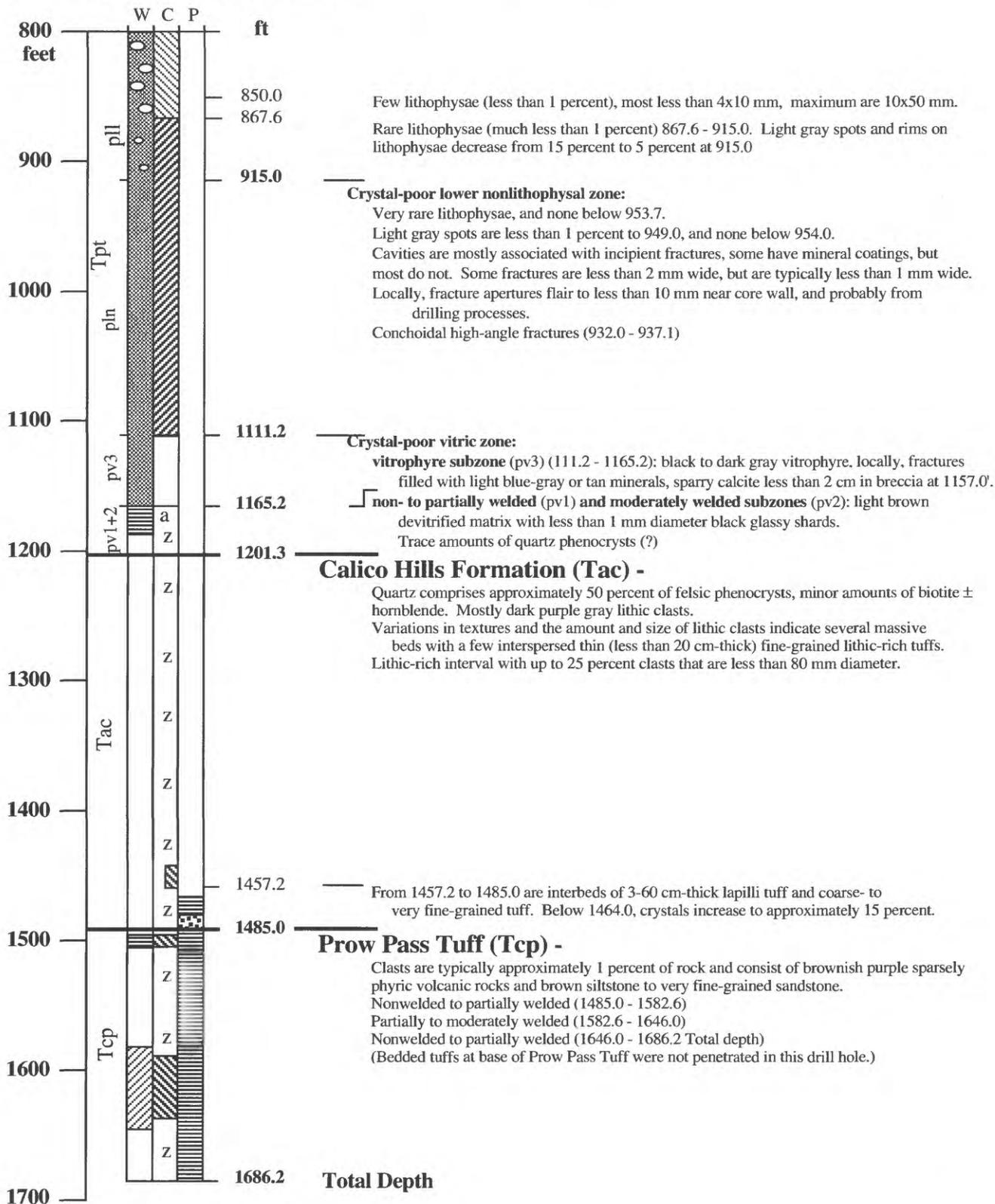


Figure 6. Lithologic log of borehole UE-25 UZ#16 (modified from Geslin and others, 1995)—Continued.

Table 1. Distribution of average fracture frequency in borehole UE-25 UZ#16 from the preliminary fracture log

[NA = Not available; total number of recorded fractures = 5,375]

Geologic unit	Depth interval, in feet		Thickness of section, in feet	Average frequency, in fractures per foot
Alluvium	0.0	39.7	39.7	NA
Tiva Canyon Tuff	39.7	160.7	121.0	4.157
Bedded Tuff	160.7	209.7	49.0	2.000
Topopah Spring Tuff	209.7	1,201.3	991.6	4.573
Calico Hills Formation	1,201.3	1,485.0	283.7	0.631
Prow Pass Tuff	1,485.0	1,686.2	201.2	0.298

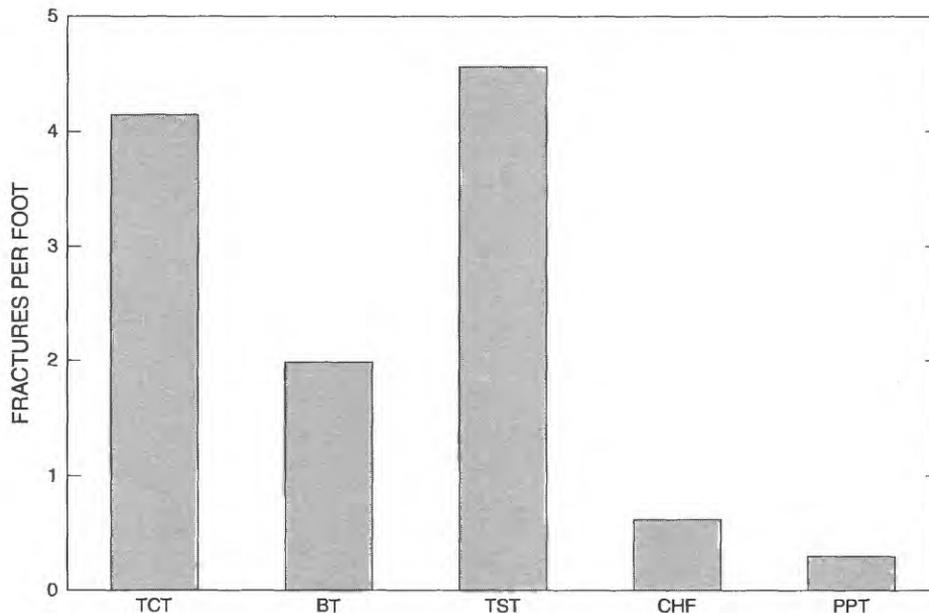


Figure 7. Distribution of average fracture frequency in borehole UE-25 UZ#16 from preliminary fracture log. [TCT: Tiva Canyon Tuff; BT: Bedded tuffs; TST: Topopah Spring Tuff; CHF: Calico Hills Formation; PPT: Prow Pass Tuff].

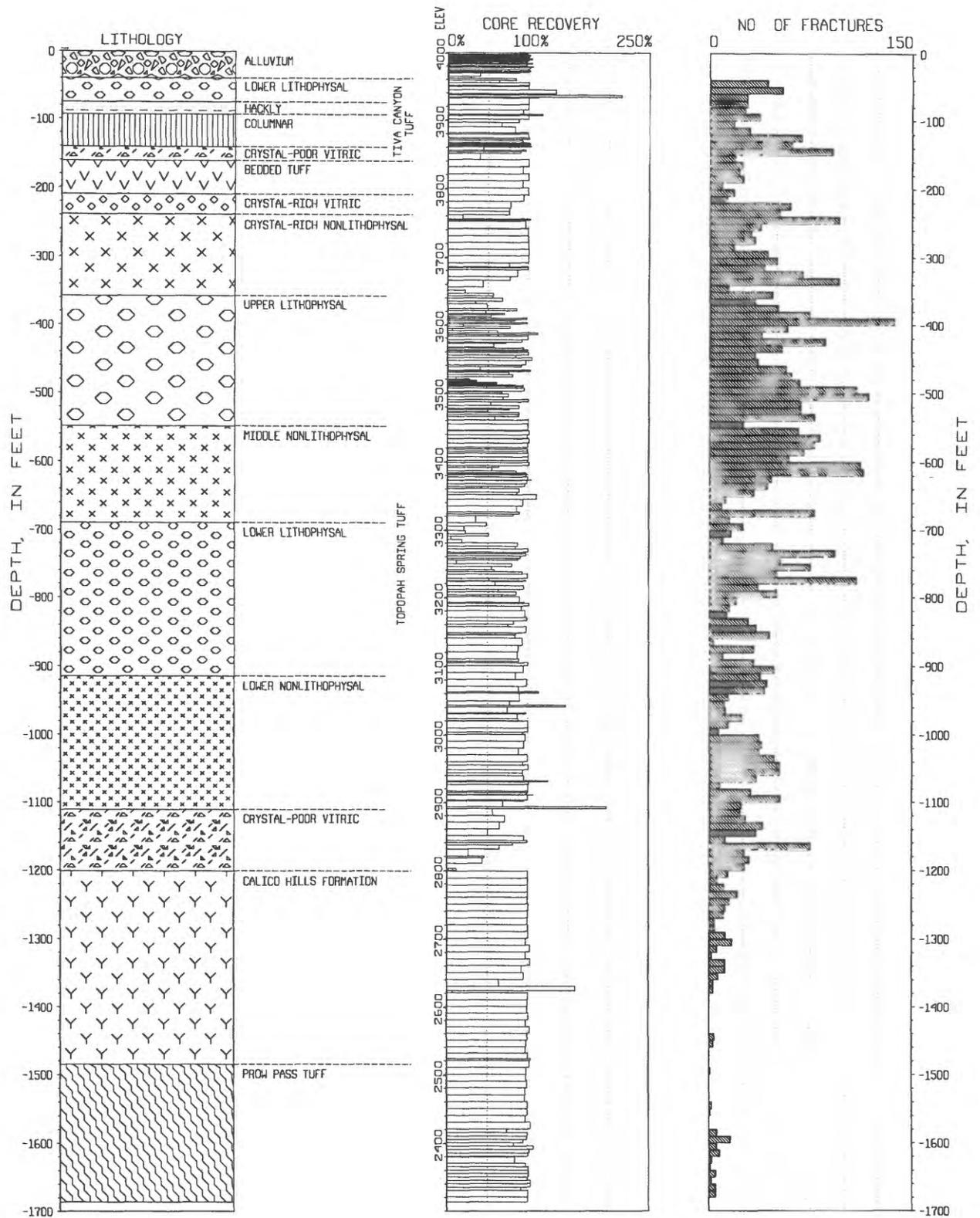


Figure 8. Core recovery rate and preliminary fracture count in borehole UE-25 UZ#16. Recovery rates per core run and fracture counts are per 10-foot intervals. [elev: elevation, in feet; %:percent] [Data Tracking Number for fracture count: TM00000000UZ16.001]

Detailed Log

A more detailed fracture log was made using core archived at the SMF. Not all the core was archived at the SMF. Some core was not retrieved as discussed in the section on "Core Specification and Recovery"; some of the retrieved core was distributed to other participants. Core distribution after it was first archived and before this detailed fracture log was conducted may have taken place. Details of such distribution was not considered essential because sections with missing core were identified when the detailed study was made. The core available for this log is listed below:

Total length of core stored at the SMF (when this fracture log was made):	1,095.56 ft
Total length of missing core:	590.6 ft
Total depth of borehole:	1,686.16 ft
Fraction of core available for this survey (including the drive core between 0 - 30 ft):	0.65
(excluding the drive core between 0 - 30 ft):	0.64

Video logs of cores were not used to study sections with missing cores because (1) the quality of the images was not good enough; some fractures that were visible on the cores were not visible on the video images, and (2) the images were made along one side of the core. A thorough core examination requires the inspection of all the core surfaces.

The following types of fractures and joints were observed, recorded, and included in the fracture count:

1. Extension joints with and without vapor-phase mineralization
2. Shear joints with slickensides
3. Vuggy veinlets (tubular structures usually associated with cooling joints)
4. Breccia

The following fractures were observed and excluded from the fracture count:

1. Drilling-induced fractures (when identified): these fractures were identified according to the methods described by Kulander and others (1990). In some cases where the fracture surfaces were not mineralized or discolored, the differentiation between natural and drilling-induced fractures was difficult or impossible; hence, some of these fractures may have been considered natural and included in the fracture count.

2. Natural fractures with traces smaller than the core diameter: these fractures greatly outnumbered the larger fractures. They were excluded from this analysis because they did not connect with neighboring fractures and were not considered important for fluid transport.

3. In the vitrophyre zone (1,111.2 ft to 1,165.2 ft), only major fractures were recorded; that is, when a fracture was surrounded by a shattered zone with parallel fractures, only the central fracture was recorded as one fracture.

Fracture parameters and measuring tools used for the detailed fracture log were:

- a. Fracture (intact or loose) location relative to depth (with a ruler);
- b. Apparent dip (with a protractor)
- c. Fracture aperture (with a ruler)
- d. Vug presence and dimension (with a ruler)
- e. Fracture filling type (with a microscope)

Dip measurements were not corrected for borehole deviation; such a correction was not considered necessary because the deviation did not exceed 3 degrees (see section on "Deviation of Borehole"). The identification and examination of vuggy fractures were limited to vugs that were visible along fracture traces or vugs in loose fracture planes; planes of intact fractures were not forced open to preserve their integrity for possible future studies. Fracture-plane orientations (strikes) were not measured because the core was not oriented.

Table 2 lists distribution of average fracture frequency in the different formations in UZ#16. Figure 9 shows the distribution graphically. Figure 10 shows the available core used for this study, number of recorded fractures, number of vuggy fractures, and the median apparent dip relative to depth. For plotting purposes, the following was done:

1. The number of fractures per 10-ft interval was calculated; no adjustments were made for missing cores; and
2. Only the median apparent dip for fractures within the 10-ft intervals is shown. Where there was an even number of measurements, the median apparent dip was equated to the arithmetic average of the two middle values.

Low median dip (< 40°) appeared in 14 locations as shown in figure 10; it was attributed to low-angle fractures with vapor phase mineralization that tend to follow the foliation of the rock. More information on this fracture log is presented in appendix 3.

Table 2. Distribution of average fracture frequency in borehole UE–25 UZ#16 from the detailed fracture log

[NA = Not available; total number of recorded fractures = 2,597]

Geologic unit	Depth interval, in feet		Average frequency, in fractures per foot	
			All	Vuggy
Alluvium	0.0	39.7	NA	NA
Tiva Canyon Tuff	39.7	160.7	1.992	0.488
Bedded Tuff	160.7	209.7	0.041	0.000
Topopah Spring Tuff	209.7	1,201.3	2.269	0.527
Calico Hills Formation	1,201.3	1,485.0	0.247	0.000
Prow Pass Tuff	1,485.0	1,686.2	0.169	0.025

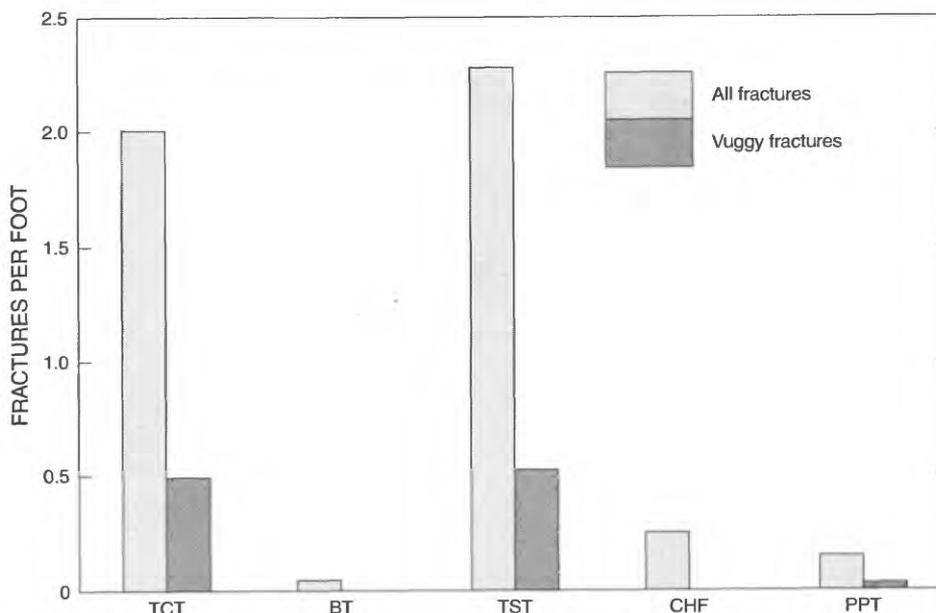


Figure 9. Distribution of average fracture frequency in borehole UE–25 UZ#16 from detailed fracture log. [TCT: Tiva Canyon Tuff; BT: Bedded tuffs; TST: Topopah Spring Tuff; CHF: Calico Hills Formation; PPT: Prow Pass Tuff] [Data Tracking Number: GS950608312232.005]

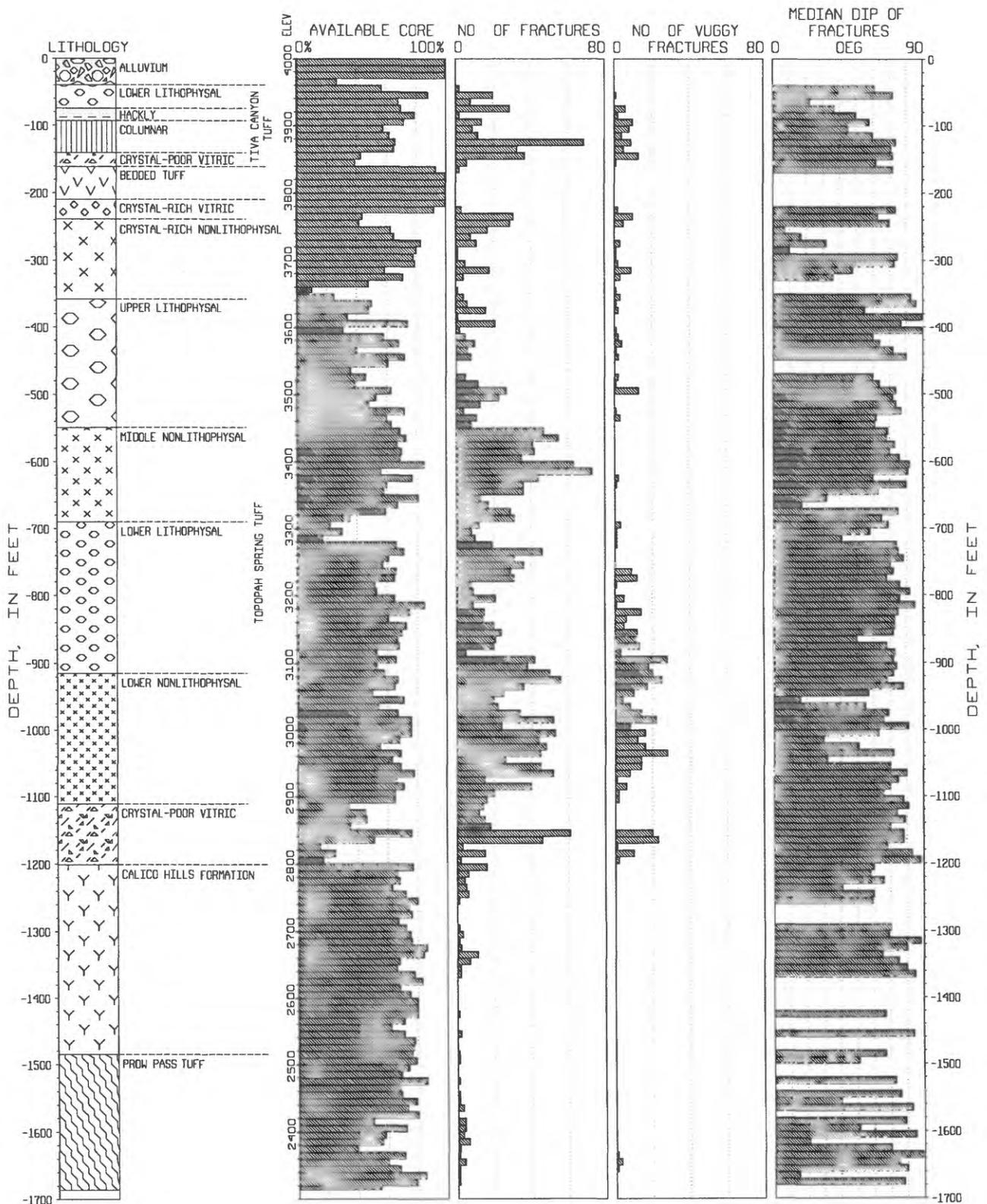


Figure 10. Fraction of available core for logging, number of recorded fractures, number of vuggy fractures, and the median apparent dip of fractures relative to depth from borehole UE-25 UZ#16. Values are per 10-foot interval. [deg: degree; elev: elevation, in feet; %: percent] [Data Tracking Number: GS950608312232.005]

Comparison of the Preliminary and Detailed Fracture Logs

The number of fractures was the only common parameter in both the preliminary log and the detailed log. Therefore, only this parameter plus the calculated fracture frequencies will be discussed in this section. Table 3 shows a summary of the two studies.

Table 3. Number of recorded fractures and length of available cores from the preliminary and detailed fracture log studies in UZ-25 UZ#16

Fracture log	Total number of recorded fractures	Total length of available core, in feet
Preliminary (P)	5,375	1,451*
Detailed (D)	2,597	1,095
P/D	2.07	1.33

* The length of available core as mentioned here is the length of recovered core. In some cases, part of the recovered core was distributed to other participants before fracture count was conducted for the preliminary study; the distributed pieces may have had intact fractures.

As mentioned in the section on “Preliminary Log”, all visible fractures were recorded. However, in the detailed log, only fractures with traces larger than the core diameter were recorded. This difference in recording criterion may account for the disproportionately larger number of counted fractures in the preliminary log.

Figure 11 shows the distribution of average fracture frequencies from both the preliminary and the detailed studies. Except for the bedded tuffs, the fracture frequencies calculated from the detailed log is approximately half that calculated from the preliminary log, which is equivalent to the proportion shown in table 3 without

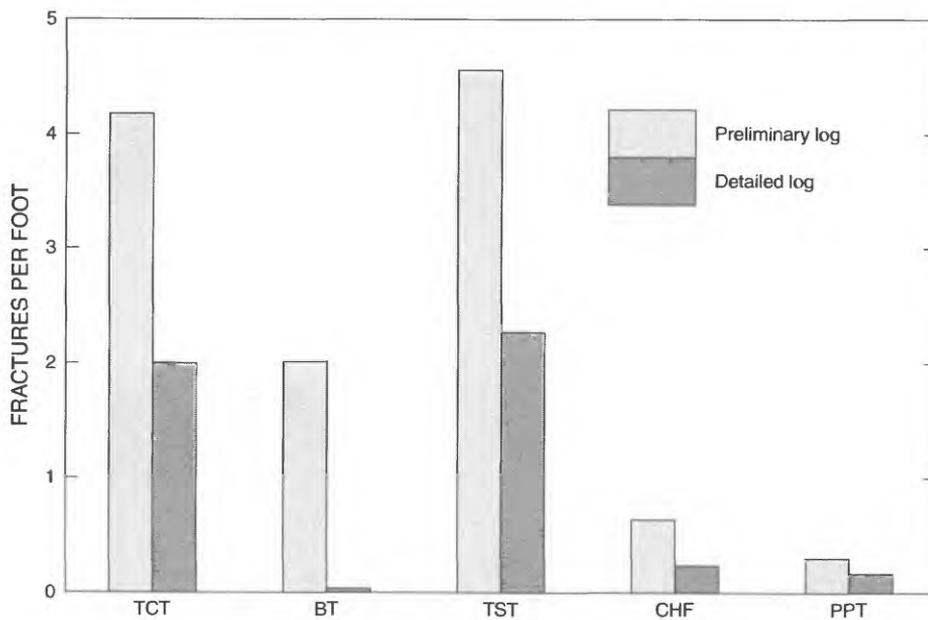


Figure 11. Distribution of average fracture frequency in borehole UE-25 UZ#16 from the preliminary and detailed fracture logs. [TCT: Tiva Canyon Tuff; BT: Bedded tuffs; TST: Topopah Spring Tuff; CHF: Calico Hills Formation; PPT: Prow Pass Tuff]

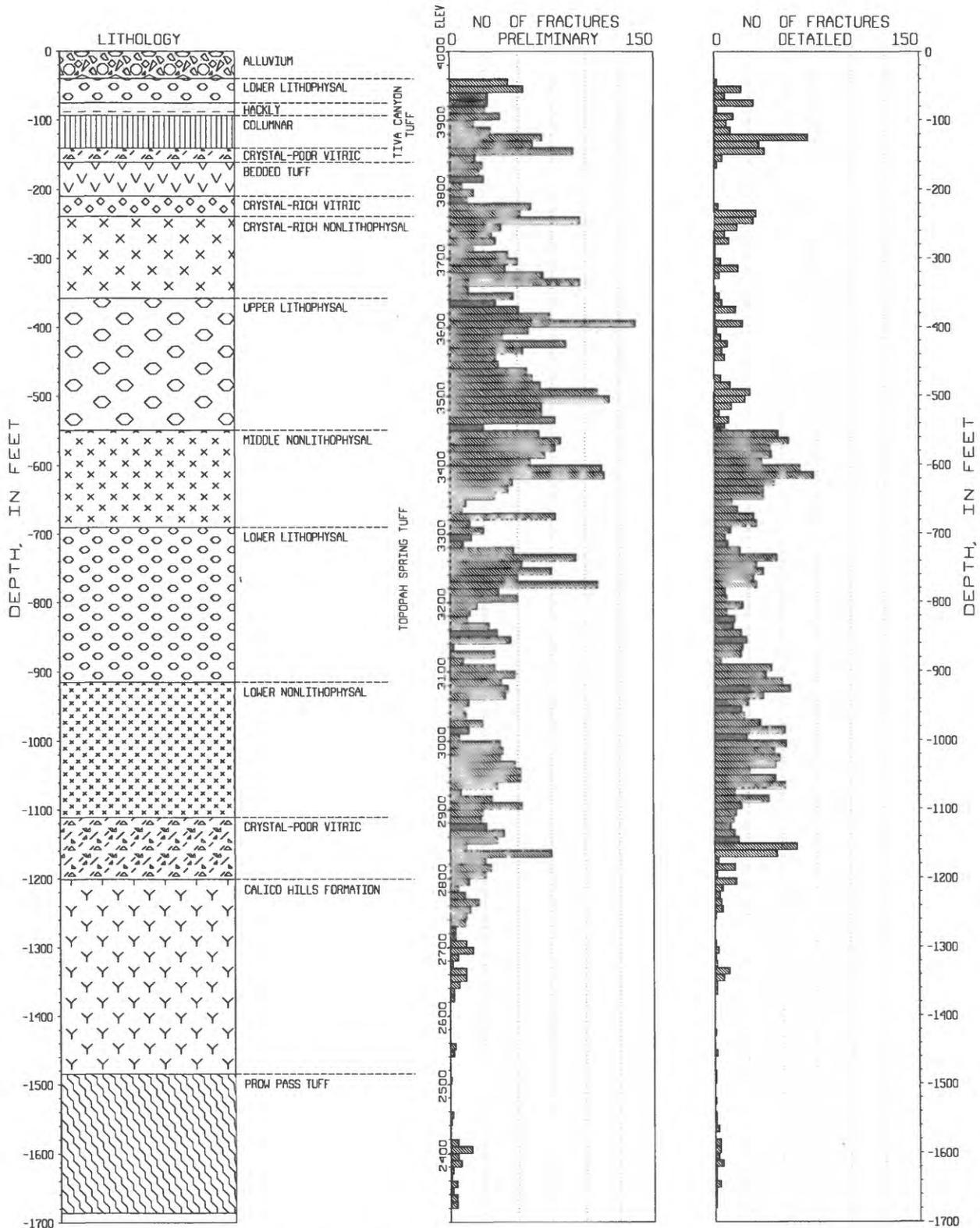


Figure 12. Number of counted fractures relative to depth from the preliminary and detailed fracture logs in borehole UE-25 UZ#16. Values are per 10-foot intervals. [elev: elevation, in feet]

adjusting to the difference in available core for each study. Figure 12 shows the counted number of fractures relative to depth from the preliminary and detailed fracture logs per 10-ft interval.

Deviation Logs

Deviation logs were required to know the location of the borehole with depth relative to its surrounding. The data consisted of the wellbore inclination and the azimuth of the plane of inclination, both at specified depths. Two deviation surveys were made and are listed in table 4.

Table 4. Deviation surveys made in borehole UE-25 UZ#16

Date	Survey made by	Depth interval, In feet	Depth increment, in feet	Remarks
03-15-93	Eastman Teleco	0.0 - 1,643	25	The depth increment is from the combined in-run and out-run ^a ; sonde hit fill in borehole at 1,650 feet
07-26-93	Schlumberger	33.5 - 1,640.5	0.5	Run made with a 4-arm caliper log. ^b

^a Two runs were made: an in-run (top to bottom every 50 feet), and an out-run (bottom to top every 50 feet). The two data sets were not made at the same depth points; depths were staggered to make 25-foot increments.

^b A caliper log was combined with this log (see section on "Caliper Logs" for more details).

The deviation log made on March 15, 1993, was used to compute wellbore departure from an assumed vertical axis that goes through the center of the borehole at the surface. Departure was calculated using two methods: (1) the sectional method and (2) the minimum curvature method.

The sectional method was developed by Long and Mitchell (1992). Calculations of departure were made using three data sets: (1) the in-run, (2) the out-run, and (3) the two data sets combined (see table 4). Figure 13 shows the results of these calculations at different depths. Point (0,0) corresponds to the borehole-center coordinates at the surface. This method was used to corroborate deviation calculations made by the service company that made the borehole measurements (see next paragraph).

The minimum curvature method was described by Taylor and Mason (1972). The same three data sets used in the sectional method also were used by Eastman Teleco to compute the wellbore departure using the minimum curvature method. The program used for the calculations was not released by Eastman Teleco because it was considered proprietary. Figure 14 shows the results of these calculations at different depths.

Both methods give similar solutions for the angle of curvature between survey stations. The strength of the sectional method is that its solution for the linear displacements dependent on the angle of curvature is continuous for very small curvatures. The minimum curvature linear displacement solutions are discontinuous as the angle of curvature approaches zero. Consequently, the American Petroleum Institute (1985) showed that the conventions for use of the minimum curvature method is to assume no curvature for curvatures less than 0.25 degree per 100 ft of measured depth. Thus, there could be minor cumulative errors if enough stations have curvatures just below this cutoff value, if the minimum curvature method is used. A more detailed comparison between the two methods and sources of error in directional drilling is documented in Mitchell (1992). Figure 15 shows the north-south and east-west departure calculations based on the two methods. Figure 16 shows the calculated true vertical depth relative to departure based on the two methods. The maximum difference in calculated departure and true vertical depth using the two methods did not exceed 0.01 ft. The true vertical depth at measured depth of 1,643.00 ft was 1,642.34 ft. Because the difference between measured and true depths is relatively small, depth corrections were not made to the data presented in this report; that is, measured depth is used throughout this report.

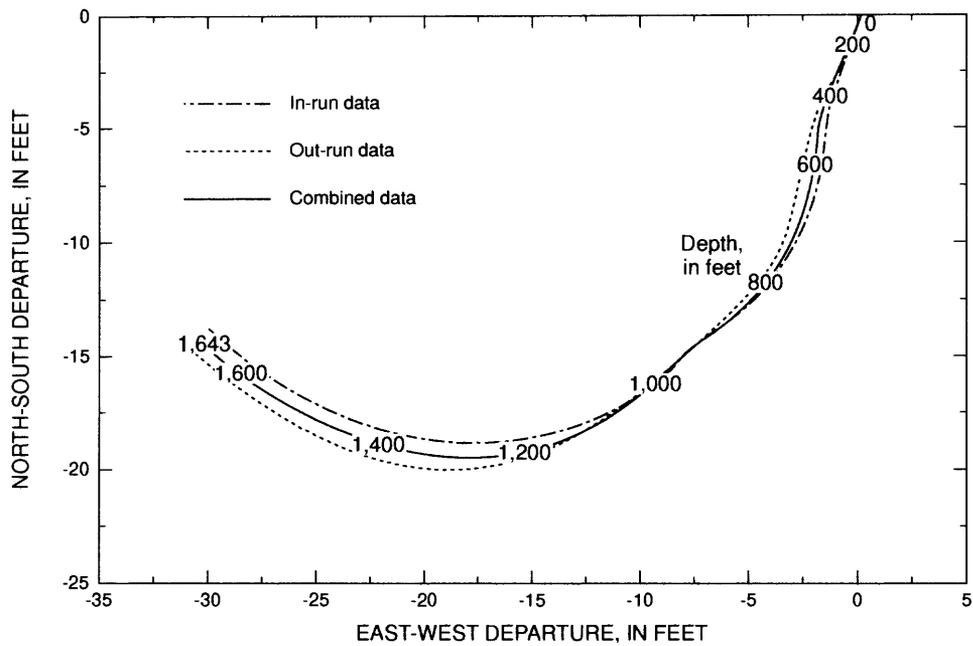


Figure 13. Calculated departure in borehole UE-25 UZ#16 based on the sectional method.

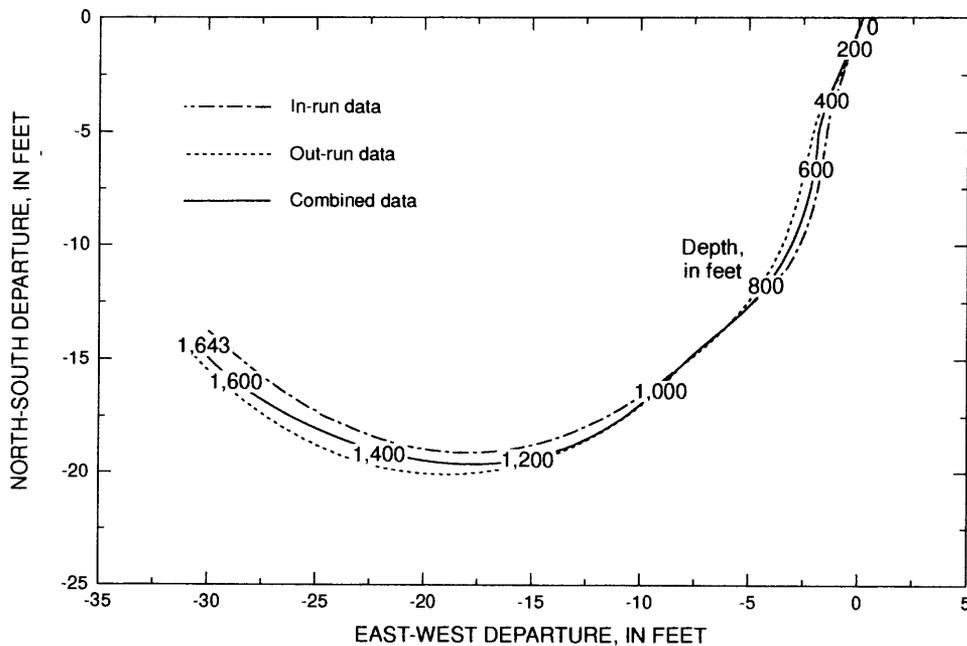


Figure 14. Calculated departure in borehole UE-25 UZ#16 based on the minimum curvature method.

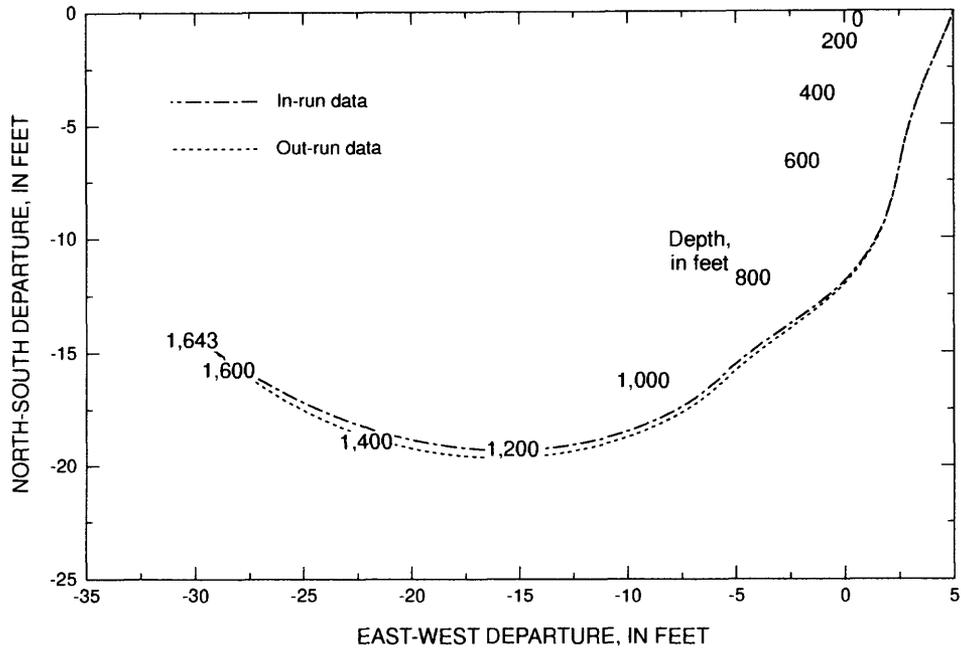


Figure 15. Calculated departure in borehole UE-25 UZ#16 based on the sectional method and minimum curvature method.

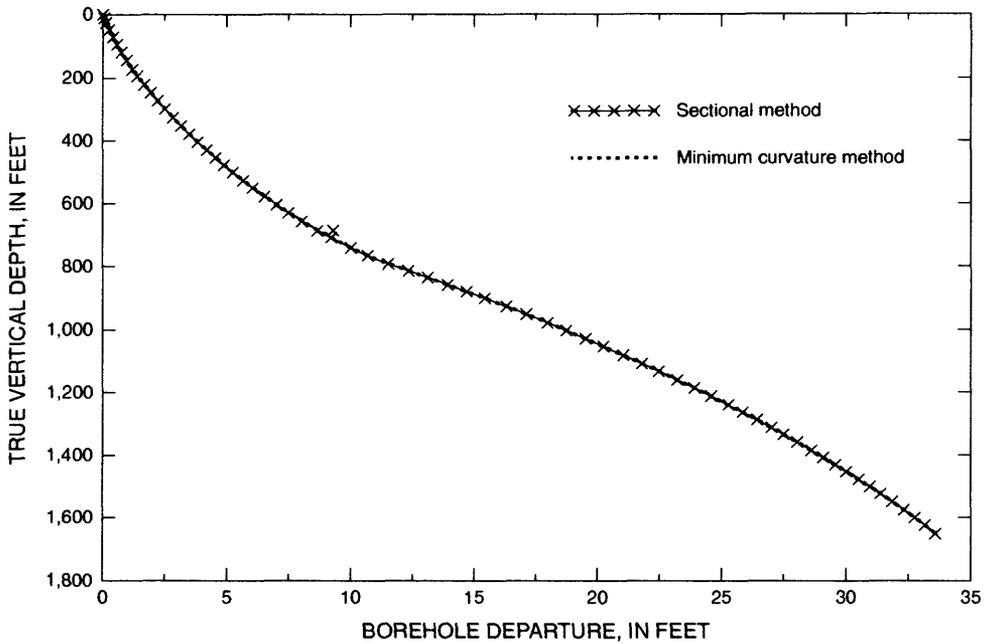


Figure 16. Calculated departure and true vertical depth in borehole UE-25 UZ#16 based on the sectional method and minimum curvature method.

Caliper Logs

Table 5 lists the caliper logs made in this borehole after its completion. Caliper logs were required to calculate the borehole volumetric capacity relative to depth that is needed to estimate the amount of grout and other fill materials needed when the VSP geophone string is emplaced. Video logs made in this borehole did not show locations where the actual hole size exceeded the limit of the caliper log. Such sections, had they existed, would have been identified by a constant caliper reading along such sections. The constant value would correspond to the maximum measurable diameter of the caliper log.

Table 5. Caliper surveys made in borehole UE-25 UZ#16 after completion

Date	Survey made by	Depth interval, in feet	Depth increment, in feet	Remarks
03-17-93	Barbour Well Surveying Corp	14.0 - 1,648.0	0.5	3-arm caliper log
07-26-93	Schlumberger	33.5 - 1,640.5	0.5	4-arm caliper log* which was run with a deviation log

* This 4-arm caliper log measures two orthogonal diameters; the two measurements do not necessarily indicate the maximum and/or minimum diameters of the measured section; they indicate the borehole diameter where the caliper pads happen to be.

Video Logs

Video logs were made during the drilling operation for three purposes: (1) view stuck or lost objects down the borehole, (2) demonstrate new types of cameras to check their applicability in dry-drilled boreholes, and (3) observe potential wetting of the formation while drilling. Effects of the following parameters on the quality of the image were examined to determine the best combination in UZ#16, which was considered a dusty borehole: (a) resolution; (b) field of view; and (c) centralizer usage.

Two sets of recorded video logs were made: video logs of cores and the open borehole.

Video logs of cores were made with a video camera as soon as each core was retrieved to the surface. The images were one-sided (that is, the core was not rotated while being filmed). The original copies of the recordings are kept at the SMF. Several down-hole video logs were made. The main purpose of these logs was to view the borehole prior to running other logs so that restricted or caved sections may be identified. Table 6 lists the logs made in this borehole with their purposes.

Table 6. Video log surveys made in borehole UE-25 UZ#16

Date	Survey made by	Depth interval, in feet	Remarks
02-26-93	Barbour Well Surveying Corp	1,268 - 1,594	Made to observe potential wetting effects on formation due to drilling.
03-12-93	Barbour Well Surveying Corp	1,381 - 1,615	Run prior to running a neutron log to examine borehole.
03-17-93	Barbour Well Surveying Corp	0 - 1,602	Oriented color video. Run prior to running a caliper log.
07-22-93	Barbour Well Surveying Corp	0 - 1,605	The camera had a Sidescan lens combined with a gyroscopic-orientation tool; tool was run to water level; sidescan recordings were made at selected levels.

Note: Copies of the original logs are kept in the Yucca Mountain Field Operations Office on the Nevada Test Site.

Other Geophysical Logs

Well logs presented here were made after total depth was reached with the exception of the neutron logs made by the USGS. All logs except the ones marked as prototype were run under a qualified QA program. The prototype logs were either newly developed by the logging services or their applicability in volcanic rock was experimental. Detailed studies on all logs are being conducted. Because this borehole was dry-drilled, well logs that did not require drilling mud to properly operate were used. Table 7 lists the geophysical logs made in this borehole. Table 8 lists the information obtained from each log.

Table 7. Geophysical well logs made in borehole UE–25 UZ#16

Type of well log	Measurement made by	Date of well log	Depth interval, in feet	Remarks
neutron	USGS (1)	03-01-93	1565-surface	
neutron	USGS	03-12-93	1568-1379	
dual induction/spectral gamma ray	Schlumberger (2)	07-26-93	1633-surface	
dielectric propagation	Schlumberger	07-27-93	1635-surface	
compensated formation density with photoelectric effect/gamma ray	Schlumberger	07-27-93	1651.0-casing bottom	
sidewall neutron porosity/gamma ray	Schlumberger	07-27-93	1653.5-52.25	
borehole gravity meter	EDCON (3)	07-27-93	1629.0-41.0	stationary measurements
borehole gravity meter	EDCON	07-28-93	1639.4-41.0	
geochemical logging tool	Schlumberger	07-28-93	1633.0-52.25	three passes were made
thermal decay time/gamma ray	Schlumberger	07-28-93	1650.0-98.0	neutron log malfunctioned at 98 ft
borehole radar tool	Schlumberger	07-30-93	1575.0-0.0	prototype log; first of four runs
borehole radar tool	Schlumberger	07-30-93	1645.0-casing bottom	prototype log
borehole radar tool	Schlumberger	07-30-93	1630.0-casing bottom	prototype log; longer tool spacing with various gains
borehole radar tool	Schlumberger	07-30-93	1630.0-casing bottom	prototype log; shortest tool spacing was used
geochemical logging tool	Schlumberger	08-02-93	1653.5-670.0	at 670 ft the detectors became saturated
nuclear porosity lithology tool/geochemical reservoir analyzer	Schlumberger	08-02-93	1650.0-52.25	prototype log; two passes were made
nuclear porosity lithology tool/geochemical reservoir analyzer	Schlumberger	08-03-93	1650.0-52.25	prototype log; third pass
geochemical logging tool	Schlumberger	08-03-93	800-52.25	aluminum activation portion of tool was used
pulsed neutron device-inelastic spectroscopy	Computalog (4)	08-09-93	1638-48	prototype log; spacer used between neutron source and detector
pulsed neutron device-inelastic spectroscopy	Computalog	08-09-93	1623-28	prototype tool; tool inside a 7-inch sleeve containing plastic
pulsed neutron device-inelastic spectroscopy	Computalog	08-10-93	39-1654	prototype tool; no spacer was used between neutron source and detector

Table 7. Geophysical well logs made in borehole UE–25 UZ#16—Continued

Type of well log	Measurement made by	Date of well log	Depth interval, in feet	Remarks
pulsed neutron device-inelastic spectroscopy	Computalog	08-10-93	1653-300	prototype tool; inelastic burst firing mode was used
spectral gamma ray with cooled germanium detector	EMC (5)	08-10-93	1625-1465	prototype tool
spectral gamma ray with cooled germanium detector	EMC	08-11-93	1405-1075	prototype tool
spectral gamma ray with cooled germanium detector	EMC	08-11-93	924-40	prototype tool
spectral gamma ray with cooled germanium detector with gamma ray log	EMC	08-11-93	1100-surface	prototype tool
magnetic resonance imaging log	Numar(6)	04-22-94	selected intervals	prototype log; two runs were made over selected intervals
magnetic resonance imaging log	Numar	04-22-94	1612-93	prototype log
magnetic resonance imaging log	Numar	04-22-94	selected intervals	prototype log; two passes made with different signal-to-noise ratio

Notes:

- (1) U.S. Geological Survey, Mercury, Nevada
- (2) Schlumberger, Houston, Texas
- (3) Exploration Data Consultants, Lakewood, Colorado
- (4) Computalog, Houston, Texas
- (5) Environmental Measurements Corporation, Bonham, Texas
- (6) Numar Corp., Houston, Texas

Table 8. Information obtained from each geophysical log made in borehole UE–25 UZ#16

Type of well log	Information used to calculate
Borehole gravity meter	formation density
Borehole radar tool	formation anomalies such as fractures and faults
Compensated formation density with photoelectric effect/gamma ray	density/lithology/natural radioactivity of formation
Dielectric propagation	dielectric constant of formation
Dual induction spectral gamma ray	resistivity/natural radioactivity of formation
Geochemical logging tool	element composition of formation (K, Th, U, Ca, Si, Fe, S, H, Cl)
Magnetic resonance imaging log	lithology free porosity and bulk volume of irreducible water
Nuclear porosity lithology tool/geochemical reservoir analyzer	porosity/element composition of formation
Neutron log	volumetric water content
Pulsed neutron device-inelastic spectroscopy	volumetric water content
Sidewall neutron porosity/gamma ray	volumetric water content/natural radioactivity of formation
Spectral gamma ray with cooled germanium detector	natural radioactivity/element composition of formation
Spectral gamma ray with cooled germanium detector and gamma ray log	natural radioactivity/element composition of formation
Thermal decay time/gamma ray	volumetric water content/natural radioactivity of formation

WATER DETECTION AND SAMPLING

Water-Detection Strategy

One of the objectives of this study was to detect wet zones and the level of potentiometric surfaces. To achieve this objective while drilling, cores were visually monitored for any increase in the amount of moisture. On the basis of measurements made in neighboring boreholes UE-25 a#1 and USW H-4 (fig. 1), the saturated zone potentiometric surface was expected to be about 1,605 ft deep (based on borehole collar elevation of 4,000 ft). The depths of perched water zones were not known prior to drilling. The first moist zone was observed in the core run between 1,609.38 and 1,614.49 ft. This core appeared entirely wet; water was dripping from it. Down-hole water sampling continued after this observation until the final depth was reached.

Water-Sampling Methods

Bottom-hole water samples were retrieved with bailers. The bailers were small enough to pass through the drilling string past the coring or reaming bits into the cored or reamed sections. Water sampling followed coring or reaming cycles. When a sample was retrieved, its pH and conductivity were measured. The remainder of the sample was chemically analyzed later. The down-hole water-sampling procedure was performed as follows:

- a. If sampling was desired after a coring cycle, the core barrel was pulled out of the drilling string;
- b. To facilitate bailer retrieval, the drilling string was pulled off the bottom far enough to allow the bailer to rest on the borehole bottom without protruding past the bit;
- c. The bailer was lowered to the bottom of the borehole with a wire line. It was left from a few minutes to several days (over weekends or holidays);
- d. The bailer was retrieved to the surface;
- e. If the bailer was nearly or completely full, then steps c and d were repeated until all the bottom-hole water was retrieved (this step applied only to zones where water did not quickly flow into the borehole).

In some cases the bailer was lowered past the bit in open-hole sections and was successfully retrieved.

Two types of bailers were used (fig. 17). The two types and their advantages and disadvantages are listed here. The ball valve filling mechanism type bailer was equipped with a bottom hole and a ball valve above the hole. When the bailer was set at the desired depth, the valve allowed water to enter the bailer. When the bailer was retrieved, the valve rested on the valve seat and sealed the bottom hole. This type has the following advantages: (a) the minimum water level required for sampling is smaller than that of the overflow filling type bailer; however, the water level has to be slightly above the ball valve seat; and (b) easy to clean. This type has the disadvantage that when the collected water is muddy, the mud causes a poor seal and allows the water to leak out while the bailer is being retrieved. Leakage is indicated when the inner walls of the bailer are wet while the bailer is empty. The overflow type bailer was equipped with an inner tube connected to the bottom of the bailer. When the bailer was set at the desired depth, the water entered into the central tube and overflowed into the bailer. It has the advantage of eliminating leakage problems. Its disadvantages are: (a) to collect a sample, the water level in the borehole has to be over the top level of the inner tube; and (b) it is more difficult to clean. The inner tube is especially difficult to clean when the bailer is used to sample muddy water.

Some of the ground water was collected and stored in anticipation of using it with the injected air while drilling; however, such requirement was not needed. Ground water from the same borehole was to be used to minimize formation contamination with foreign materials.

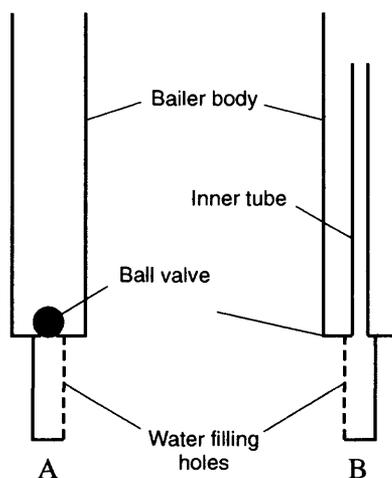


Figure 17. Diagram showing two types of water bailers used to retrieve bottom-hole water samples at borehole UE–25 UZ#16. (a) Ball valve type; (b) Overflow type.

Depths of Wet Zones

Information in this section was gathered while drilling and coring. As stated earlier, the static water level was expected at 1,605 ft of depth. Core from the interval 1,604 to 1,609 ft appeared dry. The first wet core was from the interval 1,609 to 1,619 ft; the first bottom-hole water sample also was retrieved from this interval. Recovered cores from 1,619 ft to 1,649 ft appeared dry. Some water did accumulate at the bottom of the borehole and was sensed with a down-hole water-level meter; however, the water height was not enough to allow it to be sampled (see section on “Water-Sampling Methods” for a discussion about this problem). This observation indicated that the flow rate into the borehole was low. Cores after 1,649 ft of depth appeared wet and water samples were collected. When the depth of 1,669 ft was reached, the water level rose and stabilized at 1,605 ft of depth. A chronological list of water detections in borehole UZ#16 is presented in table 9.

Ground-water samples were retrieved with bailers as described in the section on “Water-Sampling Methods.” On-site and off-site chemical analyses were made on the retrieved samples. The chemical compositions of the retrieved samples were not considered representative because: (1) too small a volume was collected; (2) most of the collected samples were contaminated with cuttings and were muddy; and (3) at 1,619 ft of depth, a sample was collected after a water-level measurement in which salt was used on the tape of the depth meter as a wetness indicator, which artificially altered the conductivity and pH values.

Table 9. Chronological list of activities and observations pertinent to water detections in borehole UE-25 UZ#16

[---- is no data]

Date	Borehole depth, in feet	Observations
----	----	No water was observed or sampled before November 16, 1992.
11-16-92	1,006.2	A small amount of water was in the bailer (amount not specified)
12-02-92	1,109.0	Free water was observed on a borehole deviation tool after it was pulled out. Prior to running the tool, air was circulated for 24 minutes. After noticing the moisture on the deviation tool, a bailer was run in the borehole; it came out empty with condensation on the top two-thirds of its body. This moisture was suspected to be caused by water condensation rather than ground water because it covered the upper part rather than the lower part of the bailer.
12-04-92	1,149.0	A bailer was run in, and was dry when retrieved the following day.
02-24-93	1,609.4	Core between 1,604.3 and 1,609.4 ft appeared dry.
02-24-93	1,619.2	Core between 1609.4 and 1619.2 ft was dripping wet; more so between 1609.4 and 1614.5 ft.
02-24-93	1,619.2	A bailer was run to the bottom of the borehole, kept there for 65 minutes and was full when retrieved. A sample was examined for radioactivity and was determined to be safe. Bailer was run back and pulled out the following day; it was filled with water plus 6 inches of mud at the bottom of the bailer.
02-25-93	1,619.2	Ran a water-level meter; which did not operate properly. Operator was only able to tell that water level was above 1,608.8 ft. A second attempt was made to measure water level; the tape of the meter broke. Most lost tools were retrieved. Bailer was run down to bottom four times and a total of 1 gallon of water was collected. The conductivity and pH of two samples were measured; they were: Conductivity=863, 1825 microsiemens per centimeter at 25°C; pH=7.91, 7.84.
02-26-93	1,619.2	Ran bailer once and water was retrieved; amount not recorded.
02-26-93	1,620.2	The interval 1,619.2 to 1,620.2 ft was cored; however, no core was recovered. Ran a borehole camera to 1,596 ft. There was fill in the core hole; no water was visible.
03-03-93	1,629.1	Core from the interval 1,620.2 to 1,629.1 ft was slightly damp to dry. When the interval 1,612.9 to 1,613.9 ft was reamed, the sample collector at the surface had water and the cuttings were damp (not wet). Cuttings from the interval 1,616.6 to 1,617.6 ft were dry. The drilling pipes were clogged with cuttings at 310 ft.
03-04-93	1,629.1	Ran a bailer to 1,628.9 ft; it was left for 5 minutes and had no water when recovered. The outer surface of the drill pipe was wet when pulled out.
03-5-93	1,629.1	Water level measured at 1,622.7 ft [elapsed time between the end of the previous bailer run and this measurement was about 20 hours]. Borehole was reamed from 1,623.6 to 1,628.9 ft. Water was collected at the sample collector. Ran a bailer to 1,628.9 ft and left in for 5 minutes. Bailer had no water when recovered.
03-08-93	1,639.2	Water level measured at 1,637.9 ft [elapsed time between the end of the previous core run and this measurement was about 17 hours]. Ran a bailer to the bottom; recovered less than 0.05 gallon of water. Bailer leaks were not mentioned.
03-08-93	1,649.3	Core between 1,639.2 and 1,649.3 ft appeared dry.
03-08-93	1,659.2	Core between 1,649.3 and 1,659.2 ft was wet. Water was collected at the sample collector at the surface.
03-08-93	1,659.2	Ran a bailer four times; collected a total of about 1 gallon of water.
03-08-93	1,669.2	Core between 1,659.2 and 1,669.2 ft was wet.
03-09-93	1,669.2	Water level measured at 1,606.0 ft [elapsed time between the end of the previous core run and this measurement was about 17.5 hours]. Ran bailer and collected 1 gallon of water. Water level measured at 1,605.7 ft. The water at the bottom of the borehole was air-lifted by lowering the drilling pipe and circulating air in the pipe; 50 gallons of water was collected in the sample collector at the surface. While the interval 1,628.9 to 1,640.6 ft was reamed, another volume of 50 gallons of water was collected at the surface.

Table 9. Chronological list of activities and observations pertinent to water detections in borehole UE–25 UZ#16—Continued

[---- is no data]

Date	Borehole depth, in feet	Observations
03-10-93	1,669.2	Water level measured at 1,608.7 ft [elapsed time between the end of the previous ream run and this measurement was about 17 hours]. Ran bailer and collected a water sample; bailer leaked.
03-12-93	1,686.2	Water level measured at 1,613.6 ft [elapsed time between the end of the previous core run and this measurement was about 19 hours].
03-15-93	1,686.2	Measured water level twice, at 1,588.6 ft and at 1,588.0 ft. Ran a bailer and collected a water sample; amount was not recorded. A logging tool that was run after the water-level measurements stopped after it hit bottom-hole fill at 1,650 ft.
03-17-93	1,686.2	Ran a video camera; water level was viewed at 1,603.1 ft
07-22-93	1,686.2	Ran a video camera; water level was viewed at 1,605.5 ft

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APPENDIXES

APPENDIX 1. LIST OF RECORDS

This appendix lists all records mentioned and/or used for this report. To obtain a copy of any of the listed records, contact the U.S. Department of Energy, Yucca Mountain Records Center.

Two types of records were used as information sources for this report: (1) QA records, and (2) non-QA records.

QA Records

Lithology

Title: Geslin, J.K., Moyer, T.C., and Buesch, B.C., 1995, Summary of lithologic logging of new and existing boreholes at Yucca Mountain, Nevada, August 1993 to February 1994: U.S. Geological Survey Open-File Report 94-342, 39 p.
DTN: GS931208314211.047

Detailed Fracture Log

Title: Fracture studies from geologic descriptions of cores, Volume A: borehole UE25 UZ#16
Data collected by: William Thordarson
DTN: GS950608312232.005

Scientific Notebooks

Number: 0026, UZ#16 volume
Title: Identification, Monitoring, and Sampling of Perched Water Encountered While Drilling Surface-Based Boreholes
Contents: A record of water occurrences and sampling attempts
DTN: GS960408312232.002

Well Logs

Title: Deviation log made by Eastman Teleco on March 15, 1993
Accession numbers: MOL.19950330.0245 (in-run)
MOL.19950330.0246 (out-run)
MOL.19950330.0247 (combined run)
MOL.19950330.0248 (combined run)
The above records were filed under TMBH-VARIOUS95.001

Non-QA Records

Preliminary Fracture Log

Title: Preliminary Field Composite Borehole Log, Revision 1 (08-02-93), Borehole UE-25 UZ#16
Data collected by: Drilling Support Division, Drilling Support and Sample Management Department, T&MSS
DTN: TM00000000UZ16.001

Drilling Operation Reports

A.
Title: YMP Daily Operations Report, Borehole UZ#16, Rig LM-300
Prepared by: Raytheon Services of Nevada
Contents: Daily drilling, testing, and logging records
Accession number: Job Package no. 92-03, MOL.19950330.0156

B.
Title: Record of Verbal Communication
Prepared by: Raytheon Services of Nevada
Contents: Changes to original drilling and testing plans, and discussions of problems encountered during the operation
Accession number: Job Package no. 92-03

APPENDIX 2. ADDITIONAL INFORMATION FROM BOREHOLE UE-25 UZ#16

This appendix contains a record of activities where additional information on this borehole may be found. The "Activity Name" and "SCP Sec. Number" refer, respectively, to the name of the test under which the corresponding parameter was measured and section number in the Site Characterization Plan (U.S. Department of Energy, 1988)

Permeability of Fractures

Activity Name: Site Vertical Borehole Studies, Surface-Based Air-Permeability Testing
SCP Sec. Number: 8.3.1.2.2.3.2e
Objectives: Measure pneumatic intrinsic permeability of fractures
Summary: The USGS conducted air-injection tests with a down-hole packer string; selected intervals totaling 275 meters were tested from the whole borehole and each packed-off interval was 4 meters long. Variable flow rates were used. This test was conducted prior to instrumenting the borehole with geophones.
Collected Data: Depth of tested interval, air-flow rate, injection pressure, and temperature
Date: November 3, 1993, to April 1, 1994
DTN: GS940108312232.003

Hydrologic Properties of the Rock Matrix

Activity Name: Matrix Hydrologic Properties Testing
SCP Sec. Number: 8.3.1.2.2.3.1
Objectives: Measure bulk and particle densities, sorptivity, porosity, and air permeability
Summary: The USGS collected samples of cores at the drilling site; they were packaged and transferred to the Hydrologic Research Facility (HRF) in Area 25 on the Nevada Test Site where they were tested. A gas pycnometer was used to calculate particle density and porosity.
Collected Data: Bulk density, particle density, sorptivity, porosity, and air permeability
Date: February 1 to June 30, 1993 (densities and porosity)
November 14 to December 2, 1994 (air permeability)
September 9, 1993, to July 30, 1994 (grain density and porosity)
DTN: GS940508312231.006 (densities and porosity)
GS950308312231.001 (air permeability)
GS950308312231.003 (pycnometer data)

Hydrologic Properties at High Temperatures

Activity Name: Hydrological Properties of Near-Field Environment
SCP Sec. Number: 8.3.4.2.4.2
Objectives: Measure hydrologic properties under elevated temperatures to simulate conditions close to the canisters of the nuclear waste
Summary: Hydrologic properties at elevated temperatures will be measured. Samples between the intervals 450 to 1,614 ft will be tested.
Collected Data: Not yet available
Date: Not yet available

Water Potential and Saturation in Cores and Cuttings

Activity Name: Matrix Hydrologic Properties Testing
SCP Sec. Number: 8.3.1.2.2.3.1
Objectives: Measure water potential and water content in cores and cuttings
Summary: The USGS collected samples at the drilling site; they were packaged and transferred to the Hydrologic Research Facility in Area 25 on the Nevada Test Site where they were tested.
Collected Data: Matric potential (which was assumed to be equal to water potential); water content
Date: February 1–June 30, 1993
DTN: GS940508312231.006
GS950308312231.001

Down-Hole Water Sampling for Chemical Evaluation

Activity Name: Unsaturated Zone Hydrochemistry

SCP Sec. Number: 8.3.1.2.2.7

Objectives: Determine the source and age of the ground water

Summary: Water samples were collected with a bailer. Sampling was done between drilling cycles and whenever it was suspected that free ground water was present. Not all sampling attempts were successful, as described in section on "Water-Sampling Methods." Concentrations of selected anions and cations, $^{16}\text{O}/^{18}\text{O}$ ratios, and age of water from ^{13}C , ^{14}C , and tritium concentrations in the ground water were measured.

Collected Data: Concentrations of selected anions and cations, pH, conductivity, and concentrations of ^3H , ^{16}O , ^{18}O , ^{13}C , and ^{14}C .

Date: Not yet available

DTN: Not yet available

Water Extraction from Cores

Activity Name: Unsaturated Zone Hydrochemistry

SCP Sec. Number: 8.3.1.2.2.7

Objectives: Determine the source and age of the ground water

Summary: Water samples were extracted from selected cores by squeezing in a uniaxial compression machine followed by distillation. When squeezing was not successful, only distillation was used. Concentration of selected anions and cations, $^{16}\text{O}/^{18}\text{O}$ ratios, and age of water from ^{13}C , ^{14}C , and tritium concentrations in the ground water were measured.

Collected Data: Concentrations of selected anions and cations, pH, conductivity, and concentrations of ^3H , ^{16}O , ^{18}O , ^{13}C , and ^{14}C .

Date: Not yet available

DTN: GS940908312272.002 (this data package has amount of water extracted from each sample; it does not contain chemical analyses).

Water Dating from Ream Cuttings and Sampled Water

Activity Name: Water Movement Test

SCP Sec. Number: 8.3.1.2.2.2

Objectives: Determine the source and age of the ground water

Summary: Chloride and ^{36}Cl concentrations in ream cuttings and sampled water from borehole were measured. Chloride concentrations provide an indirect measure of evapotranspiration rates and hence infiltration rates. Chlorine-36 is used to identify recent water that was generated during surface nuclear bomb tests. Chlorine-36 was chosen because it has a relatively long half-life (301,000 years).

Collected Data: Chloride, ^{36}Cl , and bromide concentrations in ream cuttings and water samples

Date: 1993 to present

DTN: LA000000000120.001

LA000000000124.001

Chemical Evaluation of Gas

Activity Name: Unsaturated Zone Hydrochemistry

SCP Sec. Number: 8.3.1.2.2.7

Objectives: Determine the source and age of ground water vapor and age of the ground air

Summary: Selected zones were isolated with borehole packers; gas was pumped out of the zones; water was extracted from the air with a cold trap; CO_2 was extracted with a molecular sieve; concentrations of ^{12}C , ^{13}C , and ^{14}C were measured.

Collected Data: Concentrations of ^3H from the water and ^{12}C , ^{13}C , and ^{14}C from CO_2 in the air

Date: Not yet available

DTN: GS940408312271.010
GS940408312271.011
GS940408312271.012

Isotope Evaluation of the Ground Water

Activity Name: Unsaturated Zone Hydrochemistry

SCP Sec. Number: 8.3.1.2.2.7

Objectives: To characterize the regional ground water and discriminate between perched and saturated zone water

Summary: The USGS collected water samples from the perched and saturated zones using a bailer; Sr concentrations and $^{87}\text{Sr} / ^{86}\text{Sr}$ ratios were measured using (1) a thermal ionization mass spectrometer, and (2) isotope dilution.

Collected Data: Four water samples were collected from the borehole; Sr concentrations and $^{87}\text{Sr} / ^{86}\text{Sr}$ ratios were measured.

Time of Test: December 20–24, 1993

DTN: GS941108315215.010

Sonic Velocity in Cores

Activity Name: Site Vertical Borehole Studies

SCP Sec. Number: 8.3.1.2.2.3.2

Objectives: Measure elastic wave velocity in core samples

Summary: Measurements of compressional and shear wave velocities were made in 53 samples at four effective stress levels (100, 300, 600, 1,000, and back to 100 psig); 49 air-dried samples were tested; four water- saturated samples were tested. Bulk density also was calculated.

Collected Data: Elastic wave velocities of shear and compressional waves; bulk densities. Dynamic elastic properties were calculated from the velocities and densities; they were: (a) shear, bulk, and Young's moduli; (b) Poisson's ratio; and (c) impedance. Depth range of samples was 46.3 to 1,681.8 ft.

Date: July 1993

DTN: GS940408312232.010

Magnetic Field and Magnetic-Susceptibility Study

Activity Name: Site Vertical Borehole Studies

SCP Sec. Number: 8.3.1.2.2.3.2

Objectives: Acquire magnetic field and magnetic susceptibility logs for hole-to-hole correlation of stratigraphic units

Summary: A USGS magnetic field logging tool with three orthogonal fluxgate magnetometers was used to record the magnetic susceptibility. Magnetometer data were acquired over the interval 1,644 to 0 ft with roughly three samples per foot. Magnetic susceptibility data were acquired every 0.2 ft, over the interval 1,644 to 0 ft.

Collected Data: Magnetic field logs and a magnetic susceptibility log as described above.

Date: April 15, 1993

DTN: GS941008314213.001

APPENDIX 3. DETAILED FRACTURE LOG

By William Thordarson

In the section on "Fracture Logs," counts of total and vuggy fractures, and median apparent dips were shown. Logging method and recorded parameters also were described. In this appendix, additional fracture information is presented.

Vugs, Fracture Apertures, and Porosity

The width and length of vugs or tension openings are measured with a ruler. In figure 11, the number of vuggy fractures at depth intervals was shown. The number of recorded vuggy fractures and fractures with tension openings was 587. The density of vuggy fractures seems to correlate positively with total fracture density, with breccias, and with slickensides. The increase in abundance of tension fractures, vugs, tension openings, and porous breccias between 760 to 1,200 ft may be due to tension fracturing caused by the possible nearby fault zone from 1,155.5 to 1,220.1 ft that was indicated by the major slickensides.

The vugs occur in veinlets in which the vugs appear to represent remaining channelways as the fracture was being filled with minerals such as calcite, stellerite, mordenite, quartz, tridymite, opal, chalcedony, and manganese oxide. These channelways were seen on cores that had split along mineralized fractures where drusy crystals or crystal surfaces indicated openings between two sides of a vein or veinlet in the process of being filled. The mineral fillings of stellerite may have some porosity between the rectangular zeolite crystals. The tridymite in the vapor phase fractures generally had a porosity of 0.05 to 0.20 along possible channelways with vapor phase mineralization. The fracture porosity of the cooling fractures appears to be least where the fractures are tightly closed, but they may have some porosity where they are broken apart slightly due to later tectonic stresses. The major and minor breccias generally had vugs and tension openings. The porosity in the breccias is probably greater than the porosity in ordinary fractures.

The widths of the vugs or openings in fractures and breccias generally were less than 3 millimeters in width; maximum observed widths were about 7 millimeters. Figure 18 shows number of fractures with different apertures relative to depth. Figure 19 shows the aperture distribution in the Tiva Canyon and the Topopah Spring Tuffs only. The fracture density of the Topopah Spring Tuff as shown in figure 19 is of the whole member, although most of the fractures with measurable apertures are concentrated in the lower part of it as shown in figure 18. The presence of vugs or openings suggests that there is some interconnected porosity that might allow flow of fluids such as air or water along permeable pathways. The extent of many of the fractures was generally not determinable away from the borehole.

A notable occurrence of water was reported to flow from porous open fractures in the depth interval 1,614.1 to 1,614.4 ft during coring operations. The main open fracture dips 65°, and it is intersected on the footwall by four open fractures that dip 12° to 28°. These fractures appeared to be natural and had some discoloration but lacked mineralization.

Slickensides and Rubble Zones

The 32 slickensides that were found in this test hole are divisible into two classes, major slickensides and minor slickensides. Major slickensides are those with traces that span across the examined fracture planes. Minor slickensides are those with traces contained within the examined fracture planes. The seven major slickensides are generally strong, brown, well-defined slickensides found at a depth of 671.6 ft in the middle nonlithophysal zone of the Topopah Spring Tuff; in depth intervals of 1,155.5 to 1,156.1 ft and 1,165.2 to 1,166.1 ft in rubble zones in the lower vitrophyre of the Topopah Spring Tuff; from 1,190.2 to 1,191.2 ft in a rubble zone in the lower partially welded to nonwelded zone in the Topopah Spring Tuff; and at a depth of 1,220.1 ft in the tuffaceous rocks of the Calico Hills Formation. These major slickensides suggest that there is a fault zone between 1,155.5 and 1,220.1 ft. The 25 minor slickensides are generally faint traces of slickensides on scattered manganese oxide spots; these minor slickensides may represent weak shearing action along some fractures. The dip of both major and minor slickensides generally ranges from 58° to 89°. A graph of the number of rubble zones and total and major slickensides per 10-ft interval is shown in figure 20.

Breccias

The number of breccias identified in this study was 135. They were subdivided into two classes: major and minor. Thirty-three major breccias and 102 minor breccias were identified. The major breccias are generally 20 to 50 millimeters in width and are usually found in rubble zones in the core boxes because the drilling reduced the weak, porous breccia to rubble fragments. Some of these major breccias may represent fault movements, but slickensides were generally found associated with them. The minor breccias are generally 1 to 5 millimeters in width along fractures and probably represent minor crushing action along the fractures. The dip of measurable major and minor breccias generally ranges from 55° to 90°.

A graph of the number of total and major breccias per 10-ft interval plotted relative to depth is presented in figure 21. The major breccias were only in the welded tuff.

Mineralogy of Coatings

The fractures were completely filled, partly filled, or sparsely filled with various minerals. Figure 22 shows the number of fractures containing minerals identified as calcite, black manganese oxide, opal or chalcedony, quartz or tridymite, and zeolites.

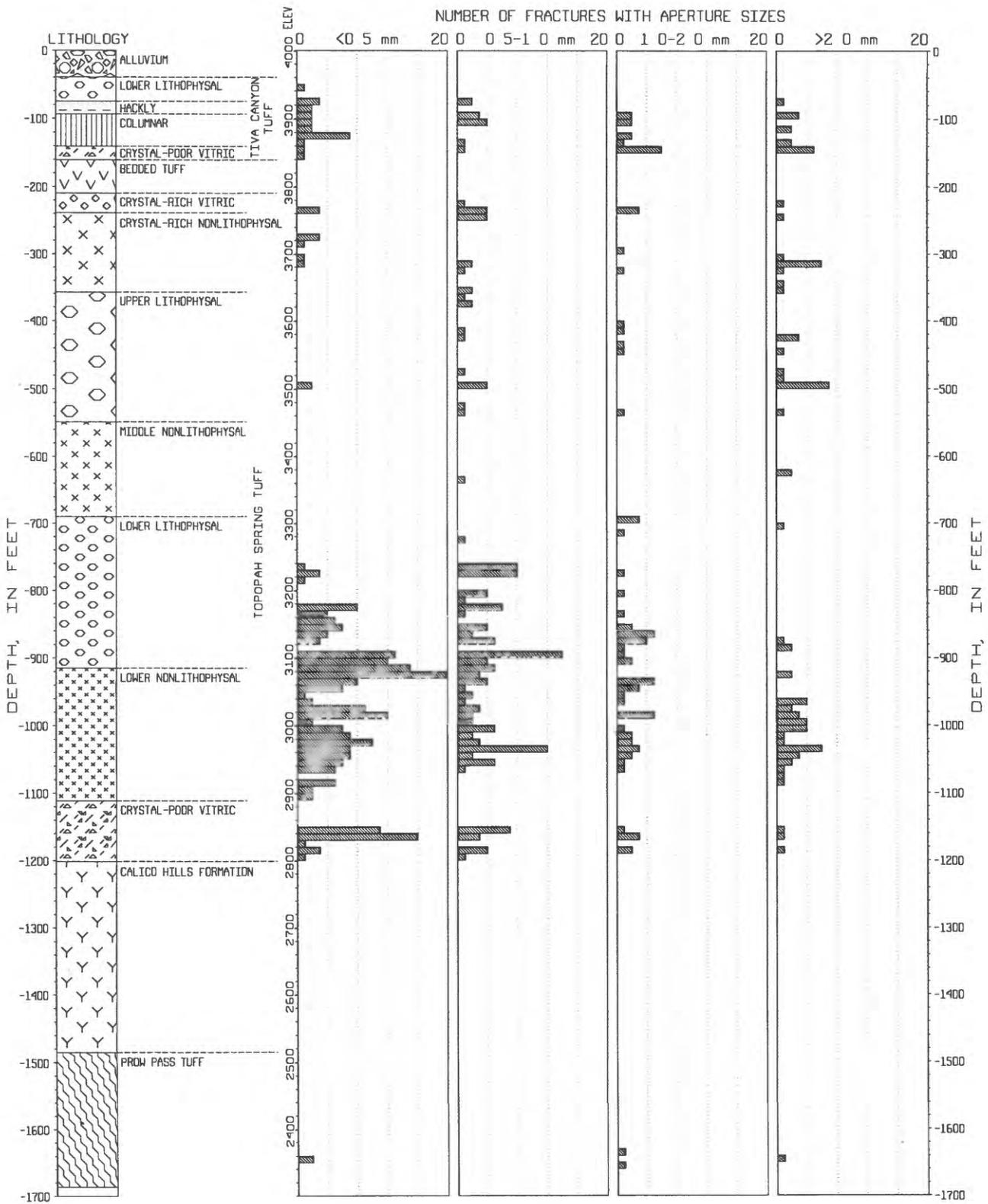


Figure 18. Lithology relative to fracture aperture from vuggy fracture count in borehole UE-25 UZ#16. Values are per 10-foot intervals. [elev: elevation, in feet; mm: millimeter] [Data Tracking Number: GS950608312232.005]

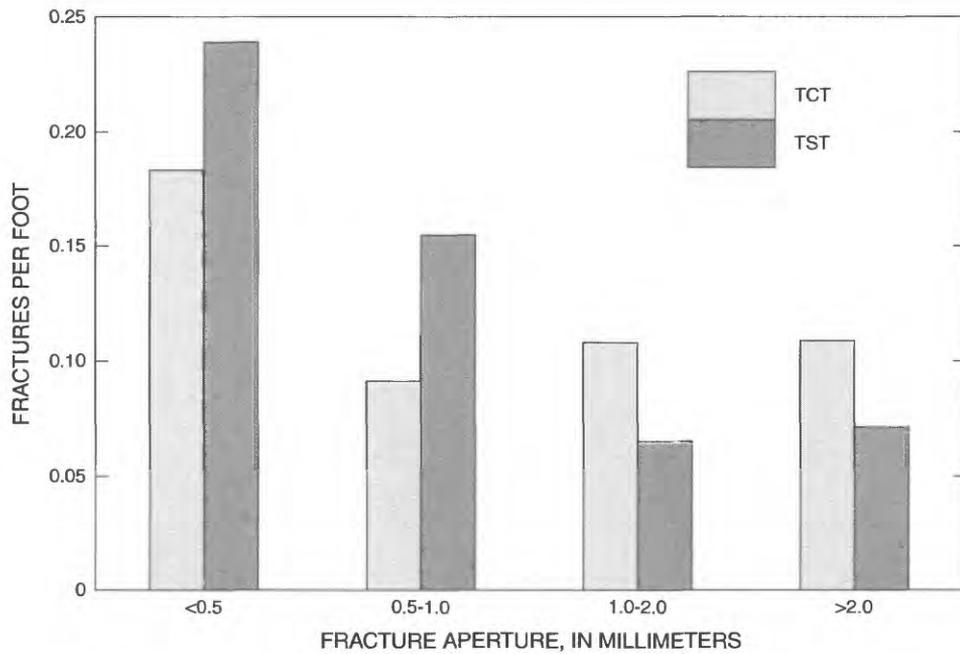


Figure 19. Distribution of aperture from vuggy fracture count in borehole UE-25 UZ#16. [TCT: Tiva Canyon Tuff; TST: Topopah Spring Tuff] [Data Tracking Number: GS950608312232.005]

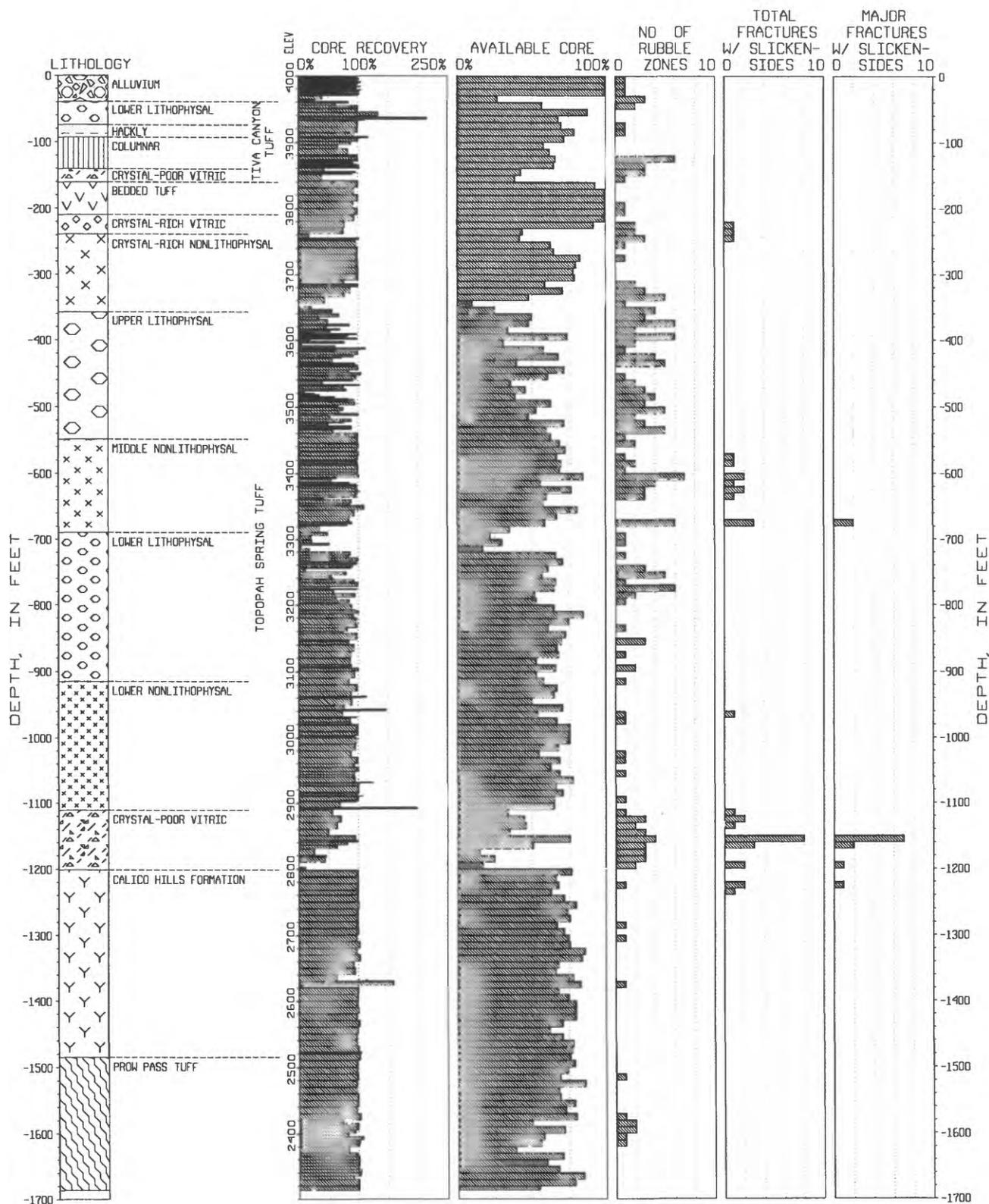


Figure 20. Lithology relative to core-recovery rate, available core for logging, number of rubble zones, and number of total and major slickensides from borehole UE-25 UZ#16. [Data Tracking Number: GS950608312232.005]

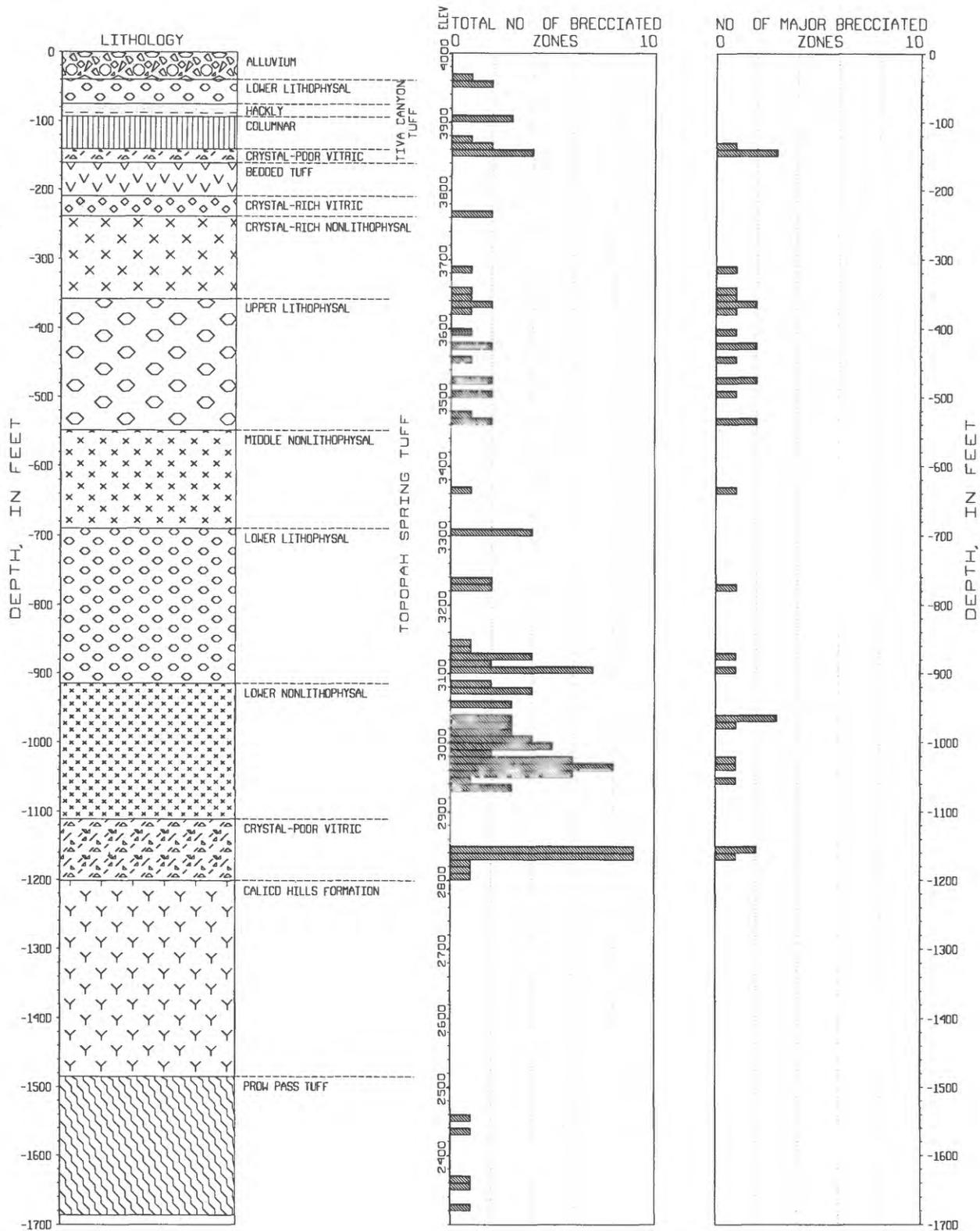


Figure 21. Lithology relative to major and total breccias in borehole UE-25 UZ#16. Values are per 10-foot intervals. [elev: elevation, in feet][Data Tracking Number: GS950608312232.005]

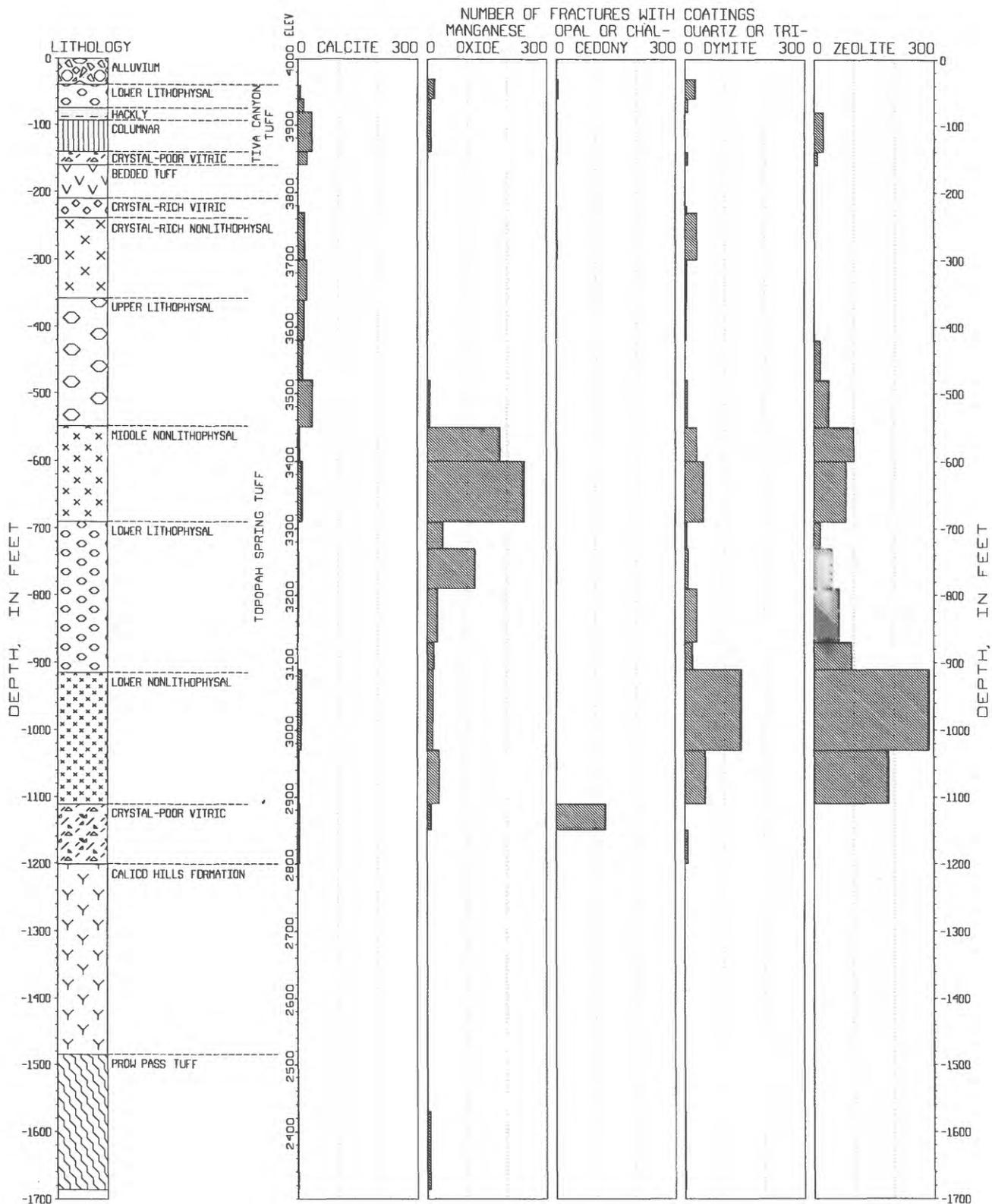


Figure 22. Lithology relative to mineralogy of fracture coatings from borehole UE-25 UZ#16. Values are per 10-foot intervals. [Data Tracking Number: GS950608312232.005]