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Analysis of Fractures in Cores from the Tuff Confining Unit beneath Yucca Flat, Nevada Test Site

March 2008

Prepared for:

U.S. Department of Energy, National Nuclear Security Administration
Nevada Site Office

Prepared by:

Lance B. Prothro
Environmental Restoration

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Abstract

The role fractures play in the movement of groundwater through zeolitic tuffs that form the tuff confining unit (TCU) beneath Yucca Flat, Nevada Test Site, is poorly known. This is an important uncertainty, because beneath most of Yucca Flat the TCU lies between the sources of radionuclide contaminants produced by historic underground nuclear testing and the regional carbonate aquifer. To gain a better understanding of the role fractures play in the movement of groundwater and radionuclides through the TCU beneath Yucca Flat, a fracture analysis focusing on hydraulic properties was performed on conventional cores from four vertical exploratory holes in Area 7 of Yucca Flat that fully penetrate the TCU.

The results of this study indicate that the TCU is poorly fractured. Fracture density for all fractures is 0.27 fractures per vertical meter of core. For open fractures, or those observed to have some aperture, the density is only 0.06 fractures per vertical meter of core. Open fractures are characterized by apertures ranging from 0.1 to 10 millimeter, and averaging 1.1 millimeter. Aperture typically occurs as small isolated openings along the fracture, accounting for only 10 percent of the fracture volume, the rest being completely healed by secondary minerals. Zeolite is the most common secondary mineral occurring in 48 percent of the fractures observed.

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List of Acronyms and Abbreviations

BN	Bechtel Nevada
cm	centimeter(s)
ft	foot (feet)
m	meter(s)
mm	millimeter(s)
NSTec	National Security Technologies, LLC
TCU	tuff confining unit
TD	total depth
UGTA	Underground Test Areas Subproject

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1.0 Introduction

This report presents results of a study of fracture characteristics of the tuff confining unit (TCU) of Yucca Flat. This work was originally conducted in 1998 and was transmitted in a Bechtel Nevada (BN) informal report to a small internal distribution. This report has been updated to meet the publication format requirements of National Security Technologies, LLC (NSTec); no new data were obtained and the results, interpretations, and conclusions are unchanged from the original report.

This study was conducted for the U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office Underground Test Area (UGTA) environmental restoration sub-project. It is part of the investigations associated with the development of groundwater flow and contaminant transport models of the Yucca Flat Corrective Action Unit at the Nevada Test Site.

1.1 Background Information

A thorough understanding of the movement of groundwater and radionuclides within the zeolitic tuffs that form the TCU beneath Yucca Flat is critical because most underground nuclear detonations in Yucca Flat were conducted within or above this important hydrogeologic unit. Beneath most of Yucca Flat the TCU separates the point sources of radionuclides (i.e., the working points of underground nuclear detonations) from the underlying regional carbonate aquifer, which is the most likely route for radionuclides in groundwater beneath Yucca Flat to exit the boundaries of the Nevada Test Site (Laczniak et al., 1996).

In the Yucca Flat-Climax Mine hydrostratigraphic framework model (BN, 2006), the TCU is divided into four hydrostratigraphic units: upper tuff confining unit, lower tuff confining unit, Oak Springs Butte confining unit, and argillic tuff confining unit. For more information on hydrogeologic and hydrostratigraphic units in and around Yucca Flat, as well as the geologic setting, see BN (2006).

The movement of groundwater within the TCU is believed to be controlled primarily by the interstitial permeability of the rocks (Winograd and Thordarson, 1975). Similarly, estimates by Winograd and Thordarson (1975) of leakage rates through the tuff aquitard (i.e., TCU) into the regional carbonate aquifer beneath Yucca Flat assume that water moves only through the matrix of zeolitic tuff, and not through fractures. However, the role fractures play in the downward leakage of water through the TCU in Yucca Flat is poorly known (Laczniak et al., 1996). This is mainly because the TCU beneath Yucca Flat is covered by younger volcanic rocks and thick valley-fill deposits, and is thus inaccessible for direct observation. Fortunately, numerous drill holes in Yucca Flat penetrate into the TCU, and many of these drill holes have conventional core (i.e., vertical rotary core samples) from the TCU available for analysis. However, no fracture analyses emphasizing hydraulic properties of fractures have previously been performed on these cores.

To gain a better understanding of the role fractures may play in the movement of groundwater and radionuclides through the TCU beneath Yucca Flat, a fracture analysis focusing on hydraulic properties was performed on conventional cores from four vertical, exploratory holes in Area 7 of Yucca Flat that fully penetrate the TCU (Figure 1-1). The holes selected for analysis are UE-7f, UE-7az, UE-7ba, and UE-7bc (Table 1-1).

Table 1-1
Core Holes Analyzed

Hole	Coordinates		Surface Elevation		Total Depth (TD)		Date TD Reached
	meters	feet	meters	feet	meters	feet	
UE-7f	N 259,845.1 E 207,114.8	N 852,510 E 680,180	1,257.0	4,124	860.8	2,824	10/21/1980
UE-7az	N 259,083.2 E 210,558.4	N 850,000 E 690,800	1,285.6	4,218	744.0	2,441	07/22/1980
UE-7ba	N 259,465.6 E 207,675.5	N 851,264 E 681,350	1,258.8	4,130	740.1	2,428	11/04/1979
UE-7bc	N 258,470.4 E 211,273.0	N 848,000 E 693,154	1,287.8	4,225	825.1	2,707	09/05/1980

Source: Raytheon Services Nevada, 1990.

This report summarizes results from the fracture analysis, providing information on fractures within a typical sequence of TCU beneath Yucca Flat. The information presented can be used to help better define parameters used in flow and transport models for the TCU beneath Yucca Flat, and also serves as a baseline for more detailed studies of the role fractures play in controlling movement of groundwater through the TCU.

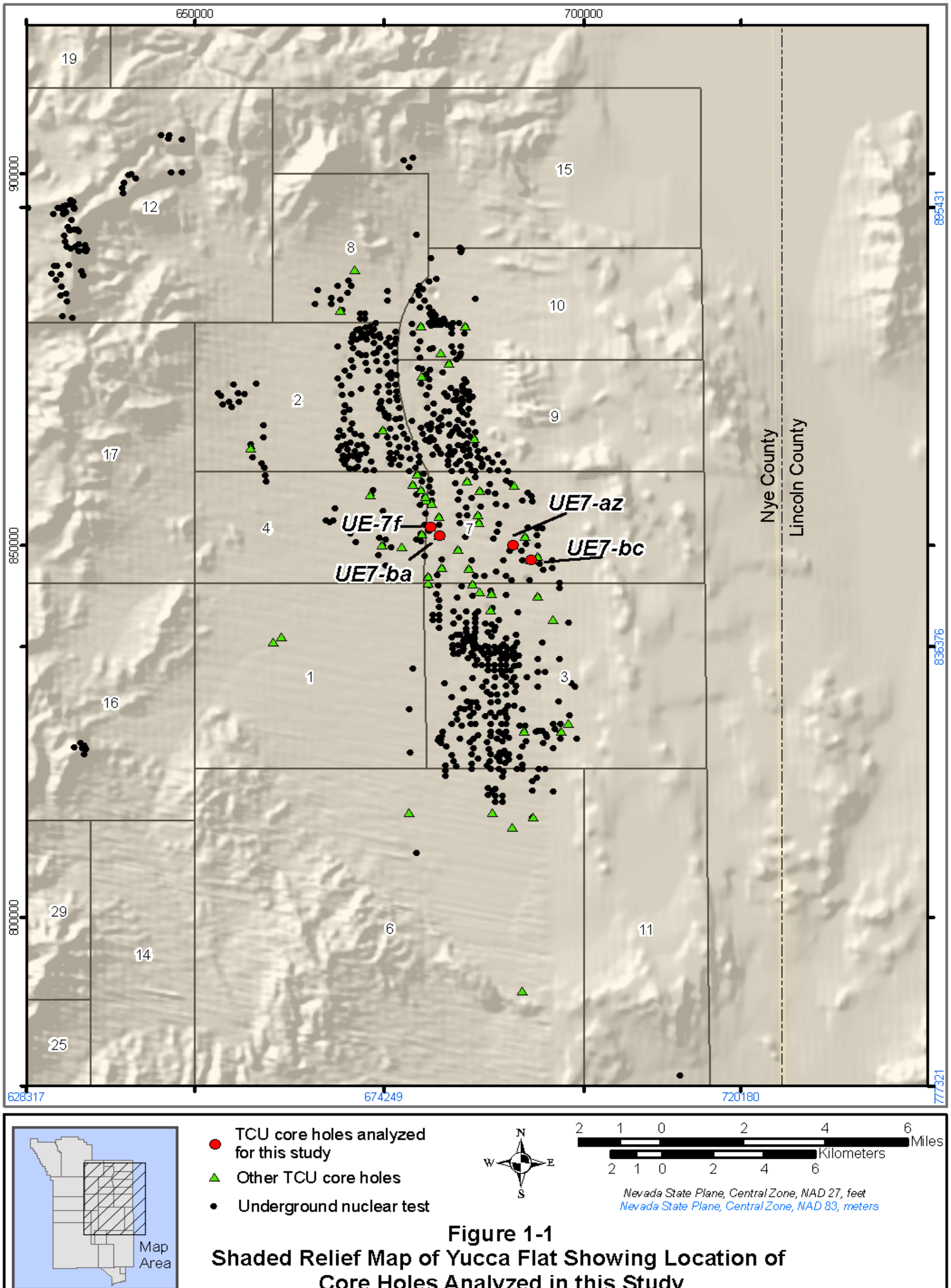

Figure 1-1
Shaded Relief Map of Yucca Flat Showing Location of Core Holes Analyzed in this Study

1.2 Objectives

The objectives of this study were:

- Examine and analyze fractures in conventional cores from the TCU beneath Yucca Flat, emphasizing attributes that are important to groundwater flow and radionuclide migration.
- Quantify observations and develop basic statistical data on fracture attributes.
- Summarize results in a report for use by the developers of the UGTA groundwater-flow and radionuclide-migration models.

1.3 Methodology

The first step of the study was to search for suitable core holes for analysis. This involved gathering and tabulating a large amount of drilling and geologic information from all the drill holes in Yucca Flat that had been at least partially cored. Because of the size of this effort and the amount of data gathered, this information has been preserved as Appendix A of this report as a reference for future geologic and hydrogeologic studies in Yucca Flat.

Core holes UE-7f, UE-7az, UE-7ba, and UE-7bc were selected for the following reasons:

- All four holes were continuously cored through a complete section of TCU.
- The TCU is greater than 300 meters (m) (1,000 feet [ft]) thick in each hole.
- The diameter of the core in each hole is less than 10 centimeters (cm) (4 inches), making the handling and examination of the core safer and less time consuming, compared with larger diameter core.

The methods used to examine and analyze fractures generally followed those outlined in Drellack et al. (1997). Table 1-2, modified from Drellack et al. (1997), provides definitions of terms used in this report.

A total of 1,842.5 m (6,045 ft) of continuous conventional core was examined at the U.S. Geological Survey Geologic Data Center and Core Library in Mercury, Nevada (Figure 1-2). Approximately 90 percent of the core from each of the four holes was available for analysis; approximately 10 percent had been packaged at the rig-site for long-term moisture preservation, and thus was unavailable for examination.

Table 1-2
Definitions of Terms Used in this Report
(Modified from Drellack et al., 1997)

Term	Definition Used in Study
Fracture	A break or crack in a rock core.
Natural Fracture	A fracture resulting from natural geologic processes. Natural fractures are usually coated or filled with secondary minerals.
Coring- and Handling-Induced Fracture	A fracture resulting from stresses created during coring or handling. Coring- and handling-induced fractures will not have secondary mineral coatings and have "fresh" appearance.
Open Fracture	A natural fracture that has open space between the sides of the fracture.
Closed Fracture	A natural fracture that is completely filled with secondary minerals, and thus has no open space along the fracture trace in the core.
Depth of Fracture	The depth below ground surface of the mid-point of the fracture recorded to the nearest tenth of a foot.
Fracture Type	Joint: Fracture without displacement. Fault: Fracture along which there has been displacement of the sides relative to one another.
Fracture Width	A representative distance in millimeters between the walls of the fracture, visually estimated as representative for the portion of the fracture exposed in the core. Fracture walls are the edges of the host rock containing the fracture.
Fracture Density	The number of fractures per vertical foot.
Fracture Orientation	The dip of the fracture. (The acute angle formed by the fracture and a horizontal plane normal to the long axis of the core, assuming the hole is vertical).
Fracture Aperture	The open distance in millimeters between the sides of the fracture, visually estimated as representative for the portion of the fracture exposed in the core. The sides may consist of the fracture walls where no secondary minerals are present, or the edges of secondary mineral coatings.
Percent Open	The estimated percent of the open space (i.e., aperture) along the entire visible portion of a fracture. When only a single fracture surface was available for examination, estimate of percent open was based on the abundance, distribution, and crystal size of the minerals observed on the fracture surface.
Secondary Mineral Coatings	Naturally occurring minerals that coat the surface of a fracture. Secondary mineralization occurs after the formation of natural fractures, and, therefore, is indicative of natural fractures.
Percent Coated	The estimated percent of the fracture surface that is coated with secondary minerals.
Surface Texture	The feel and appearance of the sides (i.e., surfaces) of a fracture. Texture was described as very smooth, smooth, rough, very rough, or slickensided. **Very Smooth**: A fracture surface that is flat and even and has a very smooth feel and appearance. **Smooth**: A fracture surface that has a very minor coarse feel and appearance. **Rough**: A fracture surface that has a coarse and somewhat jagged feel and appearance. **Very Rough**: A fracture surface that has a very coarse and jagged feel and appearance. **Slickensides**: A polished fault surface. The surface feels slick and appears glossy and shiny. Striations may be present.
Fracture Shape	The general shape of the fracture plane. Fracture shape was described as either planar continuous, curved continuous, irregular continuous, planar discontinuous, curved discontinuous, or irregular discontinuous.

Figure 1-2
A Portion of UE-7f Core Laid Out for Fracture Analysis at the U.S. Geological Survey Geologic Data Center and Core Library in Mercury, Nevada
(Core boxes are approximately 0.91 m [3 ft] long.)

Typically, core was examined megascopically; however, a 10x- to 40x-zoom binocular microscope was used for more detailed examination when necessary. Information on fracture attributes was entered on prepared, customized data sheets to assure consistency and completeness. Data collected were entered into Logplot97® log plotting software (a product of Rockware™) for graphical presentations and into an Excel® spreadsheet for statistical analysis Photographs of fractures observed in the cores were taken to provide clear illustrations of fracture attributes described and quantified during the study.

A total of 502 natural fractures was examined during the analysis. Because only natural fractures were of interest, it was necessary to differentiate between natural fractures and breaks induced during coring or handling (Figure 1-3). The presence of slickensides, offset bedding, or secondary mineral coatings on fracture surfaces is indicative of a natural fracture; therefore, all breaks in the cores were carefully examined for the presence of these characteristics (Figures 1-4 and 1-5).

Both open and closed natural fractures were examined during the analysis. The location of each fracture was recorded as the depth below ground level to the nearest tenth of a foot of the mid-point of the fracture. Each fracture was closely examined, and various attributes recorded. These included whether the fracture was a joint or fault, the shape of the fracture, surface texture, fracture width, fracture dip, size of any aperture present, percent open, presence of secondary minerals, and percent coated.

Although all fractures observed in the cores were examined and recorded, the limitations of sampling, preserving, and recognizing fractures in vertical core holes should be noted. For obvious reasons, it is impossible to obtain a representative sampling of vertical fractures in a vertical core hole. It can also be difficult to sample, preserve, and recognize large open joints and some faults in conventional core. Large open joints result in disjointed core segments, which can cause the core to jam, become highly broken, and/or cause the core to be lost. Even if the fracture is preserved in relatively good condition, it may be difficult to determine the original size of the aperture. Zones of argillic alteration and more intense fracturing are sometimes associated with faults. Such zones can also result in highly broken or missing core. The abundant clay present in argillic zones can obscure many features of the core, making it difficult to recognize individual fractures.

Note the following characteristics which are all typical of coring-induced breaks: near-vertical orientation, irregular trace, rough texture, and fresh appearance of the break surfaces. Core is from the 278.3-m (913-ft) depth in hole UE-7bc

Figure 1-3
Coring-Induced Breaks

Note the near-vertical orientation and rough surface texture of this fracture, very similar to that shown in Figure 1-3. However, also note the secondary mineral coatings of white zeolite on the fracture surfaces, indicating that this is a natural fracture that broke apart during coring. Core is from the 489.2-m (1,605-ft) depth in hole UE-7az.

Figure 1-4
Natural Fracture

Note the striated secondary mineral coatings of reddish-orange iron oxide and white zeolite.
Core is from the 544.4-m (1,786-ft) depth in hole UE-7az.

Figure 1-5
Natural Fracture with Well Developed Slickensides

1.4 Acknowledgments

Several people provided critical support and assistance during this study. Jose Gonzales helped in recording fracture attributes and entering data into a spreadsheet format. Joel Metcalf produced statistical data on fracture attributes. Dawn Haugstad provided Figure 1-1. Appendix A was produced mainly through the efforts of Sigmund Drellack and Jose Gonzales. Margaret Townsend assisted with document preparation.

Access to the core analyzed during this study was facilitated by the staff of the U.S. Geological Survey's Geologic Data Center and Core Library in Mercury, Nevada.

The following people performed technical reviews of this report and provided insightful and constructive suggestions: Gayle Pawloski of Lawrence Livermore National Laboratory, Chuck Russell of the Desert Research Institute, Wayne Belcher of the U.S. Geological Survey, and Greg Ruskauff of Stoller-Navarro Joint Venture.

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2.0 Fracture Attributes

This section describes and lists basic statistics for fracture attributes observed in core holes UE-7f, UE-7az, UE-7ba, and UE-7bc. The information provided in this section emphasizes fracture characteristics important to groundwater flow and radionuclide migration within the TCU, such as spacing, aperture, and secondary mineral coatings.

2.1 Types of Fractures

Seventy-two percent of the fractures observed were classified as joints, and 28 percent as faults (Table 2-1). Many of the joints have subtle, indistinct linear textures along their surfaces, and thus may actually be faults (Figure 2-1). Consequently, faults may represent a larger percentage of the fractures observed than indicated in Table 2-1.

Table 2-1
Types of Fractures

Type of Fracture	Core Hole				Average for All Four Core Holes
	UE-7f	UE-7az	UE-7ba	UE-7bc	
Joint	71%	66%	82%	76%	72%
Fault	29%	34%	18%	24%	28%

Most of the faults have poorly-developed slickensides, and less than 1 cm of normal offset (Figure 2-2). This indicates that most of the faults probably represent small, normal, dip-slip adjustments related to regional normal faulting, or to differential compaction.

2.2 Fracture Shape and Orientation

More than half of the fractures observed cut completely through the core along a straight plane, and thus were classified as planar and continuous in shape (Table 2-2). These fractures form a straight elliptical trace around the outside of the core (Figure 2-3). Other fractures were observed to be curved or irregular in shape (Figure 2-4). Almost 30 percent of the fractures appear to end within the core, and thus were classified as discontinuous.

Table 2-2
Shapes of Fractures

Fracture Shape	Core Hole				Average for All Four Holes
	UE-7f	UE-7az	UE-7ba	UE-7bc	
Planar and Continuous	60%	46%	45%	41%	51%
Curved and Continuous	8%	8%	9%	10%	8%
Irregular and Continuous	11%	6%	21%	17%	12%
Planar and Discontinuous	11%	10%	15%	9%	11%
Curved and Discontinuous	1%	8%	3%	3%	4%
Irregular and Discontinuous	9%	22%	7%	20%	14%

Fracture shape provides information on fracture interconnectivity and the tortuosity of flow paths through the fracture, as well as through the host rock itself. Fractures with planar shapes are characteristic of systematic fracture sets (Twiss and Moores, 1992). Systematic fractures tend to be straighter, more through-going, and extensive. Thus, if open, they provide more direct flow paths. Curved or irregular shapes are characteristic of nonsystematic fractures. Nonsystematic fractures tend to terminate against systematic fractures, and thus may provide important interconnective pathways between systematic fractures. However, flow paths within nonsystematic fractures will be considerably more tortuous than those in systematic fractures.

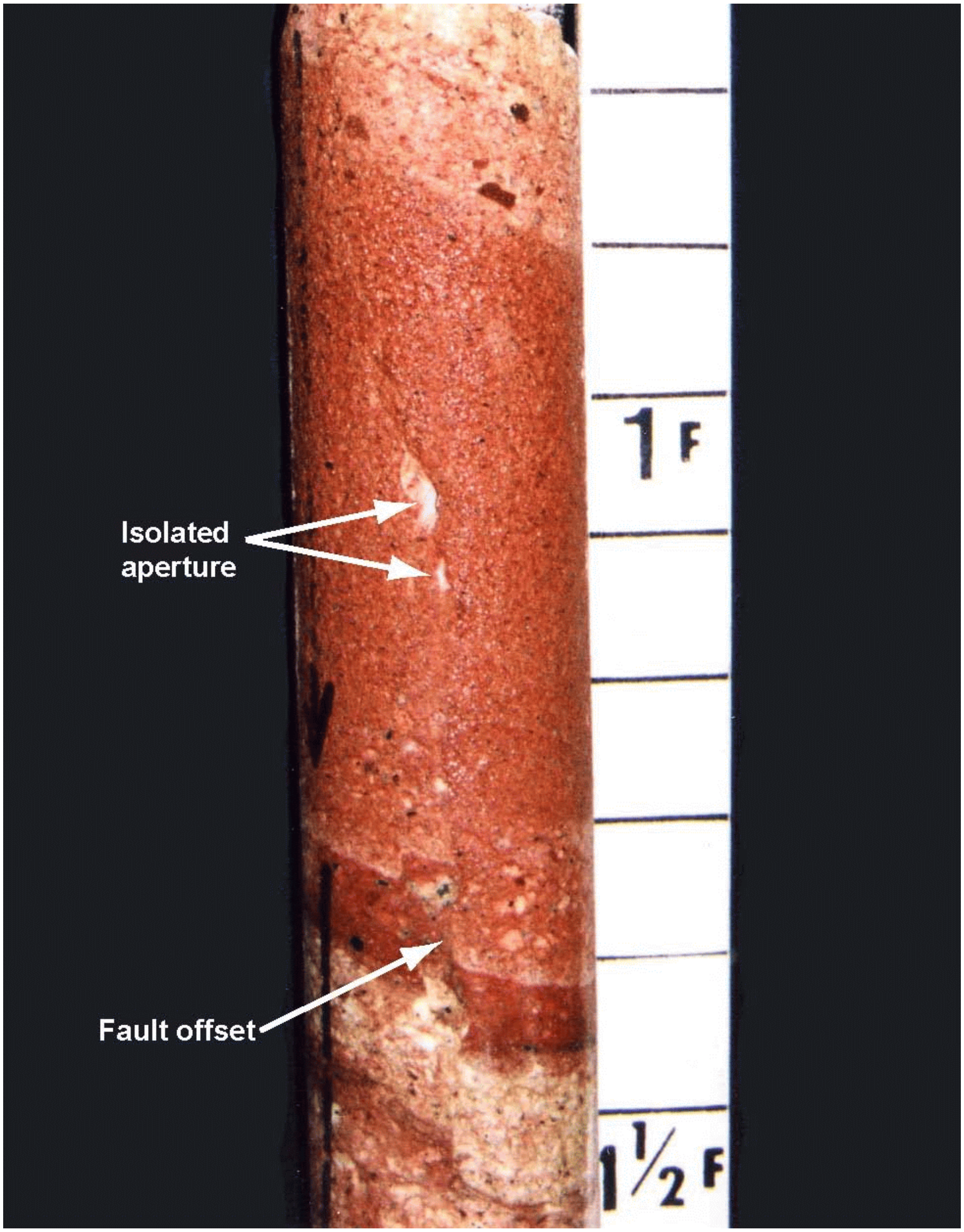
The dips of fractures range from 15° to vertical (90°). These values should be considered approximations because dip determinations assume the core hole is perfectly vertical. Table 2-3 shows that the average dip of the fractures for all four holes is 69°.

Table 2-3
Dips of Fractures

Fracture Dip	Core Hole				Average for All Four Holes
	UE-7f	UE-7az	UE-7ba	UE-7bc	
Average Dip of Fractures	69^0	64^0	69^0	75^0	69^0

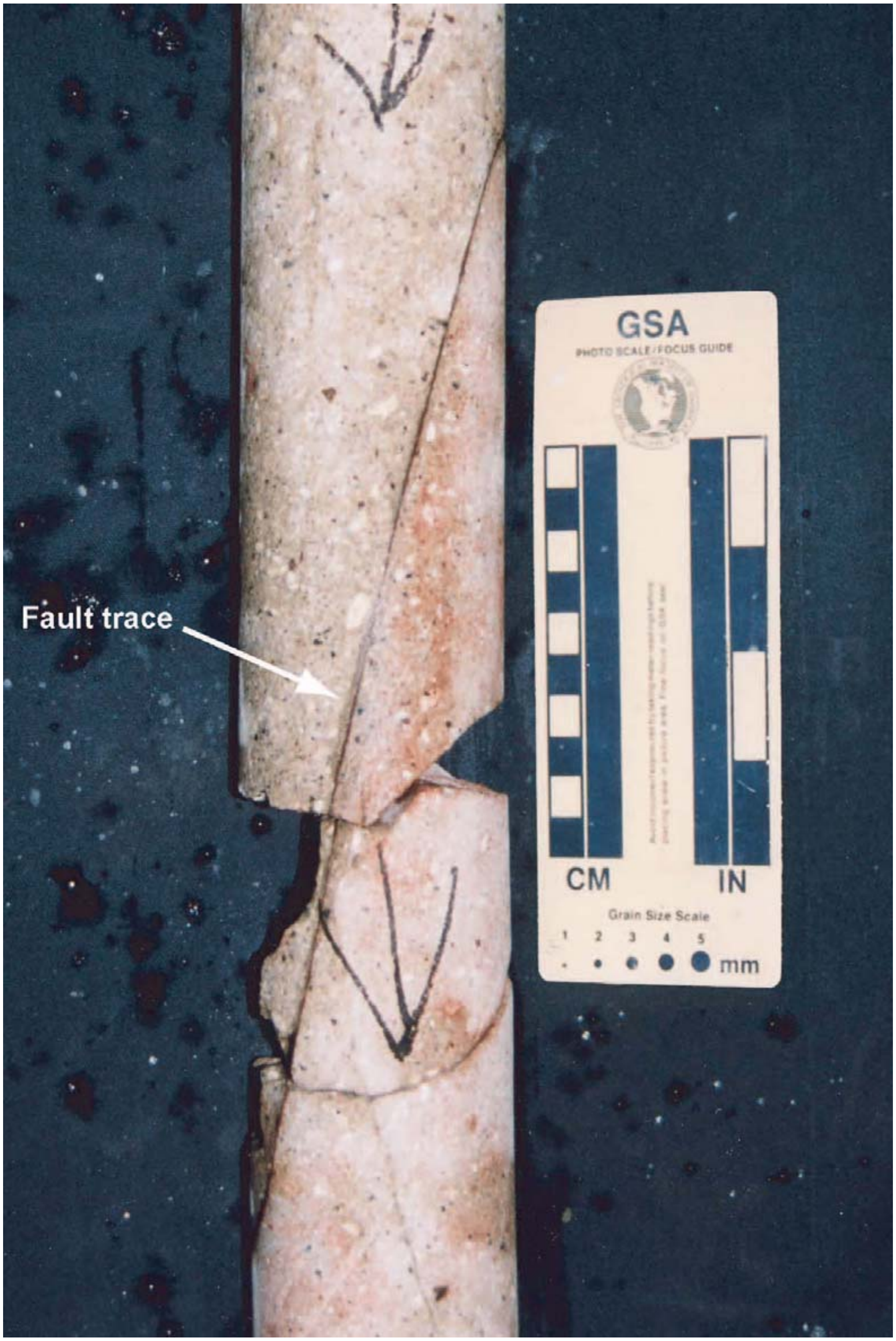
Core is from the 425.5-m (1,396-ft) depth in UE-7az.

Figure 2-1
Natural Fracture Showing a Subtle Linear Texture on Fracture Surfaces



Note 1-cm offset of bedding at bottom of photograph. Also note the discontinuous trace with isolated aperture. Core is from the 557.5-m (1,829-ft) depth in hole UE-7az. Core was moistened prior to photographing to better reveal details.

Figure 2-2
Small Normal Fault



This fracture is a fault dipping 75°. Note the thin (0.5 millimeter) width, planar and continuous shape, and lack of any visible aperture. Fault appears to be filled with metallic oxides. Black arrows on core point down-hole. Core is from the 538.6-m (1,767-ft) depth in hole UE-7f.

Figure 2-3
Natural Fracture with a Planar, Continuous Shape

This irregular, continuous fracture is completely filled with white zeolite. Core is from the 628.8-m (2,063-ft) depth in hole UE-7f. Core was moistened prior to photographing to better reveal details.

Figure 2-4
Natural Fracture with an Irregular, Continuous Shape

Because core orientation had not been marked on the cores during drilling, it is impossible to determine strike of the fractures or the direction of dip. However, it is reasonable to assume that many of the fractures formed in response to the same stresses as the larger structures mapped at the surface and in the subsurface in the vicinity of Yucca Flat, and thus are oriented similarly. Most faults in the Yucca Flat vicinity strike in a northerly direction and dip steeply in either eastward or westward (Frizzell and Shulters, 1990).

2.3 Fracture Density and Spacing

Figures 2-5 through 2-8 show the vertical distribution of fractures in the four core holes. The stratigraphic and lithologic columns are based on original unpublished detailed lithologic logs held in the weapons testing program files at NSTec. Stratigraphic nomenclature was updated where appropriate using nomenclature from Ferguson et al. (1994). The figures show that greater fracture densities generally are seen in rocks older than the Grouse Canyon Tuff. The distribution of fractures appears to be independent of lithology. The general scarcity of fractures observed in the argillic rocks, particularly in UE-7az, is probably due partly to the difficulty in recognizing fractures in the highly altered and mechanically broken core segments of these rocks (Figure 2-9). In any case, the intense argillic alteration observed in many of these rocks probably precludes the formation and existence of extensive open fractures. This is due to the non-brittle character of argillic tuffs, and the likelihood that any fractures that are present are filled with clay. The latter condition is observed in the underlying Paleozoic-age carbonate rocks where fractures in carbonate rocks that directly underlie the argillic tuffs are completely filled with clay (Figure 2-10).

Tables 2-4a and 2-4b show that 502 fractures were observed in 1,842.5 m (6,045 ft) of core. Of these, 116 fractures, or 23 percent, were observed to be at least partially open (i.e., observed to have some aperture). Drill holes UE-7f and UE-7az show the highest density of fractures, at about 0.43 fractures per vertical meter of core (0.13 fractures per vertical foot of core), followed by UE-7ba and UE-7bc at 0.19 and 0.12 fractures per vertical meter of core (0.06 and 0.04 fractures per vertical foot of core), respectively. The average fracture density for all four holes is 0.27 fractures per vertical meter of core (0.08 fractures per vertical foot of core).

The density of open fractures in each of the four holes is considerably less than that for all fractures (Tables 2-4a and 2-4b). Densities for open fractures range from an average of 0.12 fractures per vertical meter of core (0.04 fractures per vertical foot of core) in UE-7f to 0.01 fractures per vertical meter of core (0.004 fractures per vertical foot of core) in UE-7bc. The average for all four holes is 0.06 fractures per vertical meter of core (0.02 fractures per vertical foot of core).

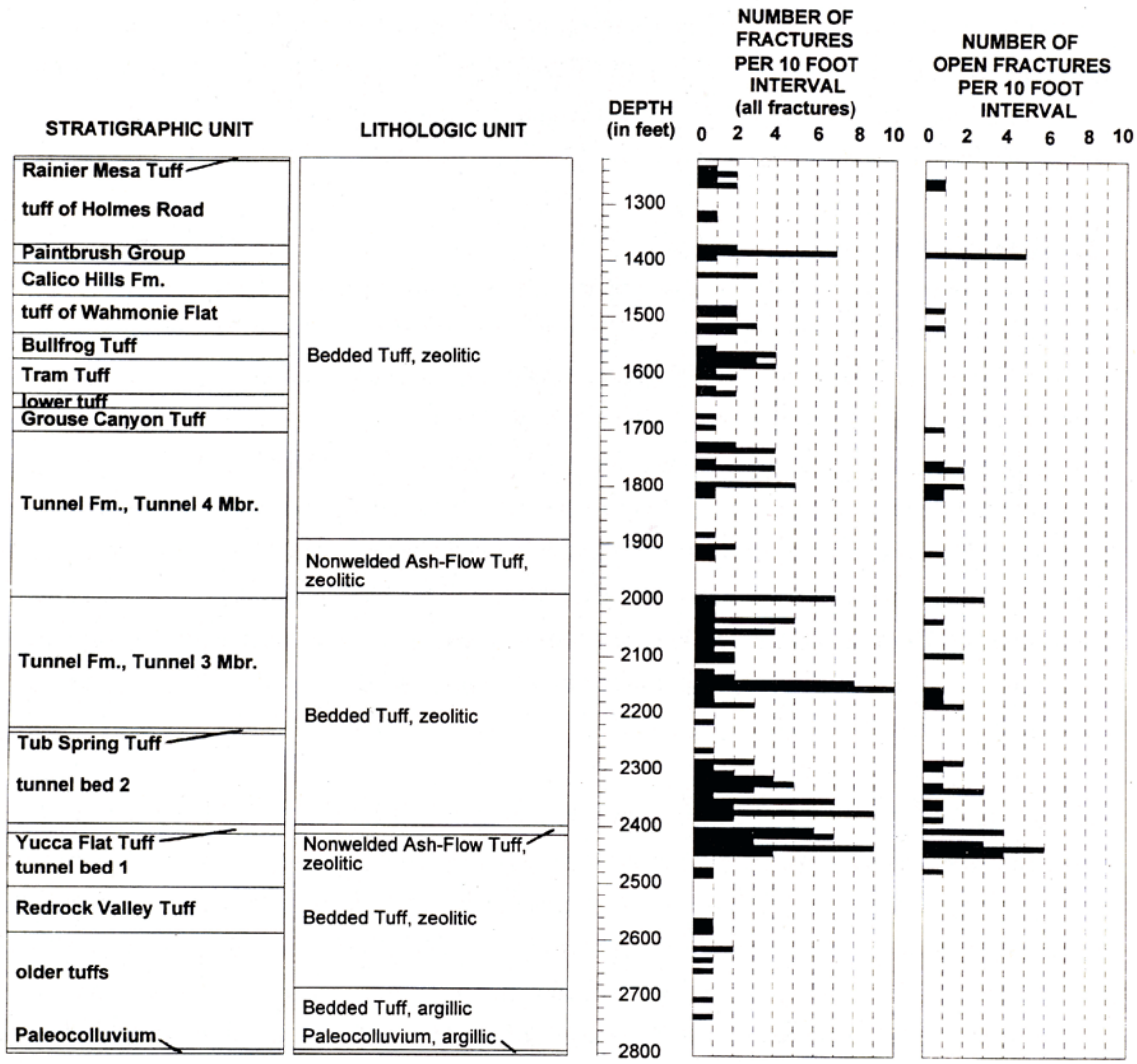


Figure 2-5
Vertical Distribution of Fractures within the TCU in UE-7f

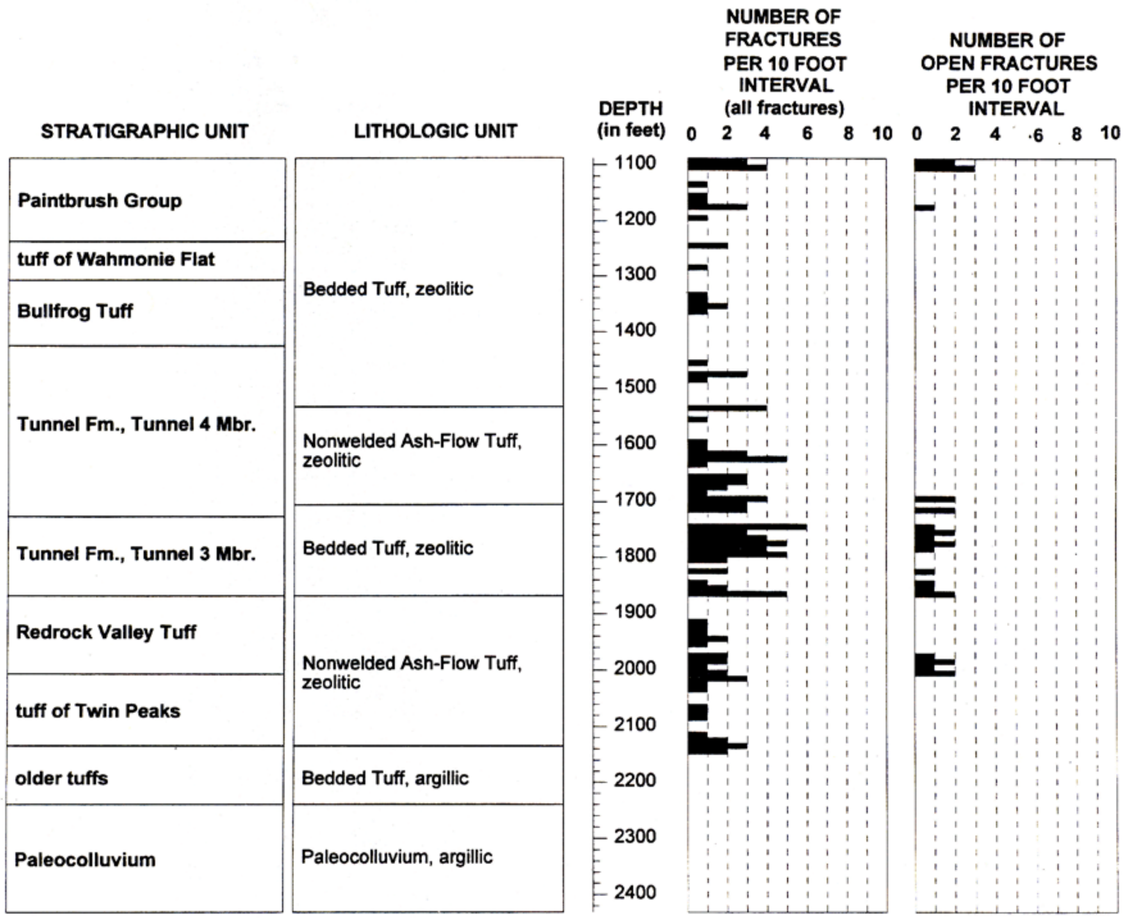


Figure 2-6
Vertical Distribution of Fractures within the TCU in UE-7az

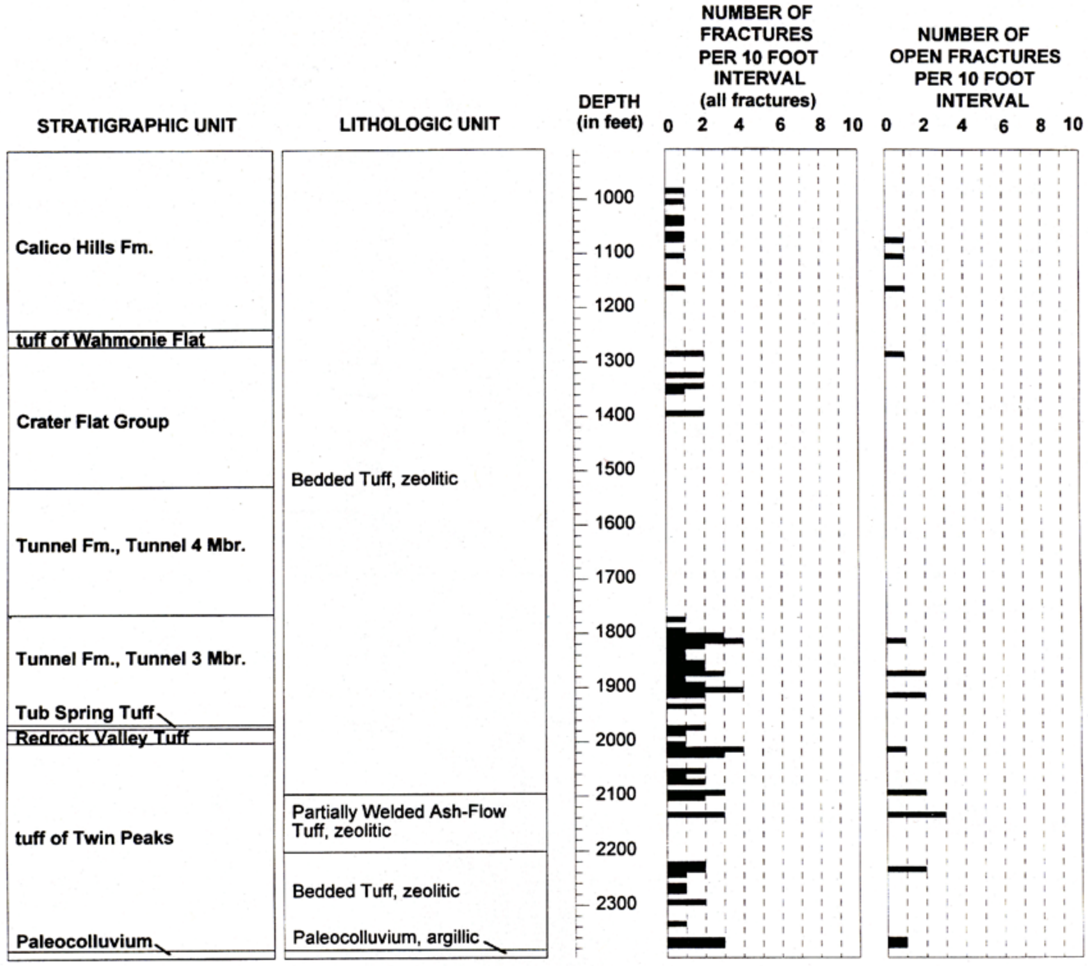


Figure 2-7
Vertical Distribution of Fractures within the TCU in UE-7ba

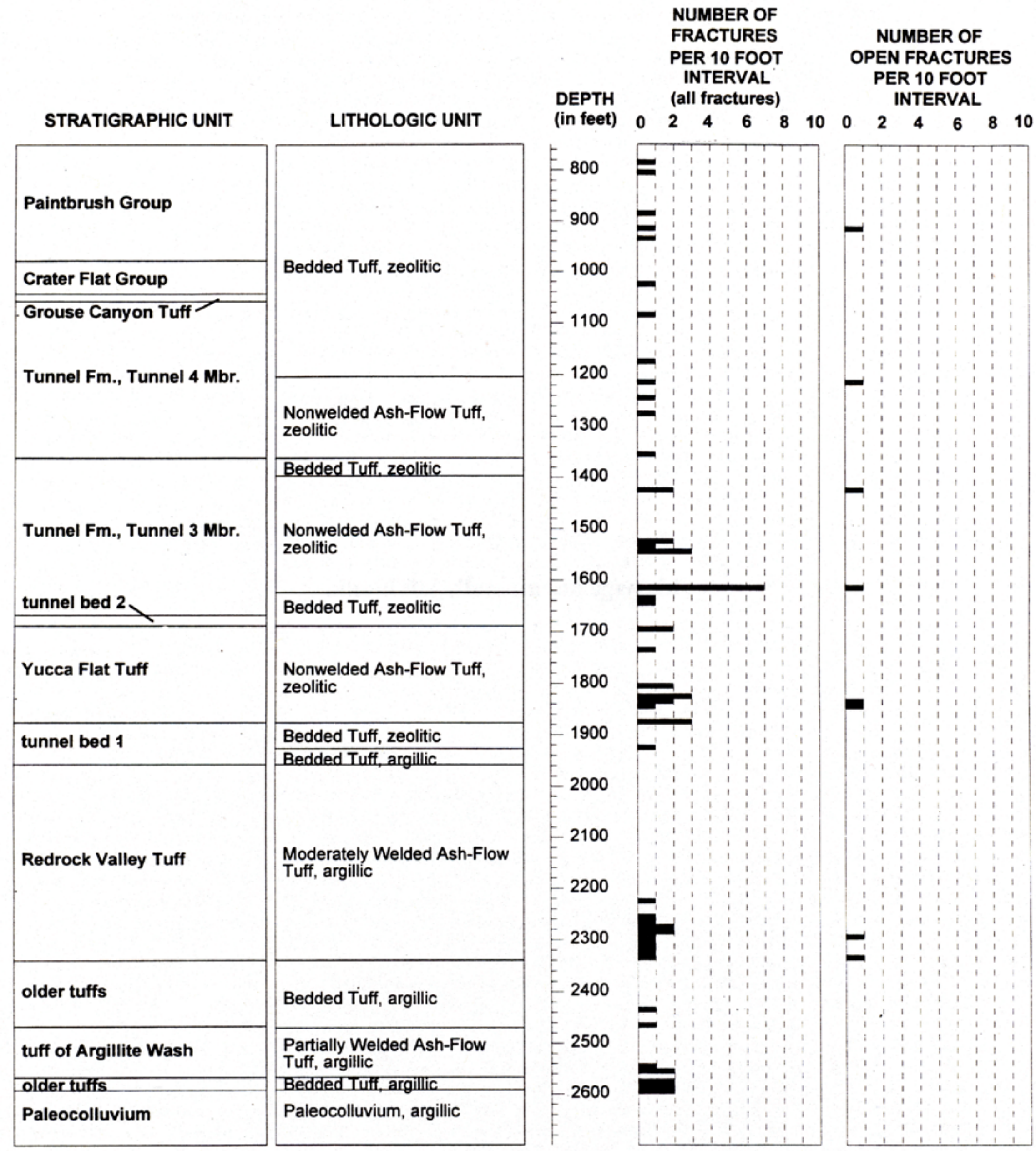
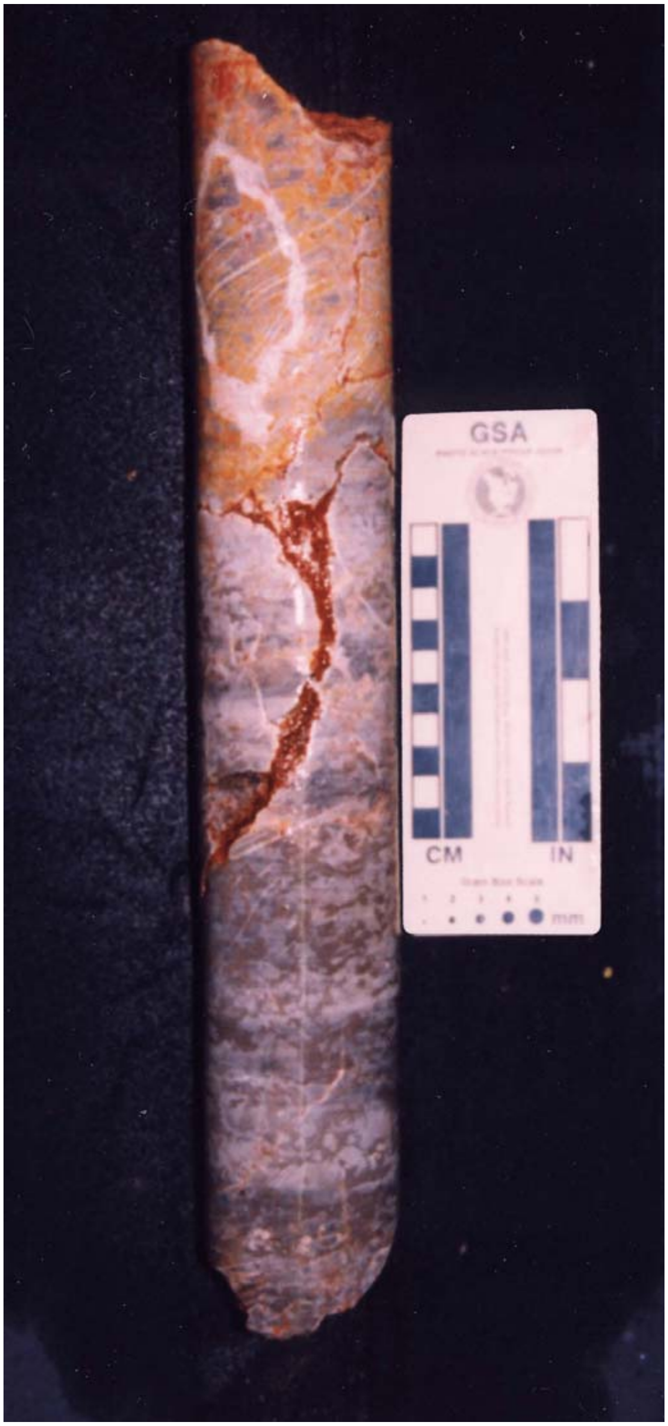


Figure 2-8
Vertical Distribution of Fractures within the TCU in UE-7bc

This core was highly broken up during the coring process. Sample is from the interval 838.8 to 841.9 m (2,752 to 2,762 ft) in UE-7f.

Figure 2-9
Argillic Tuff Showing Highly Broken Character



Note the reddish-brown clay that fills fracture in gray limestone. This fracture is at the very top of the Pre-Tertiary section in this core hole. Highly argillized, reddish-brown, tuffaceous paleocolluvium directly overlies the Pre-Tertiary rocks and is probably the source of the clay. Core is from the 730.9-m (2,398-ft) depth in UE-7ba. Core was moistened prior to photographing to better reveal details.

Figure 2-10
Clay-Filled Fracture in Paleozoic-Age Limestone

Table 2-4a
Fracture Density and Spacing
(in meters)

Attribute	Core Hole				Total/Average for All Four Holes
	UE-7f	UE-7az	UE-7ba	UE-7bc	
Total Length of Interval Analyzed	477.0 m	322.5 m	449.0 m	594.1 m	1,842.5 m (Total)
Number of Fractures Observed	211	134	87	70	502 (Total)
Number of Open Fractures Observed	58	31	19	8	116 (Total)
Percent of Fractures that are Open	27%	23%	22%	11%	23% (Average)
Fracture Density (number of fractures per vertical meter of core)	0.44	0.42	0.19	0.12	0.27 (Average)
Density of Open Fractures (number of open fractures per vertical meter of core)	0.12	0.10	0.04	0.01	0.06 (Average)
Apparent Spacing, All Fractures (vertical distance between fractures)	2.2 m	2.4 m	4.9 m	8.0 m	3.5 m (Average)
Apparent Spacing, Open Fractures Only (vertical distance between fractures)	6.8 m	9.4 m	21.9 m	62.3 m	13.6 m (Average)
True Spacing, All Fractures	0.8 m	1.1 m	1.7 m	2.1 m	1.3 m (Average)
True Spacing, Open Fractures Only	2.4 m	4.2 m	7.7 m	16.1 m	5.0 m (Average)

Table 2-4b
Fracture Density and Spacing
(in feet)

Attribute	Core Hole				Total/Average for all Four Holes
	UE-7f	UE-7az	UE-7ba	UE-7bc	
Total Footage Analyzed	1,565 ft	1,058 ft	1,473 ft	1,949 ft	6,045 ft (Total)
Number of Fractures Observed	211	134	87	70	502 (Total)
Number of Open Fractures Observed	58	31	19	8	116 (Total)
Percent of Fractures that are Open	27%	23%	22%	11%	23% (Average)
Fracture Density (number of fractures per vertical foot of core)	0.13	0.13	0.06	0.04	0.08 (Average)
Density of Open Fractures (number of open fractures per vertical foot of core)	0.04	0.03	0.01	0.004	0.02 (Average)
Apparent Spacing All Fractures (vertical distance between fractures)	7 ft	8 ft	16 ft	26 ft	12 ft (Average)
Apparent Spacing Open Fractures Only (vertical distance between fractures)	22 ft	31 ft	72 ft	204 ft	45 ft (Average)
True Spacing, All Fractures	3 ft	4 ft	6 ft	7 ft	4 ft (Average)
True Spacing, Open Fractures Only	8 ft	14 ft	25 ft	53 ft	16 ft (Average)

Tables 2-4a and 2-4b show that cores from holes UE-7f and UE-7az have greater densities of fractures than cores from UE-7ba and UE-7bc. The reason for the greater densities is uncertain. However, underground nuclear testing can be ruled out as the cause of the differences because almost all the fractures recorded have secondary minerals associated with them, and thus are natural fractures. Fractures are often associated with other structural features, such as faults

(Twiss and Moores, 1992). Therefore, the difference in densities could be related to the position of the holes relative to the larger, basin-forming faults in Yucca Flat. However, a look at the position of the core holes relative to faults mapped at the surface and in the subsurface in Yucca Flat revealed no obvious relationships between fracture densities and the position of the holes relative to these faults.

The apparent fracture spacing (i.e., vertical distance between fractures) for all fractures ranges from an average of 2.2 m (7 ft) in UE-7f to 8.0 m (26 ft) in UE-7bc. The average for all the holes is 3.5 m (12 ft). Using an average dip of 69°, the 3.5 m (12 ft) average apparent fracture spacing can be corrected to an average true spacing of 1.3 m (4 ft). However, this corrected value is a minimum, as it assumes all the fractures belong to the same fracture set and have similar orientations.

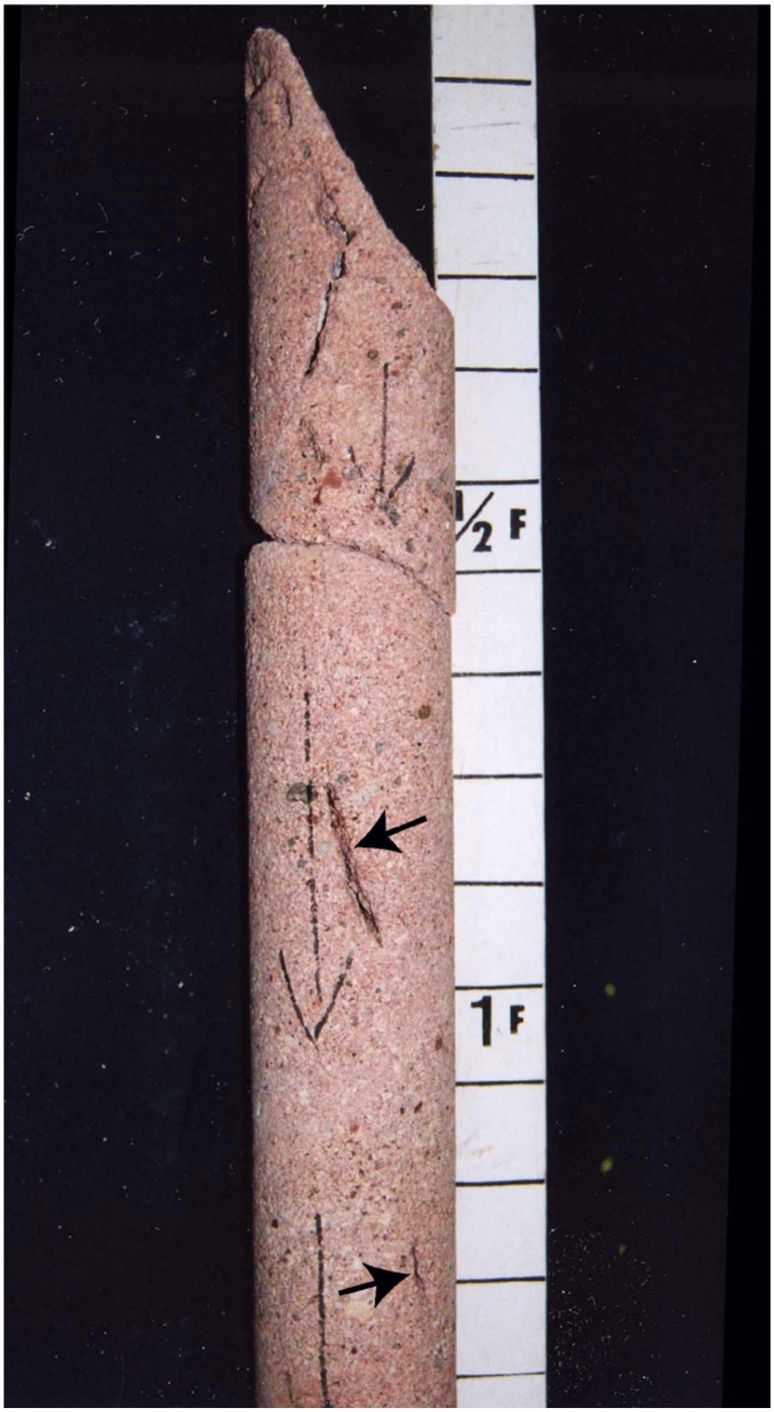
Considering only open fractures, the apparent fracture spacing ranges from 6.8 m (22 ft) in UE-7f to 62.3 m (204 ft) in UE-7bc, averaging 13.6 m (45 ft) for all the holes. Again, using an average dip of 69°, the average true spacing (i.e., the minimum distance between parallel fractures) of open fractures for all the holes is 5.0 m (16 ft).

2.4 Fracture Width, Aperture, and Openness

Fractures range in width from 0.1 to 10 millimeters (mm), averaging 0.8 mm (Table 2-5). Some fractures have no visible trace, and were recognized only by an obvious alignment of openings along the outside of the core (Figure 2-11). In addition, it seemed that some fractures might not have been recognized if the core had not broken along the fracture to reveal thin secondary mineral coatings along the fracture surface.

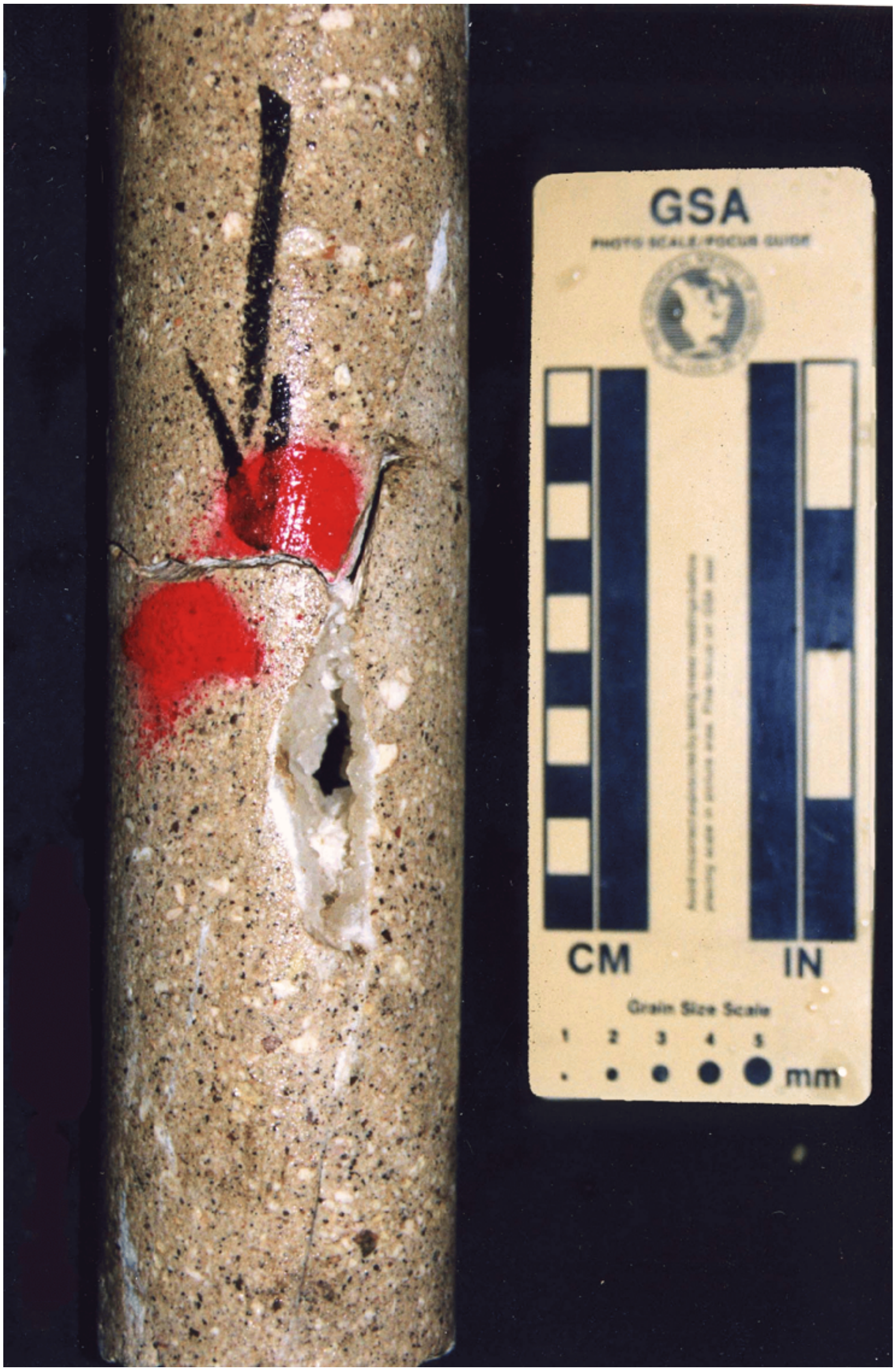
Aperture ranges from 0.1 mm or less to 10 mm, averaging 1.1 mm. Aperture generally appears as small isolated openings along the trace of the fracture (Figures 2-2 and 2-11). Only a few large (greater than 5 mm) through-going openings were observed (Figure 2-12). On average, fractures with aperture consist of only 10 percent open space (i.e., aperture).

Some of the aperture observed may have resulted from minor movement along fault planes. Openings formed by separation along small steps in the fault plane could have formed isolated aperture along the fault.



Note alignment of aperture (small black arrows) along outside of core with no visible trace connecting aperture. Large black arrows on core show down-hole direction. Cores is from the 562.4-m (1,845-ft) depth in hole UE-7az.

Figure 2-11
Alignment of Aperture Along Outer Surface of Core



Opening is 1 cm wide. Note coarsely crystalline calcite that partially fills opening. Red paint indicates core was purposely broken during the boxing process. Black arrow on core indicates down-hole direction. Core is from the 423.2-m (1,388.5-ft) depth in UE-7f. Core was moistened prior to photographing to better reveal details.

Figure 2-12
Fracture with Large, Through-Going Aperture

Table 2-5
Fracture Width, Aperture, and Openness

Attribute	Core Hole				Average for All Four Holes
	UE-7f	UE-7az	UE-7ba	UE-7bc	
Range of Fracture Widths (in millimeters)	0.1 - 10	0.1 - 10	0.1 - 5	0.1 - 10	--
Average Width of Fractures (in millimeters)	0.8	0.9	0.9	0.7	0.8
Range of Aperture Sizes (in millimeters)	0.3 - 10	0.1 - 3	0.1 - 2	0.3 - 2	--
Average Aperture Size (in millimeters)	1.4	0.9	0.6	0.8	1.1
Range of Percent of Fracture that is Open	0.5 - 75%	1 - 50%	1 - 25%	1 - 25%	--
Average Percent of Fracture that is Open	9%	13%	10%	7%	10%

2.5 Fracture Surface Texture

Most of the fractures have surfaces that are rough or very rough (Figure 1-4). Surface textures of joints appear to be related to the grain size of the unit. Coarser grained units that consist of large pumice and lithic fragments typically have joints with rough fracture surfaces. Coarse-grained bedded tuffs are common in all four holes, which accounts for the high percentage of rough fracture surfaces observed. The surface textures of faults appear to be dependent not only on the grain-size of the unit, but also on the degree of development of the fault surface. Faults in coarse-grained units and with poorly developed slickensides typically have rough fracture surfaces. However, some faults in coarse-grained units have well developed slickensides, and thus have very smooth fracture surfaces.

The texture of fracture surfaces can have a significant affect on ground water flow and radionuclide migration through fractures. For example, rough textures result in more tortuous flow paths along fractures, and increase the surface area of fractures, which could have important implications with regards to sorption of radionuclides.

2.6 Secondary Mineral Coatings

Almost all fractures observed were coated or filled with some type of secondary mineral, with many fractures containing more than one type of secondary mineral (Figure 2-13). Zeolite occurs most often, being observed in 48 percent of the fractures examined (Table 2-6). Zeolite is typically white, chalky to slightly waxy, and very fine-grained (Figure 2-14).

Metallic oxides were the second most common secondary mineral observed. They occur in 37 percent of the fractures examined. The metallic oxides typically occur as thin reddish-brown to black coatings and staining along fracture walls. Although quite common, metallic oxides often occur in minor abundance with other secondary minerals. Iron oxides appeared to be the most common metallic oxide observed with manganese oxide (Figure 2-15) being somewhat less common.

Crystalline quartz was observed in 14 percent of the fractures (Figure 2-16). It is most common below approximately 609.6 m (2,000 ft), where it occurs as subhedral crystals up to 1 mm in size, or as very-fine-grained material with a sugary texture. Other secondary minerals observed included calcite, chalcedony, and clay.

The identification of secondary minerals was based solely on visible characteristics of the minerals. No laboratory analyses were performed.

This 1-cm-wide fracture is completely filled with quartz, calcite, and very minor iron oxide (red color). Quartz is the most abundant secondary mineral, and was the first to form in this fracture. Calcite was deposited in lesser amounts within cracks and openings in the quartz probably caused by reactivation of the fracture. Iron oxide is associated with the quartz. Core is from the 776.2-m (2,546.5-ft) depth in UE-7bc. Core was moistened prior to photographing to better reveal details.

Figure 2-13
Fracture Filled with Quartz, Calcite, and Iron Oxide

Table 2-6
Secondary Minerals Observed Visually in Fractures

Secondary Mineral	Core Holes				Average for All Four Holes
	UE-7f	UE-7az	UE-7ba	UE-7bc	
None	11%	5%	6%	10%	8%
Zeolite	44%	41%	58%	66%	48%
Chalcedony	1%	3%	3%	3%	2%
Metallic oxides	44%	40%	31%	14%	37%
Calcite	4%	4%	13%	13%	7%
Fault gouge	2%	6%	2%	0%	3%
Crystalline quartz	16%	10%	9%	19%	14%
Clay	0%	4%	0%	0%	1%
Unknown	0%	5%	0%	0%	1%

This core segment has broken along part of a vertical zeolite-filled joint. Note very fine-grained, white zeolite filling the fracture and coating the fracture surfaces. Core is from the 495.4-m (1,625.4-ft) depth in hole UE-7bc. Core was moistened prior to photographing to better reveal details.

Figure 2-14
Zeolite-Filled Fracture

Note the deposit of dark manganese oxide partially coating the surface of this vertical joint. Core is from the 709.0-m (2,326-ft) depth in UE-7bc.

Figure 2-15
Joint Surface Coated with Manganese Oxide

Core is from the 609.9-m (2,001-ft) depth in UE-7az.

Figure 2-16
Joints Completely Filled with Crystalline Quartz

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3.0 Summary

Fractures observed in the TCU from four core holes in Area 7 of Yucca Flat consist mostly of joints, with faults accounting for about 28 percent of the fractures observed. Approximately half the fractures were observed to be planar and continuous in shape. Almost 30 percent are discontinuous. The average dip of the fractures is 69°. The density of fractures averages 0.27 fractures per vertical meter of core (0.08 fractures per vertical foot of core). Open fractures, or those observed to have some aperture, average 0.06 fractures per vertical meter of core (0.02 fractures per vertical foot of core). Fracture spacing averages 1.3 m (4 ft) for all fractures, and 5.0 m (16 ft) for open fractures. Fractures are typically thin, averaging less than 1 mm in width. Aperture ranges from less than 0.1 to 10 mm wide, averaging 1.1 mm, and typically was observed as small isolated openings. On average, aperture accounts for only 10 percent of the fracture volume, the rest being completely healed with secondary minerals. Most fracture surfaces have rough to very rough textures. Zeolite is the most common secondary mineral filling, occurring in 48 percent of the fractures. Metallic oxide is the second most common mineral filling, often occurring in minor abundance with other secondary minerals.

The results of this study indicate that the TCU in the central portion of Yucca Flat is poorly fractured. Fracture attributes observed suggest that fractures within the TCU in the vicinity of the four holes do not substantially increase the permeability of the TCU. Because this study presents data for fractures within typical sequences of TCU from the central portion of Yucca Flat, the data and conclusions are probably applicable to other areas of the basin. However, the core holes analyzed in this study are located significant distances (greater than 609.6 m [2,000 ft]) from major faults. Also, because only natural fractures were examined, fractures that may have formed as a result of underground nuclear testing were not included in the analyses. The potential for increases in permeability due to enhanced fracturing of the TCU beneath Yucca Flat by faulting and underground nuclear detonations is poorly understood (Laczniak et al., 1996).

Because Yucca Flat is an extensional basin, the information in this report may also be applicable to other extensional basins, such as Frenchman Flat. However, outside these basins, in less extended terrain such as that at Rainier and Aqueduct mesas, the TCU may be even less fractured than reported here.

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Appendix A
List of Core Holes in Yucca Flat

APPENDIX A

Core and Borehole Information for Conventional Core Holes in Yucca Flat

(unless otherwise noted all values are in feet)

Core Hole	Core Hole Location (Central Nevada State Planar Coordinates, NAD 27)		Surface Elevation (above mean sea level)	Total Depth	Depth of Cored Interval		Depth to Top of Stratigraphic Unit	Stratigraphic Unit*	Hydrogeologic Unit**	Core Diameter (inches)
	Northing	Easting			Top	Bottom				
UE1a	837000	660000	4303	957	510	517	320	Tlt	TCU	4
					820	825	320	Tlt	TCU	
					952	957	900	Pz	CCU	
UE1b	837000	662000	4272	1254	510	530	0	QTa	AA	4
					1154	1160	760	Pz	CCU	
					1249	1254	760	Pz	CCU	
UE1c	837000	666000	4206	1880	510	530	0	QTa	AA	4
					1444	1454	1340	Tn4	VTA	
					1875	1880	1771	Pz	CA	
UE1d	837700	661050	4295	857	510	530	430	Tlt	TCU	3.5
					850	855	750	Pz	CCU	
UE1e	836500	663600	4244	1704	510	530	0	QTa	AA	3.5
					663	673	530	Tmrl/Th	VTA	
					1200	1205	960	Tn4	VTA	
					1570	1575	1540	Pz	CA	
					1697	1702	1540	Pz	CCU	
UE1f	836212	661373	4277	703	358	363	0	QTa	AA	3.5
					510	530	0	QTa	AA	
					649	701	560	Pz	CCU	
UE1g	838500	662900	4263	1442	510	530	0	QTa	AA	3.5
					586	591	530	Tmrl/Th	VTA	
					707	713	530	Tmrl/Th	VTA	
					1437	1442	1382	Pz	CCU	
UE1h	820000	675000	3995	3358	794	798	0	QTa	AA	3.5
UE1j	824500	673250	4040	1632	1433	1444	0	QTa	AA	3.5
UE1k	833500	677500	4053	2338	2332	2338	2180	Tmr	WTA	3.5
UE1l	837000	654001	4454	5339	2925	2945	200	Pz	CCU	5.25
					4206	4235	200	Pz	CCU	
UE1m	825407	657842	4478	514	8.75	514	?	?	?	1.875
UE1p	826269	662299	4232	782	580	587.2	0	QTa	AA	2.5
					773	782	773	Pz	CA	
U2a	879400	671951	4402	760	752	762	0	QTa	AA	3.5
U2b	879145	672900	4384	560	540	548	0	QTa	AA	3.5
U2g	875599	671950	4373	760	740	748	0	QTa	AA	?
U2h	875854	671000	4390	560	540	548	0	QTa	AA	3.5
U2n#1	873580	672168	4353	2273	200	208	0	QTa	AA	3.5
					720	728	0	QTa	AA	
					730	735	0	QTa	AA	
					770	778	0	QTa	AA	
					870	878	0	QTa	AA	
					917	925	0	QTa	AA	
U2p#1	874578	671829	4369	1405	1290	1298	0	QTa	AA	3.5

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(unless otherwise noted all values are in feet)

Core Hole	Core Hole Location (Central Nevada State Planar Coordinates, NAD 27)		Surface Elevation (above mean sea level)	Total Depth	Depth of Cored Interval		Depth to Top of Stratigraphic Unit	Stratigraphic Unit*	Hydrogeologic Unit**	Core Diameter (inches)
	Northing	Easting			Top	Bottom				
U2q#1	861188	678773	4195	1390	1000	1008	0	QTa	AA	3.5
					1100	1103.4	1050	Tmr	WTA	
					1103.4	1108	1050	Tmr	WTA	
					1250	1256	1050	Tmr	WTA	
					1300	1308	1050	Tmr	WTA	
					1350	1358	1050	Tmr	WTA	
U2r#1	865500	674070	4262	3342	1971	1974	0	QTa	AA	3.5
					2000	2009	0	QTa	AA	
					2600	2604	2451	Tv	TCU	
					3336	3342	2969	Tn	TCU	
							3337	Pz	CA	
U2au	863020	678300	4209	1405	1300	1354	1181	Tmr	WTA	3.5
UE2a#1	864601	668200	4330	2460	2260	2268	2129	Pz	CA	3.5
UE2s	863050	657169	4583	1970	611	619	0	QTa	AA	3.5
					965	973	840	Tmr	VTA	
					1346	1354	1339	Tbg	VTA	
					1646	1654	1421	Tn	TCU	
					1847	1854	1736	Pz	CA	
					1962	1970	1736	Pz	CA	
UE2u	870198	653250	4871	1473	658	666	522	Tv	?	?
					844	852	732	Tn	?	
					1465	1473	1421	Pz	CA	
UE2v	880035	665289	4539	1668	774	1660	0	QTa	AA	3.5
							751	Tv	?	
							1257	Pz	?	
UE2ad	867000	661001	4448	866	850	866	781	Pz	CA	3.5
UE2ar	864593	674656	4241	2351	2320	2334	2110	Tmr	VTA	3.5
UE2aw#1	867821	674380	4272	2328	various depths		?	?	?	
UE2ax	875218	670026	4398	2920	2115	2125	2070	Tp	VTA	3.5
					2175	2185	2070	Tp	VTA	
					2235	2245	2070	Tp	VTA	
UE2co	861900	657400	4562	1921	940	960	869	Tp	VTA	3.5
					1905	1920.5	1772	Pz	CA	
UE2dj	870400	670000	4341	2350	1586	1590	0	QTa	AA	?
					1783.5	1792.5	0	QTa	AA	
					1972	1984.5	0	QTa	AA	
					1990	1993	0	QTa	AA	
UE2en#1	864600	675600	4226	2500	2245	2252.3	2149	Tp	?	3
UE2ep	863550	674950	4226	2700	2240	2257	2047	Tmr	VTA	3
Grav.H#1	873000	662700	4440	145	120	145	0	QTa	AA	2.155
							144	Pz	CA	
TH3-9	838989	697901	4176	1953	1945	1953	1890	Pz	CA	4
U 3ah#1	836312	686479	4021	1215	1135	1200	0	QTa	AA	3.5
U 3ah#2	836346	686475	4020	1260	1135	1175	0	QTa	AA	3.5
U 3ah#3	836386	686471	4020	1260	1190	1200	0	QTa	AA	3.5
U 3ai#2	835650	685504	4020	1215	1155	1200	0	QTa	AA	3.5
U 3ak	835310	687177	4014	1215	1200	1210	0	QTa	AA	3.5
U-3ak-1	835335	687177	4014	1252	426	468	0	QTa	AA	?
U-3ak-2	835370	687177	4014	1250	1135	1200	0	QTa	AA	3.5
U 3amS	843321	685645	4071	1620	1425	1428	0	QTa	AA	?
TH3-E	839989	696001	4172	2620	394	1500	0	QTa	AA	2.155

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(unless otherwise noted all values are in feet)

Core Hole	Core Hole Location (Central Nevada State Planar Coordinates, NAD 27)		Surface Elevation (above mean sea level)	Total Depth	Depth of Cored Interval		Depth to Top of Stratigraphic Unit	Stratigraphic Unit*	Hydrogeologic Unit**	Core Diameter (inches)
	Northing	Easting			Top	Bottom				
							450	Tmr	WTA	
							750	Tmrl/Th	VTA	
							1151	Tbgb	VTA	
							1159	Tn4	TCU	
U 3an#3	843221	683662	4061	3555	3545	3555	3230	Pz	CA	3.5
U 3cn#5	841255	687998	4012	3030	90	3030	0	QTa	AA	3.5
							925	Tma	VTA	
							955	Tmr	VTA	
							1165	Tmrl/Th	TCU	
							1395	Twlb	TCU	
							1430	Tc	TCU	
							1655	Tn4	TCU	
							1801	Tn4E	TCU	
							2102	Tor	TCU	
							2250	Tot	TCU	
							2685	Tlt	TCU	
							2821	Pz	CA	
UE3eh#1	843514	688051	4093	1750	1424	1655	1175	Tmrl/Th	TCU	?
							1434	Tbgb	TCU	
							1444	Tn4	TCU	
U-3ev-1	839200	698000	4189	1100	0	150	0	QTa	AA	2.155
U 3fd#1	827599	687950	3981	1800	1447	1546.5	1440	Tmr	WTA	
U3ge Ex.#1	825039	681718	3988	980	670	930	630	Tmr	WTA	5.25
U3ge Ex.#2	825306	682007	3988	656	645	654	630	Tmr	WTA	4
U3gi Ex.#1	831000	688349	3992	1075	775	1021	0	QTa	AA	3
U3gs Ex.#2	824931	697035	4009	950	773	900	770	Th	VTA/TCU	3.5
							883	Twlb	TCU	
U 3hc	832700	689500	4000	663	660	663	0	QTa	AA	?
U 3hd#1	831664	690565	3996	1560	1540	1560	1440	Tmr	WTA	?
U 3he	829100	688900	3984	952	950	952	0	QTa	AA	?
U 3hp	821000	687800	3960	1300	1300	1303	0	QTa	AA	?
U 3hq	824000	685800	3970	1100	1100	1103	0	QTa	AA	?
U 3hr	821800	683000	3970	942	941	942	890	Tmr	?	?
U 3hs	824426	689849	3968	427	425	426	0	QTa	AA	?
U-3ht Ex. #1	824165	690299	3970	1115	460	471.5	0	QTa	AA	
					855.5	1106	0	QTa	AA	3
U 3hu	823726	689500	3966	1078	1075	1078	0	QTa	AA	?
U 3hv	824031	688814	3968	852	850	850.5	0	QTa	AA	?
U 3hx	820002	689000	3955	1052	1050	1052	0	QTa	AA	?
U3hx Ex#1	820210	688950	3955	1200	850	1150	?	?	?	5
U 3hz#1	827558	689075	3981	1460	1240	1401	1235	Tmr	WTA	?
U 3ja	821949	690321	3959	1120	1040	1043	1040	Tma	VTA	?
					1120	1123	1070	Tmr	VTA	
U 3jb	822381	689778	3961	1360	1360	1363	1170	Tmr	WTA	?
U-3jc Ex#1	822226	689051	3961	1150	850	1097	?	?	?	?
U 3jd	821897	689965	3960	530	400	401	0	QTa	AA	?
					528	530	0	QTa	AA	
U-3je Ex#1	829000	686050	3986	1200	850	1136	?	?	?	?
U 3jh	817400	687650	3948	1424	1200	1203	0	QTa	AA	?
					1410	1413	0	QTa	AA	
U 3ji	816500	687650	3945	973	970	973	0	QTa	AA	?
U 3jj	816910	688225	3946	573	570	573	0	QTa	AA	?

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Core and Borehole Information for Conventional Core Holes in Yucca Flat

(unless otherwise noted all values are in feet)

Core Hole	**Core Hole Location** (Central Nevada State Planar Coordinates, NAD 27)		**Surface Elevation** (above mean sea level)	**Total Depth**	**Depth of Cored Interval**		**Depth to Top of Stratigraphic Unit**	**Stratigraphic Unit***	**Hydrogeologic Unit****	**Core Diameter** (inches)
	Northing	Easting			Top	Bottom				
U 3jq	843200	694000	4175	1903	1900	1902	1845	Ton1	TCU	?
U 3jq#1	843201	694050	4175	2224	1600	1951	1260	Tbgb	TCU	4
							1706	Toy	TCU	
							1845	Ton1	TCU	
U3js#1	821600	688750	3959	1200	981	1132	?	?	?	5.25
U3jt#1	820975	689050	3957	950	700	890	?	?	?	5
U3ju	827880	689850	3979	553	420	423	0	QTa	AA	?
					550	553	0	QTa	AA	
U3jw	827480	689890	3977	553	420	423	0	QTa	AA	?
					550	553	0	QTa	AA	
U3jx	820779	689790	3957	503	500	503	0	QTa	AA	?
U3ka	831499	688900	3995	1160	1160	1163	0	QTa	AA	?
U3kb	828201	686350	3983	1510	1310	1312	0	QTa	AA	?
					1510	1512	0	QTa	AA	
U3kc	820400	687497	3957	1112	1110	1112	0	QTa	AA	?
U3kf	839600	687250	4047	663	660	663	0	QTa	AA	?
U3kg	820000	691400	4002	660	662	664	0	QTa	AA	?
U3ki	822001	685499	3963	1150	1150	1153	0	QTa	AA	?
U3ko	843700	686600	4077	1400	1400	1403	1285	Tc	TCU	?
U3kp	827098	687302	3979	1410	1410	1412	0	QTa	AA	?
U3ks	825000	692300	3966	1615	1610	1613	1430	Tcb	TCU	?
U3kt	831500	682000	4005	1510	1510	1512	0	QTa	AA	?
UE3a	826000	698000	4035	1706	419	425	190	Tmr	WTA	3.5
					1105	1110	910	Twlb	TCU	
UE3as	826000	698000	4035	1706	210	220	190	Tmr	WTA	3.5
					931	936	910	Twlb	?	
					1300	1305	910	Twlb	TCU	
UE3b	843950	682000	4080	780	770	780	610	Tmr	VTA	2.155
UE3e#2	844938	679983	4081	2372	1950	2372	1695	Tmrl/Th	TCU	2.5
							1984	Twlb	TCU	
							2095	Tc	TCU	
							2191	Tcb	TCU	
							2364	Tn4	TCU	
U4a	858603	679099	4169	3152	3152	3153	3060	Pz	CA	?
U4d#1	857531	679038	4167	2536	1883	2480	1685	Tc	TCU	3.5
							1907	Tbgb	TCU	
							1946	Tn4	TCU	
							2353	Tn3	TCU	
U4e	858201	678000	4173	3353	2426	2428	2245	Tn4	TCU	?
					3343	3353	3265	Pz	CA	
U4e#1	858200	677550	4178	3240	3230	3240	3230	Pz	CA	?
Sidetrack			4178	3259	3245	3259	3230	Pz	CA	?
U4h	859600	678500	4175	2400	2400	2401	2295	Ton2	TCU	?

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Core Hole	**Core Hole Location** (Central Nevada State Planar Coordinates, NAD 27)		**Surface Elevation** (above mean sea level)	**Total Depth**	**Depth of Cored Interval**		**Depth to Top of Stratigraphic Unit**	**Stratigraphic Unit***	**Hydrogeologic Unit****	**Core Diameter** (inches)
	Northing	Easting			Top	Bottom				
UE4a	856041	679741	4155	3028	873	3013	750	Tmr	VTA	3.5
							1668	Tbgb	TCU	
							1696	Tn4	TCU	
							2087	Tn3	TCU	
							2166	Tn3bc	TCU	
							2321	Tub	TCU	
							2333	Ton2	TCU	
							2695	Tot	TCU	
							2885	Tv	TCU	
							2990	Tlt	TCU	
					2387	2900	1973	Tn4	TCU	
							2845	Pz	CA	
					3055	3153	2845	Pz	CA	
UE4f	851591	679126	4129	3593	2995	3593	2495	Tn3bc	TCU	4
							3005	Tor	TCU	
							3050	Tv	TCU	
							3140	Tot	TCU	
							3185	Tv	TCU	
							3465	Tlt	TCU	
							3515	Pz	CA	
UE4g#2	856600	679549	4152	2452	1494	2452	1210	Tmrl/Th	VTA	1.875
							1500	Twlb	VTA	
							1540	Tc	TCU	
							1710	Tbgb	TCU	
							1747	Tn4	TCU	
							2003	Tn4E	TCU	
							2100	Tn3	TCU	
							2369	Tub	TCU	
							2376	Ton2	TCU	
UE4t	855565	680350	4144	1993	728	930	555	Tmr	WTA	0.75
					1280	1390	1240	Twlb	TCU	
							1290	Tc	TCU	
					1529	1530	1480	Tn4	TCU	
					1852	1870	1760	Tn4E	TCU	
					1927	1992	1910	Tn3bc	TCU	
					2029	2031	1910	Tn3bc	TCU	
UE4ab	856750	672450	4201	2650	1202	1210	1030	Tmr	TCU	?
					2640	2650	2549	Pz	CA	
UE4ac	855950	659250	4271	1677	1304	1314	1175	Tn	CA	
UE4ah	850000	674000	4142	2851	1632	1662	1512	Tma	VTA	3
					2285	2315	2146	Tc	TCU	
					2841	2849	2785	Pz	CA	
UE4al	848700	672570	4155	2187	1784	1990	1670	Pz	CA	3.5
					2057	2173	1670	Pz	CA	

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Core Hole	**Core Hole Location** (Central Nevada State Planar Coordinates, NAD 27)		**Surface Elevation** (above mean sea level)	**Total Depth**	**Depth of Cored Interval**		**Depth to Top of Stratigraphic Unit**	**Stratigraphic Unit***	**Hydrogeologic Unit****	**Core Diameter** (inches)
	Northing	Easting			Top	Bottom				
DI#1	?	?	?	?	0	200	0	Pz	?	2.155
DI#2	?	?	?	?	12	53	11	Pz	?	?
DI#3	?	?	?	?	4	160	1	Pz	?	?
DI#4	?	?	?	?	22	200	21	Pz	?	?
DI#6	?	?	?	?	2	96	2	Pz	?	?
DI#7	?	?	?	?	10	106	?	?	?	?
DI#8	?	?	?	?	1	200	?	?	?	?
DI#9	?	?	?	?	0	100	?	?	?	?
DI#10	?	?	?	?	0	200	?	?	?	?
DI#12	?	?	?	?	0	141	?	?	?	?
U6b	810000	678450	3932	429	427	429	0	QTa	AA	?
UE6d	814000	677500	3947	3896	1100	1111	0	QTa	AA	3.5
					3886	3896	3810	Ton1	TCU	
UE6d#2	813500	693505	3932	1487	817	1487	680	Tmr	WTA	2.5
							990	Tmrl/Th	VTA/TCU	
							995	Tpc	TCU	
							1086	Tpt	WTA	
							1364	Th	TCU	
							1416	Twlb	TCU	
							1478	Tc	TCU	
UE6e	814000	688200	3936	4209	133	1384	0	QTa	AA	4
							1368	Tmab	VTA	
					1460	1478	1398	Tmr	WTA	
					1748	1762	1745	Tpc	TCU	
					1885	1895	1878	Tpt	WTA	
					2050	2060	1878	Tpt	WTA	
					2295	2297	2210	Th	TCU	
					4161	4173	3985	Pz	CA	
TWC	790082	692061	3921	1701	503	1548	215	Tpt	WTA	?
							510	Th	TCU	
							560	Twlb	TCU	
							659	Tc	TCU	
							659	Tn4	TCU	
							1210	Ton1	TCU	
							1355	Pz	CA	
TWB	812044	690713	3929	1675	395	1450	0	QTa	AA	2.155
							950	Tmr	WTA	
							1297	Tmrl/Th	VTA/TCU	
							1411	Tpt	WTA	
ER-6-1	814004	696780	3933	3206	2129	3206	1770	Pz	CA	3.3
ER-6-2	805317	672494	4231	3430	2006	3430	101	Pz	CA	3.4
U7a	858614	684999	4255	2699	2600	2605	1610	Tn4	TCU	3.5

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Core Hole	Core Hole Location (Central Nevada State Planar Coordinates, NAD 27)		Surface Elevation (above mean sea level)	Total Depth	Depth of Cored Interval		Depth to Top of Stratigraphic Unit	Stratigraphic Unit*	Hydrogeologic Unit**	Core Diameter (inches)
	Northing	Easting			Top	Bottom				
U7a#1	858619	684970	4255	1350	800	806	770	Tmr	WTA	3.5
					1100	1108	1010	Tmrl/Th	VTA	
					1150	1158	1010	Tmrl/Th	TCU	
					1200	1208	1010	Tmrl/Th	TCU	
					1250	1258	1010	Tmrl/Th	TCU	
					1300	1303	1010	Tmrl/Th	TCU	
					1342	1348	1010	Tmrl/Th	TCU	
U7h#1	848043	685457	4118	1250	660	912	0	QTa	AA	3
							758	Tma	WTA	
							790	Tmr	WTA	
							890	Tmrl/Th	VTA	
U7z	849449	683799	4108	1906	1903	1906	1510	Tmrl/Th	TCU	?
U7ab	848501	694000	4251	1703	1700	1703	1630	Toy	TCU	?
U7ac	846900	685200	4102	2213	2210	2213	2205	Toy	TCU	?
U7ad	857308	686615	4285	1965	1850	1853	1820	Ton2	TCU	?
U7ae	851150	692450	4266	2853	2050	2053	2020	Tor	TCU	?
					2843	2853	2690	Pz	CA	
U7af	853100	686500	4207	1988	1988	1990	1855	Toy	TCU	?
U7ah	854100	683902	4180	3210	3201	3210	2830	Pz	CA	3.5
U7ai	844801	685699	4084	2180	2180	2182	1660	Tn4E	TCU	?
U7am	854100	686301	4219	2050	2050	2055	2020	Toy	TCU	?
U7an	847000	681700	4100	3161	3151	3162	2915	Tlt	TCU	?
U7ap	853900	681350	4148	2050	2050	2053	1910	Toy	TCU	?
U7aq	845800	679901	4094	3620	3500	3510	3440	Tlt	TCU	3.5
					3610	3620	3560	Pz	CA	
U7at	858800	685958	4384	1510	1510	1512	1401	Pz	CA	?
UE7a	856000	681400	4163	292	282	292	241	Tma	WTA	2.155
							283	Tmr	WTA	
UE7b	853698	681900	4153	262	220	262	220	Tmr	VTA	?
UE7c	851500	681200	4131	343	333	343	310	Tma	?	2.155
UE7d	851500	682400	4138	298	290	298	150	Tmr	WTA	2.155
UE7e	849400	681300	4118	482	472	482	472	Tmr	WTA	2.155
UE7f	852510	680180	4124	2824	770	2498	750	Tmr	WTA	2.5
							1224	Tmrl/Th	TCU	
							1465	Twlb	TCU	
							1515	Tc	TCU	
							1674	Tbgb	TCU	
							1704	Tn4	TCU	
							1894	Tn4E	TCU	
							1999	Tn3	TCU	
							2047	Tn3bc	TCU	
							2230	Tub	TCU	
							2239	Ton2	TCU	
							2399	Toy	TCU	
							2415	Ton1	TCU	
					2498	2824	2415	Ton1	TCU	2.155
							2560	Tot	TCU	
							2573	Tv	TCU	
							2796	Tlt	TCU	
							2804	Pz	CA	

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Core Hole	Core Hole Location (Central Nevada State Planar Coordinates, NAD 27)		Surface Elevation (above mean sea level)	Total Depth	Depth of Cored Interval		Depth to Top of Stratigraphic Unit	Stratigraphic Unit*	Hydrogeologic Unit**	Core Diameter (inches)
	Northing	Easting			Top	Bottom				
UE7aa	845149	696449	4259	2154	1575	1580	1465	Pz	CA	3.5
UE7ax	858084	691025	4390	1359	253	843	0	QTa	AA	2.5
							264	Tmrl/Th	VTA	
							380	Twlb	VTA	
							445	Tc	VTA	
							590	Tbgb	TCU	
							654	Tn4	TCU	
							788	Tn4E	TCU	
					843	1169	788	Tn4E	TCU	2.5, 2.155
							905	Tn3	TCU	
							968	Tn3bc	TCU	
							1053	Tub	TCU	
							1067	Ton2	TCU	
							1161	Toy	TCU	
					1169	1359	1161	Toy	TCU	2.155
							1239	Ton1	TCU	
							1287	Tot	TCU	
							1335	Tv	TCU	
							1339	Tlt	TCU	
							1343	Pz	CA	
UE7az	850000	690800	4218	2441	1021	2363	880	Tmr	VTA	2.5
							1088	Tmrl/Th	TCU	
							1236	Twlb	TCU	
							1306	Tc	TCU	
							1474	Tbgb	TCU	
							1475	Tn4	TCU	
							1532	Tn4E	TCU	
							1726	Tn3	TCU	
							1750	Tn3bc	TCU	
							1825	Ton2	TCU	
							1868	Tor	TCU	
							2007	Tot	TCU	
							2135	Tv	TCU	
							2240	Tlt	TCU	
					2364	2441	2240	Tlt	TCU	2.155
							2432	Pz	CA	
UE7ba	851264	681350	4130	2428	360	2428	314	Tma	WTA	2.5
							440	Tmr	WTA	
							912	Tmrl/Th	TCU	
							1237	Twlb	TCU	
							1290	Tc	TCU	
							1525	Tbgb	TCU	
							1526	Tn4	TCU	
							1629	Tn4E	TCU	
							1763	Tn3	TCU	
							1837	Tn3bc	TCU	
							1967	Tub	TCU	
							1975	Ton2	TCU	
							2096	Toy	TCU	
							2201	Ton1	TCU	
							2382	Tlt	TCU	
							2396	Pz	CA	

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Core Hole	**Core Hole Location** (Central Nevada State Planar Coordinates, NAD 27)		**Surface Elevation** (above mean sea level)	**Total Depth**	**Depth of Cored Interval**		**Depth to Top of Stratigraphic Unit**	**Stratigraphic Unit***	**Hydrogeologic Unit****	**Core Diameter** (inches)
	Northing	Easting			Top	Bottom				
UE7bc	848000	693154	4225	2707	740	2707	646	Tmrl/Th	TCU	2.5
							830	Twlb	TCU	
							900	Tc	TCU	
							1043	Tbgb	TCU	
							1058	Tn4	TCU	
							1200	Tn4E	TCU	
							1240	Tn3	TCU	
							1397	Tn3bc	TCU	
							1689	Toy	TCU	
							1877	Ton1	TCU	
							1958	Tor	TCU	
							2340	Tv	TCU	
							2467	Tot	TCU	
							2567	Tv	TCU	
							2592	Tlt	TCU	
							2699	Pz	CA	
UE7be	856500	685521	4241	2604	2602	2604	2570	Pz	CA	?
UE7ns	855600	693700	4367	2205	1666	1673	1640	Pz	CA	?
					1724	1730	1640	Pz	CA	
					1798	1803	1640	Pz	CA	
					1848	1854	1640	Pz	CA	
					1898	1908	1640	Pz	CA	
					1948	1954	1640	Pz	CA	
					1998	2008	1640	Pz	CA	
					2048	2058	1640	Pz	CA	
					2110	2120	1640	Pz	CA	
					2148	2155	1640	Pz	CA	
					2190	2200	1640	Pz	CA	
U8a#1	884497	665748	4613	1238	1230	1238	1175	Pz	CCU	?
U8a#3	884288	665728	4610	1322	1314	1322	1250	Pz	?	4
U8a#4	884358	665734	4614	1925	1128	1406	1050	Tn	?	3.5
							1214	Pz	CCU	
U8a#5	884010	665698	4604	1915	607	1652	591	Tmr	VTA	3.5
							830	Tp	VTA	
							899	Tbgb	VTA	
							971	Tn	VTA	
							1270	Pz	CCU	
U8a#9	882816	665574	4575	1860	1330	1432	1181	Tv	?	3.5
							1381	Pz	?	
U8a#10	882419	665534	4569	1918	872	1918	0	QTa	AA	3.5
							906	Tma	?	
							991	Tmr	?	
							1138	Tv	?	
							1224	Tbgb	?	
							1280	Tn	?	
							1450	Pz	?	

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	Northing	Easting			Top	Bottom				
UE8d	882280	671280	4438	1246	1239	1246	1175	Pz	CA	3.5
UE8e	881600	668700	4489	2470	1800	1810	1710	Tv	TCU	3.5
UE8f	882386	666019	4560	2248	1109	1118	1099	Tma	VTA	?
					1155	1165	1099	Tma	VTA	
							1158	Tbgb	VTA	
					2235	2248	2139	Pz	CCU	
UE8h	882756	664746	4594	1610	1298	1305	1230	Pz	CA	3.5
UE8i	882139	665388	4566	1200	300	306	0	QTa	AA	?
					808	809	0	QTa	AA	
U9d#1	864046	680127		1010	840	999	0	QTa	AA	3.5
							850	Tmr	WTA	
U9i#1	864306	685898	4230	758	600	610	351	Tv	TCU	3.5
U9i#2	?	?	?	?	850	860		?	?	3.5
U9k	862910	685180	4261	782	775	785	650	Tv	?	?
U9n	865860	681270	4200	595	450	460	0	QTa	AA	?
					570	574	0	QTa	AA	
U9q	864231	679548	4198	715	690	698	0	QTa	AA	3.5
U9r	866002	680269	4204	595	545	555	0	QTa	AA	3.5
U9u	867001	681301	4204	595	570	580	0	QTa	AA	3.5
U9v	862300	680550	4177	875	850	860	0	QTa	AA	3.5
U9w	863480	683790	4225	610	590	600	0	QTa	AA	3.5
U9x	862060	684820	4258	865	760	765	551	Tmr	WTA	3.5
					850	860	551	Tmr	WTA	
U9y	866761	677878	4239	735	710	720	0	QTa	AA	3.5
U9z	862760	682860	4208	765	750	760	0	QTa	AA	3.5
U9aa	866180	679770	4209	760	740	750	0	QTa	AA	?
U9ab	863360	681040	4187	765	740	748	0	QTa	AA	3.5
U9ac	865369	681300	4197	450	430	438	0	QTa	AA	3.5
U9ad	870300	679650	4234	1813	1615	1625	1460	Tmr	VTA	
					1805	1813	1460	Tmr	VTA	3.5
U9ae	859999	683000	4213	1323	943	949	899	Tmr	WTA	3.5
U9ak	865071	684039	4267	860	823	831	732	Tv	?	?
U9ao	871350	679999	4231	1655	1621	1629	1549	Tv	VTA	3.5
U9ay	865600	683771	4221	909	685	693	551	Tmr	WTA	?
U9bb#1	867645	684910	4254	800	792	800	390	Tmr	WTA	3.5
U9bd#1	860969	686944	4317	650	556	558	499	Tmr	VTA	?
					600	608	499	Tmr	VTA	
							607	Tv	VTA	
U9be#1	860028	686022	4287	725	572	725	479	Tmr	VTA	3.5
							722	Tv	VTA	
U9bh#1	862940	687167	4310	810	665	673	217	Tmr	WTA	?
					715	808	217	Tmr	WTA	
U9bj#1	860600	686820	4314	800	690	748	522	Tmr	WTA	3.5
U9bn#1	862762	686315	4292	979	820	916	509	Tv	VTA	?
U9bp#1	861451	684980	4264	800	636	800	0	QTa	AA	3.5
							679	Tmr	WTA	

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	Northing	Easting			Top	Bottom				
U9br#1	861915	686335	4298	1000	450	458	374	Tmr	VTA	3.5
					650	658	564	Tv	VTA	
					710	718	564	Tv	VTA	
					800	808	564	Tv	VTA	
					850	858	564	Tv	VTA	
					900	908	564	Tv	VTA	
					941	947	564	Tv	VTA	
					992	1000	951	Tbgb	VTA	
U9ca#1	872700	679098	4244	3210	1400	1408	0	QTa	AA	3.5
							1401	Tv	VTA	
					1700	1708	1401	Tv	VTA	
					1950	1958	1939	Tbgb	TCU	
					2050	2058	1939	Tbgb	TCU	
					2150	2158	1939	Tbgb	TCU	
					2236	2249	1939	Tbgb	TCU	
					3077	3085	1939	Tbgb	TCU	
							3081	Pz	CA	
U9cb#4	873298	681856	4245	1858	1471	1479	1329	Tn	CA	?
					1569	1577	1329	Tn	?	
					1676	1684	1329	Tn	?	
					1721	1729	1329	Tn	?	
					1771	1779	1329	Tn	?	
					1850	1858	1329	Tn	?	
U9ce#1	871860	678982	4242	1420	1196	1204	0	QTa	AA	3.5
U9ci#1	863795	684966	4249	1239	463	493	0	QTa	AA	?
					496	515	0	QTa	AA	
							499	Tmr	VTA	
U9itsUEs25	869990	682296	4222	2028	2025	2028	1959	Pz	CA	3.5
U9itsUEu22	868840	683200	4223	1817	940	1024	853	Tc	?	?
UEu29#1	871618	683624	4248	1248	1228	1248	1138	Pz	CA	3.5
UEu29#2	871505	683105	4242	1572	1542	1546	1421	Pz	CA	3.5
FT1	?	?	?	?	0	100	?	?	?	2.155
FT1#1	?	?	?	?	0	17	?	?	?	2.155
FT1#2	?	?	?	?	0	10	?	?	?	2.155
FT1#3	?	?	?	?	0	10	?	?	?	2.155
A3#1	?	?	?	?	0	50	?	?	?	2.155
U10a	883040	677799	4293	1410	1300	1410	1129	Tn	?	3.5
U10b	883000	674700	4375	1501	1300	1339	591	Pz	CA	3.5
U10b#3	883000	674725	4375	1400	667	1339	551	Pz	CA	3.5
U10b#4	883700	674700	4379	1400	706	1348	702	Pz	CA	3.5
U10b#5	884399	674700	4388	1400	733	1358	678	Pz	CA	3.5
U10c#1	874028	678179	4260	3058	1600	3058	1549	Tmr	WTA	3.5
							1900	Tv	VTA	
							3051	Pz	CA	
U10e	874500	682599	4266	1635	1600	1608	1240	Tn	TCU	3.5
U10e#1	874508	682581	4266	1700	600	608	554	Tmr	WTA	?
					1230	1235	1171	Tbgb	?	
					1415	1420	1240	Tn	?	
					1515	1523	1240	Tn	?	
					1687	1695	1240	Tn	?	
U10i	885894	680999	4335	1745	1745	1753	1640	Pz	CA	?

APPENDIX A

Core and Borehole Information for Conventional Core Holes in Yucca Flat

(unless otherwise noted all values are in feet)

Core Hole	Core Hole Location (Central Nevada State Planar Coordinates, NAD 27)		Surface Elevation (above mean sea level)	Total Depth	Depth of Cored Interval		Depth to Top of Stratigraphic Unit	Stratigraphic Unit*	Hydrogeologic Unit**	Core Diameter (inches)
	Northing	Easting			Top	Bottom				
U10i#1	885872	681020	4335	1360	950	1358	850	Tv	?	4
							974	Tbgb	?	
							1050	Tv	?	
U10k	879520	679000	4273	2391	1843	1851	1729	Tn	TCU	
					1960	1968	1729	Tn	TCU	3.5
U10k#1	879475	679030	4272	2289	2173	2192	1729	Tn	TCU	4
					2207	2243	1729	Tn	TCU	
U10l#1	875918	681559	4264	2208	1070	1078	1024	Tv	VTA	3.5
					1200	1208	1024	Tv	TCU	
					1470	1478	1460	Tn	TCU	
					1570	1578	1460	Tn	TCU	
					1770	1778	1460	Tn	TCU	
					1870	1878	1460	Tn	TCU	
U10n#1	883949	674700	4382	1115	729	783	722	Pz	CA	3.5
UE10j	887033	670453	4574	2613	370	378	358	Tub	TCU	3.5
					668	676	623	Tor	TCU	
					750	758	748	Tot	TCU	
					1035	1038	1024	Pz	CA	
					1290	1295	1024	Pz	CA	
					1620	1623	1024	?	CA	
					1640	1644	1024	Pz	CA	
					1860	1865	1024	Pz	CA	
					2050	2058	1024	Pz	CA	
					2150	2156	1024	Pz	CA	
U10aq#1	879503	684717	4343	1637	900	1020	814	Tbgb	VTA	?
							919	Tn	TCU	
					1100	1120	919	Tn	TCU	
UE10aa	889500	683300	4401	1390	1266	1264	1132	Pz	CCU	?

EXPLANATION

* Stratigraphic Unit Symbols

Qta	Alluvium
Tma	Ammonia Tanks Tuff
Tmab	bedded Ammonia Tanks Tuff
Tmr	Rainier Mesa Tuff
Tmrl/Th . . .	pre-Rainier / post Wahmonie bedded tuffs
Tp	Paintbrush Group
Tpc	Tiva Canyon Tuff
Tpt	Topopah Springs Tuff
Th	Calico Hills Formation
Twlb	tuff of Wahmonie Flat
Tc	Crater Flat Group
Tcb	Bullfrog Tuff
Tbg	Grouse Canyon Tuff
Tbgb	bedded Grouse Canyon Tuff
Tn	Tunnel Formation
Tn4	Tunnel 4 Member
Tn4E	beds 4E, Tunnel 4 Member
Tn3	Tunnel 3 Member
Tn3BC . . .	beds 3BC, Tunnel 3 Member
Tub	Tub Spring Tuff
Ton2	tunnel bed 2
Toy	Yucca Flat Tuff
Tor	Redrock Valley Tuff
Tot	tuff of Twin Peaks
Tv	Tertiary volcanics, undivided
Tlt	tuffaceous paleocolluvium
Pz	Paleozoic rocks, undivided

** Hydrogeologic Unit Symbols

AA	alluvial aquifer
VTA	vitric-tuff aquifer
WTA	welded-tuff aquifer
TCU	tuff confining unit
CCU	clastic confining unit
CA	carbonate aquifer

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