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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STRATIGRAPHY AND STRUCTURE OF VOLCANIC ROCKS IN DRILL HOLE USW-G1, YUCCA MOUNTAIN, NYE COUNTY, NEVADA

By

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ABSTRACT

Detailed subsurface studies in connection with the Nevada Nuclear Waste Storage Investigations program are being conducted to investigate the stratigraphic and structural features of volcanic rocks underlying Yucca Mountain, a volcanic highland situated along the western boundary of the Nevada Test Site in southern Nevada. As part of this continuing effort, drill hole USW-G1 was cored from 292 ft to a depth of 6,000 ft from March to August 1980.

The stratigraphic section is composed of thick sequences of ash-flow tuff and volcanic breccia interbedded with subordinate amounts of fine- to coarse-grained volcaniclastic rocks. All rocks are of Tertiary age and vary in composition from rhyolite to dacite. Major stratigraphic units that were identified from the drill-hole data include the Paintbrush Tuff, tuffaceous beds of Calico Hills, and the Crater Flat Tuff. Below the Crater Flat Tuff, three general stratigraphic intervals have not been correlated with previous mapped units and, therefore, separation of these intervals was made on the basis of lithologic characteristics. They include, in descending order, flow breccia, lithic-rich tuff, and older ash-flow and bedded tuff.

The 3,005-ft level in the drill hole represents a significant demarcation between unaltered and altered volcanic rocks. For the most part, tuff units above 3,005 ft appear devitrified and show little secondary alteration except within tuffaceous beds of Calico Hills, where the rock contains 60-80 percent zeolites. Below 3,005 ft, most rocks show intermittent to pervasive alteration to clay minerals and zeolites.

Examination of core for structural features revealed the presence of 61 shear fractures, 528 joints, and 4 conspicuous fault zones. Shear fractures mainly occurred in the Topopah Spring Member of the Paintbrush Tuff, flow breccia, and near fault zones. Compilation of the rake of striations on shear surfaces indicates oblique-slip movement but suggests a strong component of lateral slip. Conspicuous fault zones, arbitrarily defined by their disruption of more than 5 ft of core, were recognized by the concentration of shears coupled with the presence of fault breccia, clay gouge, and granulated core; magnitudes of displacement could not be established for any of these faults.

A coincidence occurs between joint development and the degree of welding. Jointing is largely confined to (1) the densely welded Topopah Spring, (2) the Tram unit (lower part of the Crater Flat Tuff), and (3) the

flow brecia where 49.6, 22.2, and 7.9 percent of the total joints occur, respectively.

Nearly 88 percent of shear and joint surfaces show evidence of coatings, most of which consist of either calcite silica, iron and manganese oxides, clay, zeolites, or combinations of the above mentioned coatings. Approximately 40 percent of the fractures were categorized as completely healed.

Rock quality characteristics as defined by the "core index" indicate that greater amounts of broken and lost core are commonly associated with (1) the densely welded zone of the Topopah Spring, (2) highly silicified zones, and (3) fault zones.

INTRODUCTION

Since 1978 the USGS (U.S. Geological Survey) has been a participant in the Nevada Nuclear Waste Storage Investigations program. On behalf of the DOE (U.S. Department of Energy), the USGS has been actively involved in geologic exploration to characterize rock masses suitable for storage of nuclear waste at or contiguous to the NTS (Nevada Test Site) in southern Nevada. Current site-specific exploration is focused within the northeastern part of Yucca Mountain, which is situated along the western edge of NTS (fig. 1). At this location, interlayered ash-flow tuff sheets and tuffaceous sediments of Tertiary age attain a combined thickness of more than 6,000 ft. Bounded by major Basin and Range faults along its western and northeastern edges, this segment of Yucca Mountain encompasses an area of about 4 mi^2 where surface mapping has indicated a relatively low density of faulting within the area with maximum displacements rarely exceeding a few tens of feet (fig. 2).

This report is part of a continuing study to gather and interpret information on the thickness, lateral extent, correlation, and structural characteristics of volcanic rocks within and surrounding the area of interest. Geologic descriptions and interpretations presented herein are based on results obtained from USW-G1, a drill hole continuously cored to a depth of 6,000 ft from March to August 1980. Observations are based on core logging and supplemented by petrographic studies of 66 thin sections. Identities of alteration products were verified, as occasion demanded, by semiquantitative X-ray diffraction analyses. Chemical analyses of selected samples were made to aid in rock classification.

Because this study is essentially confined to descriptions and interpretations of core, other studies in connection with the drill hole are not included in this report. Instead, the reader is referred to "References Cited" and, in particular, to previous subsurface studies at Yucca Mountain as described in Spengler and others (1979), and Spengler and Rosenbaum (1980).

All measurements related to drill-hole location and depth are given in English units. If metric units are desired, refer to the following conversion factors:

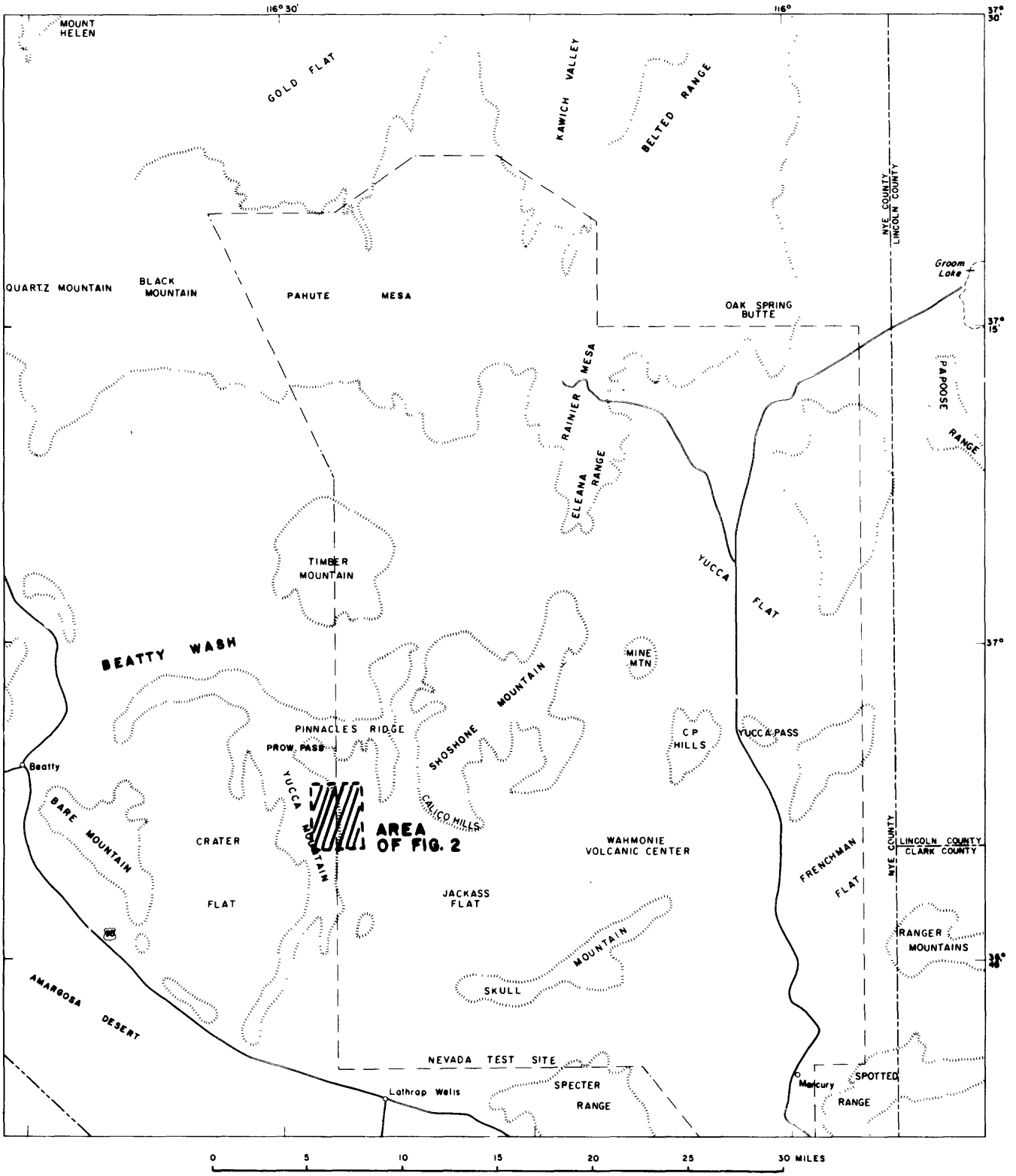


Figure 1.--Index map of the Nevada Test Site and vicinity showing location of study area.

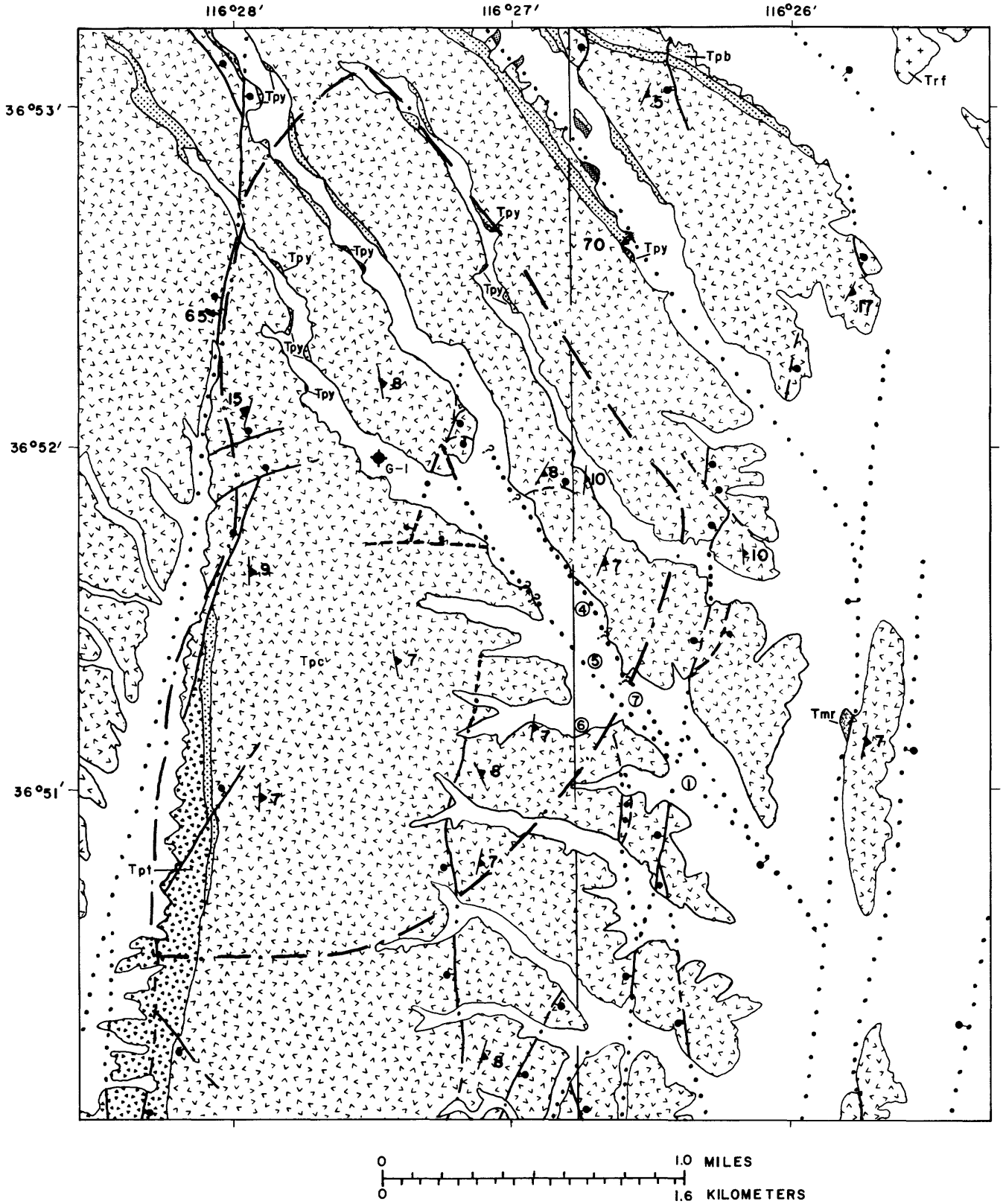
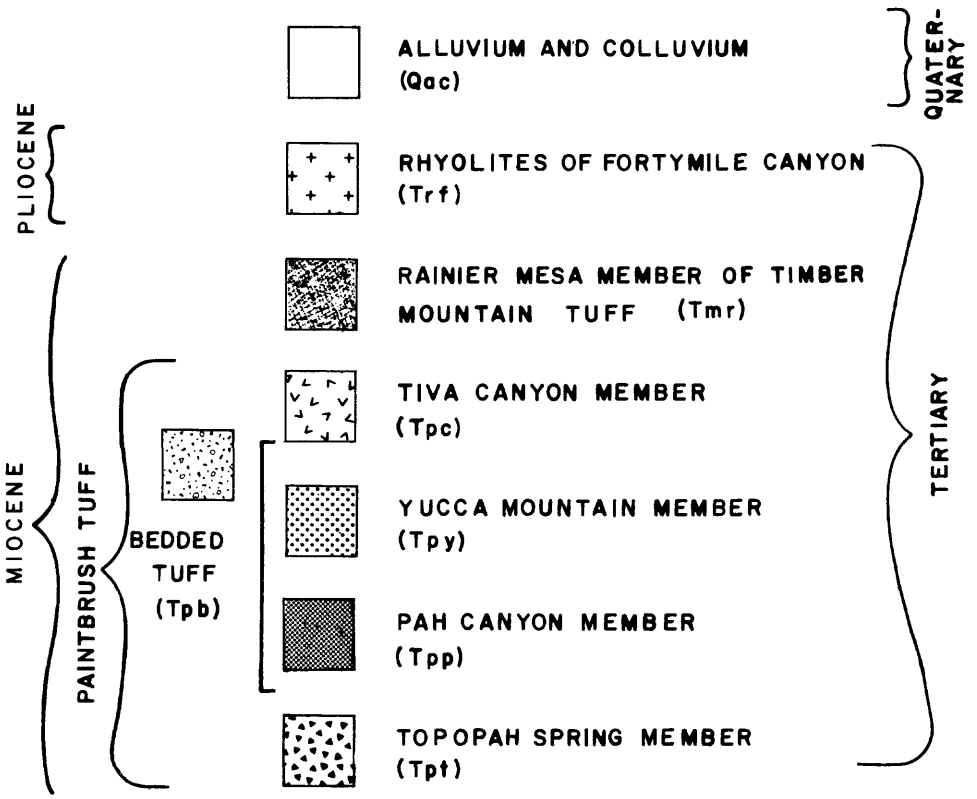


FIGURE 2-- GENERALIZED GEOLOGIC MAP OF THE AREA OF INTEREST AND LOCATION OF USW-G1.

EXPLANATION



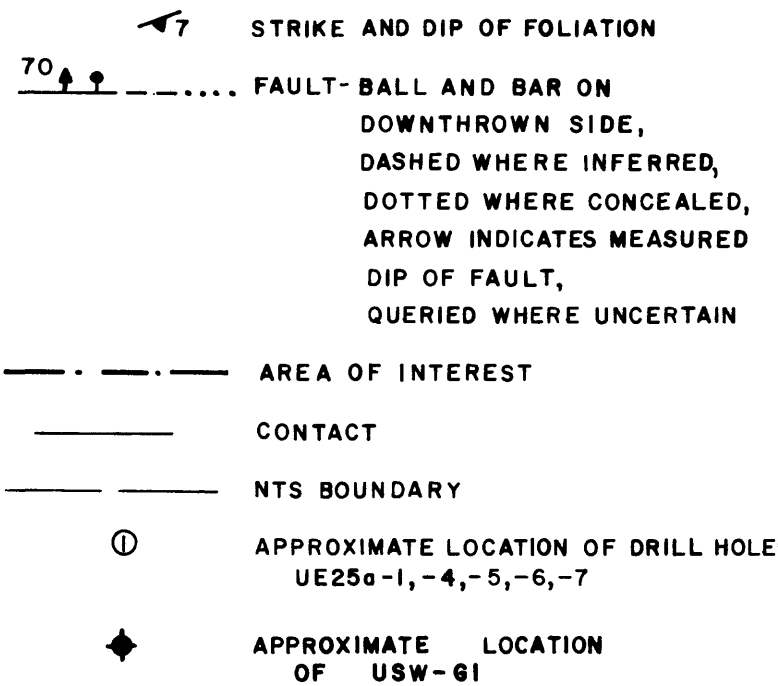


FIGURE 2.--
CONTINUED

Multiply English units	By	To obtain metric units
foot (ft)	0.3048	meters (m)
inch (in.)	2.54	centimeters (cm)
mile (mi)	1.61	kilometers (km)
gallon (gal)	3.785	liter (L)

ACKNOWLEDGMENTS

Appreciation is expressed for the valuable assistance given by geologists M. P. Chornack, A. J. Gordon, R. B Livermore, S. L. Koether, R. W. Orsak, L. D. Parrish, and G. A. De Paolis of Fenix & Scisson, Inc., in monitoring sampling operations. Several colleagues in the USGS assisted in this study by providing chemical and mineralogic data; these individuals are acknowledged at appropriate places in this report.

SITE SELECTION

Geologic exploration, as applied to nuclear waste storage at Yucca Mountain, is directed toward determining the homogeneity, lateral continuity, and structure of subsurface volcanic layers. At this early (1980) stage in the exploratory program, acquisition of geologic data was required from the central part of the area of interest as perceived at this time (fig. 2) and, specifically, from a location free of structural complexities where representative thicknesses and characteristics of the various tuff units could be obtained with a relatively high degree of confidence.

Drill hole USW-G1 is located at approximatey lat 36°52' N. and long 116°27 1/2' W. in a branch of the prominent northwest-trending wash transecting the area of interest (fig. 2). Several factors which were used to help select this site are listed below:

1. North-trending faults show a systematic decrease in number and displacement toward an east-west hinge line near lat 36°52 1/2' N. (Christiansen and others, 1977; Spengler and others, 1979). The drill-hole site was placed near this inferred structural zone close to the central part of the area of interest.

2. High-level aeromagnetic surveys suggest a low-amplitude, east-west-trending magnetic high over Calico Hills extending westward over most of northern Yucca Mountain; the southern extent of which coincides approximately with the southern boundary of the area of interest (G. D. Bath, written commun., 1980) (fig. 2). Because little is known about geologic factors controlling the steeper parts of this anomaly to the south, it was avoided by siting the drill hole in a relatively "quiet area" near the central part of the area of interest.

3. A steep local gravity anomaly over most of northern Yucca Mountain suggests an increase in thickness of tuffs of Tertiary age over the central part of the area of interest (D. B. Snyder, written commun., 1980).

DRILLING HISTORY

USW-G1 was first drilled to a depth of 292 ft, corresponding to the top of the upper vitrophyre within the Topopah Spring Member of the Paintbrush Tuff. Surface casing was set and a hole 3.88 in. in diameter, was cored to 6,000 ft using a wire-line core rig and polymer drilling fluid (table 1). Throughout most of the coring operation, circulation of drilling fluid was poor to nonexistent. Daily fluid losses during coring averaged almost 20,500 gal throughout the entire length of the hole. Most of this loss can be attributed to the high fracture permeability existing within the thick, densely welded zone of the Topopah Spring. While coring below the water table (approximately 1,893 ft; F. E. Rush, oral commun., 1980), the fluid column was reported by drilling specialists of Fenix & Scisson, Inc., to fluctuate between 1,200 and 1,400 ft; an estimate determined while lowering the sand-line to retrieve core samples.

Operational difficulties worthy of note were experienced at a depth of 997 ft where a portion of HQ drill rods and several types of retrieval tools were lost downhole. These problems were chiefly attributed to poor hole conditions at depths of 328, 570, and 824 ft. The situation was remedied by reaming the hole to a diameter of 6.25 in. Unstable zones were secured by cementing from 785 to 1,013 ft and drilling through the cemented zone to a depth of 1,016 ft.

Inclination surveys were made at 100-ft stations during the coring operation. Multishot gyroscopic surveys were obtained at increments of 50 ft upon reaching depths of 1,016 and 6,000 ft. This subsurface directional survey indicated a sizable deviation of the hole in a southwesterly direction. By using the combined-run computation, the drill hole was found to deviate 475 ft south and 400 ft west of its original surface location (fig. 3).

STRATIGRAPHY

Rock units consist entirely of rhyolitic ash-flow tuff, one interval of volcanic breccia of dacitic composition, and subordinate amounts of fine- to coarse-grained volcaniclastic rocks.

Major stratigraphic units penetrated in the drill hole and their respective thicknesses are outlined in table 2. For the most part, stratigraphic nomenclature conforms with that originally applied by Christiansen and Lipman, 1965; Lipman and McKay, 1965; Orkild, 1965; and Byers and others, 1976. Rock units below the Tram unit have not been confidently correlated with mapped units, and therefore, separation of these units was made on the basis of lithologic characteristics. Lithologic variations occurring within each major stratigraphic interval are described in table 3 and presented graphically on plate 1.

Table 1.--Abridged drill-hole history of USW-G1, Yucca Mountain

Location: lat 36°52'0.08", long 116°27'29.28"

Nevada State Coordinates: N. 770,500.2 ft
E. 561,000.5 ft

Ground Elevation: 4,348.6 ft

Drill Rigs: Ideco #40 (surface casing); Joy #1 (drill hole)

Drill-Hole Sizes	
23 in.	0-27 ft
17.5 in.	27-280 ft
8.75 in.	280-290 ft
6.25 in.	290-1,014.5 ft
4.5 in.	1,014.5-1,016 ft
3.875 in.	1,016-6,000 ft

Circulating Media: bentonite, air foam, polymer mud (Nalco WFR) II

Drilling Record: Spudded 3-12-80
Completed coring 8-7-80

Remarks: Bridges at depths of 328, 570, and 824 ft required reaming hole to 6.25 in. and cementing from 785 to 1,013 ft; a total of 58,181 barrels of mud were lost to the formation

Well-Site Geologists: M. P. Chornack, A. J. Gordon, R. B. Livermore, S. L. Koether, R. W. Orsak, L. P. Parrish, G. A. De Paolis, J. B. Warner

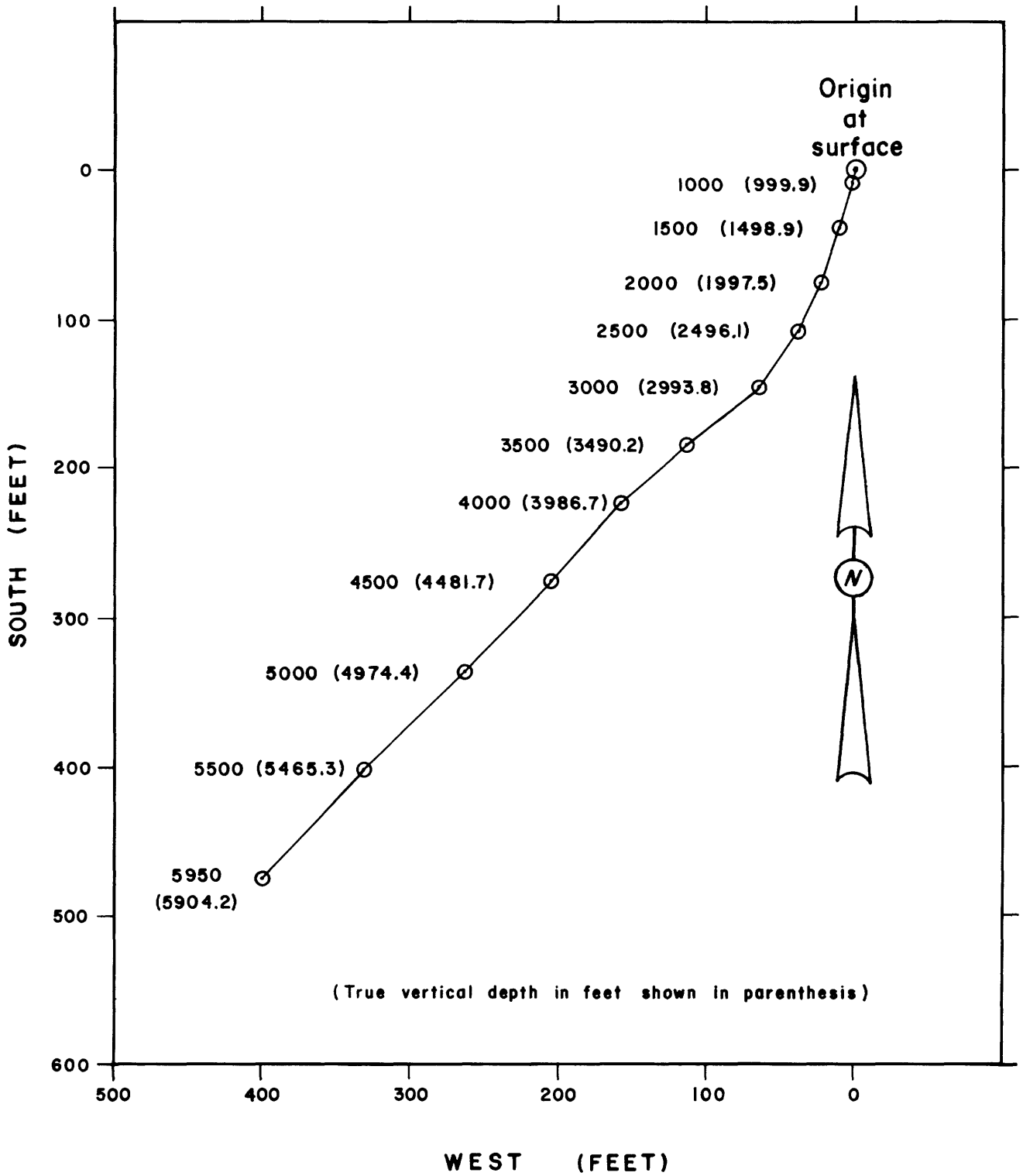


Figure 3.--Horizontal projection of hole deviation in drill hole USW-G1 (derived from Eastman Whipstock Gyroscopic survey).

Table 2.--Major geologic units identified in drill hole USW-G1

Age	Rock Unit	Thickness (ft)
Quaternary	Alluvium and colluvium	60
Miocene	Paintbrush Tuff	
	Yucca Mountain Member	75
	Pah Canyon Member	100
	Topopah Spring Member	1,190.5
	Tuffaceous beds of Calico Hills	376.0
	Crater Flat Tuff	
	Prow Pass Member	372.5
	Bullfrog Member	466.4
	Tram unit (informal unit)	918.8
	Flow breccia[1]	387.6
	Lithic-rich tuff[1]	994.4
	Older ash-flow and bedded tuffs[1]	1,059.8

[1]Age uncertain.

Table 3.--Lithologic log of drill hole USW-G1

[Elev. 4,348.6 ft. Color designations are from the Rock-Color Chart (Goddard and others, 1948)]

Stratigraphic and lithologic description	Thickness of interval (feet)	Depth to bottom of interval (feet)
Alluvium, gravel, sand, silt, containing fragments of densely welded Tiva Canyon Member, and partially welded Yucca Member, a few fragments are partially coated with caliche	60	60
Paintbrush Tuff		
Yucca Mountain Member		
Tuff, ash-flow, grayish-orange-pink and pale-yellowish-brown, partially welded, vapor-phase crystallization; rare pumice, moderate-brown, reddish-brown, and white, vapor-phase, commonly 1-2 mm; rare phenocrysts	25	85
Tuff, ash-flow, pale-yellowish-brown and dark-yellowish-brown, nonwelded, vitric; rare pumice, grayish-orange-pink and light-brown, vitric; rare phenocrysts; contains abundant glass shards	15	100
Tuff, bedded, reworked, white and pinkish-gray, poorly consolidated, vitric; pumice, sparse, white, vitric; mixture of pumice and rhyolitic lithic fragments	35	135
Pah Canyon Member		
Tuff, ash-flow, grayish-orange-pink, nonwelded, vitric; pumice, white, vitric; contains sparse bronze biotite	45	180
Tuff, ash-flow, moderate- to dark-yellowish-brown, nonwelded, vitric; pumice, dark-yellowish-brown, vitric; rare biotite	55	235
Topopah Spring Member		
Tuff, ash-flow, white and grayish-orange, nonwelded, vitric; pumice, white, vitric; conspicuous bronze biotite	10	245
Tuff, ash-flow, grayish-orange-pink to moderate-orange pink, nonwelded, vitric; pumice, yellowish-gray and white, vitric; sparse bronze biotite	5	250
Tuff, ash-flow, grayish-yellow to yellowish-gray, nonwelded, vitric; pumice, grayish-yellow and white, vitric; hornblende and pyroxene present	5	255
Tuff, ash-flow, very pale orange to light-brown, nonwelded, vitric; pumice, light-brown, vitric; hornblende and pyroxene present	15	270
Tuff, ash-flow (vitrophyre), moderate-reddish-brown, densely welded, glassy; 10-15 percent phenocrysts	10	280
Tuff, ash-flow, grayish-red, densely welded, vitric; pumice, pale-red to grayish-red, devitrified (some vapor phase), 2-10 mm; 5-10 percent phenocrysts (sanidine, plagioclase, hornblende and biotite) (quartz latitic caprock)	12.5	292.5
Tuff, ash-flow, grayish-red, densely welded, devitrified; pumice, brownish-gray and grayish-red, very light gray to light-gray, mostly 5 mm to 3 cm, but as large as 5 cm; vapor-phase crystallization; 5-7 percent phenocrysts (predominantly plagioclase and sanidine); sparse light-gray rhyolitic lithic fragments; flattening and alinement of pumice fragments well developed	145.5	438.0
Tuff, ash-flow, light-gray to medium-light-gray, densely welded, devitrified; pumice, white to light-gray and brownish-gray, devitrified, 5 mm to 6 cm; 2-3 percent phenocrysts (sanidine and plagioclase); sparse light-gray rhyolitic lithic fragments; unit contains 10-30 percent lithophysae, mostly 1-3 cm in diameter, but as large as 6 cm	18.5	456.5

Table 3.--Lithologic log of drill hole USW-G1--Continued

Stratigraphic and lithologic description	Thickness of interval (feet)	Depth to bottom of interval (feet)
Paintbrush Tuff--Continued		
Topopah Spring Member--Continued		
Ash, brownish-gray, unconsolidated to poorly consolidated, contains minute pumice fragments and sanidine phenocrysts as well as tridymite and cristobalite	0.4	456.9
Tuff, ash-flow, light-gray to medium-light-gray, densely welded, devitrified; pumice, white to light-gray and brownish-gray, devitrified, 5 mm to 6 cm; 2-3 percent phenocrysts (plagioclase and sanidine); sparse light-gray rhyolitic lithic fragments; unit contains 10-30 percent lithophysae, mostly 1-3 cm in diameter but as large as 6 cm	5.8	462.7
Tuff, ash-flow, light-gray to medium-light-gray, densely welded, devitrified; pumice, light-gray and light-brownish-gray, devitrified, 1-5 cm; 1-2 percent phenocrysts, sparse light-gray rhyolitic lithic fragments	29.8	492.5
Tuff, ash-flow, light-gray to medium-light-gray, densely welded, devitrified; pumice, white to light-gray and light-brownish-gray, devitrified, 5 mm to 6 cm; 2-3 percent phenocrysts (plagioclase and sanidine); rare light-gray rhyolitic lithic fragments; contains 20-30 percent lithophysae, mostly 1-3 cm in diameter, but as large as 6 cm; cavities are commonly lines with secondary minerals, predominantly feldspar	220.9	713.4
Tuff, ash-flow, brownish-gray, pale-reddish-brown (mottled in places), densely welded, devitrified; pumice, light-brownish-gray and brownish-gray, sparse devitrified, less than 1 percent phenocrysts, rare dark-yellowish-brown and medium-light-gray volcanic lithic fragments, rare lithophysae, as large as 3 cm	58.6	772.0
Tuff, ash-flow, light-brownish-gray and very light gray, densely welded, devitrified; pumice, brownish-gray and light-gray, devitrified, commonly 1-2 cm in length; less than 1 percent phenocrysts (sanidine and plagioclase); 5-15 percent lithophysae, ranging from 1-3 cm, commonly filled and spherical	17.3	789.3
Tuff, ash-flow, grayish-red and pale-reddish-brown (mottled), densely welded, devitrified; pumice, light-brownish-gray and very light gray, devitrified, commonly 1-2 cm; less than 1 percent phenocrysts; very light gray to medium-light-gray volcanic fragments, commonly 1-2 cm in length, occasional flattened lithophysae	25.5	814.8
Tuff, ash-flow, pale-red and pale-reddish-brown (mottled), densely welded, devitrified; pumice, grayish-red and pale-red, devitrified, commonly 1-2 cm; less than 1 percent phenocrysts (sanidine and plagioclase); unit contains 5-20 percent lithophysae, mostly 2-3 cm in diameter, but as large as 5 cm, usually completely filled with secondary mineralization; conspicuous increase in light-gray to dark-gray rhyolitic lithic fragments as large as 4 cm (notable accumulation of lithic fragments from 840 to 841.2 ft)	151.7	966.5
Tuff, ash-flow, pale-red and pale-reddish-brown (mottled), densely welded, devitrified; pumice, grayish-red and pale-red, devitrified, commonly 1-2 cm; less than 1 percent phenocrysts; unit contains 20-30 percent lithophysae, commonly 1-2 cm in diameter, but as large as 4 cm, nearly spherical, some flattened, commonly completely filled with secondary minerals; sparse light-gray rhyolitic lithic fragments; core contains numerous very thin (less than 0.5 mm) silica veinlets from 988.3 to 993.5 ft	30.5	997.0

Table 3.--Lithologic log of drill hole USW-G1--Continued

Stratigraphic and lithologic description	Thickness of interval (feet)	Depth to bottom of interval (feet)
Paintbrush Tuff--Continued		
Topopah Spring Member--Continued		
Tuff, ash-flow, grayish-red to moderate-yellowish-brown (mottled), densely welded, devitrified; pumice, grayish-red and medium-gray, devitrified, 1-3 cm, pumice foliation well developed; less than 1 percent phenocrysts; sparse light-gray to medium-gray rhyolitic lithic fragments, commonly 1-3 cm in diameter; 5-15 percent lithophysae, as large as 4 cm, cavities filled with argillic material in upper half of unit, open in lower half; interval from 1,100.6 to 1,107.0 ft contains numerous silica veinlets	202.2	1,199.2
Tuff, ash-flow, grayish-red to moderate-yellowish-brown (mottled), densely welded, devitrified; pumice, grayish-red, devitrified, commonly 1-3 cm in length, foliation of pumice fragments well developed; less than 1 percent phenocrysts; occasional lithophysal cavities; sparse medium-gray rhyolitic lithic fragments, commonly 2-4 cm in length; lower 1.5-2.0 ft of unit appears slightly altered	87.8	1,287.0
Tuff, ash-flow, dark-gray to black (vitrophyre), densely welded, glassy; pumice, black, vitric, commonly 5 mm to 2 cm; 1-2 percent phenocrysts (predominantly sanidine); 1-2 percent rhyolitic lithic fragments, pale-red and gray; concentrated in upper 3 ft of unit	55.4	1,342.4
Tuff, ash-flow, dark-gray, moderately welded, vitric; pumice, light-brown to moderate-brown, vitric, 0.5 to 3 cm; less than 1 percent phenocrysts (sanidine and plagioclase); rare pale-red and light-gray volcanic lithic fragments, 5 mm to 2 cm; groundmass composed of abundant black glass shards	18.1	1,360.5
Tuff, ash-flow, medium-dark-gray, grades downward to dark-yellowish-brown, partially welded to nonwelded, decreases in welding downward, vitric; pumice, light-brown to moderate-brown, vitric, commonly 1-4 cm in length, as large as 8 cm; less than 1 percent phenocrysts; sparse pale-reddish-brown and medium-gray volcanic lithic fragments, 1-2 cm in diameter; abundant glass shards	33.8	1,394.3
Tuff, ash-flow, light-brown and light-brownish-gray, nonwelded, devitrified (slightly silicified, slightly zeolitized); pumice, light-brownish-gray and pale-red, devitrified (some zeolitized), 1-3 cm; less than 1 percent phenocrysts; sparse grayish-red volcanic lithic fragments, 5 mm to 1 cm; unit contains abundance of grayish-red volcanic lithic fragments, 5 mm to 1 cm; unit contains abundance of grayish-red, pale-red, and medium-dark-gray volcanic cobbles ranging in size from 4 to 6 cm from 1,399.0 to 1,399.9 ft	9.6	1,403.9
Tuff, bedded, reworked, light-brownish-gray, light-gray, and pale-reddish-brown; individual beds range in thickness from 0.1 to 2.5 ft; pumice fragments well rounded, generally 5 mm to 1 cm; pale-red beds occasionally silicified; pumice-rich bed from 1,416.0 to 1,417.5 ft	21.6	1,425.5

Table 3.--Lithologic log of drill hole USW-G1--Continued

Stratigraphic and lithologic description	Thickness of interval (feet)	Depth to bottom of interval (feet)
Tuffaceous beds of Calico Hills (informal unit)		
Tuff, ash-flow, light-brown, moderate-orange-pink, and light-olive-gray, nonwelded, devitrified (zeolitized and slightly argillic; pumice, pinkish-gray, yellowish-gray, dusky-yellow, moderate-orange-pink, and light-red, zeolitized, slightly argillic, commonly 5 mm to 2 cm, as large as 3.5 cm; 2-3 percent phenocrysts (sanidine, quartz, and plagioclase); sparse medium-light-gray, grayish-red, and dark-reddish-brown volcanic lithic fragments, commonly 5-30 mm in length, as large as 6 cm; unit shows a gradational downward increase to 4-7 percent lithic fragments 2-3 cm in length from 1,468.0 to 1,482.0 ft; apparent increase in zeolitization from 1,520.9 to 1,540.9 ft	113.7	1,539.2
Tuff, bedded, reworked, moderate-orange-pink to moderate-yellow-green, slightly indurated; 70-80 percent pumice fragments, zeolitized; abundant grayish-red volcanic lithic fragments, 5 mm to 1 cm	1.7	1,540.9
Tuff, ash-flow, grayish-orange, nonwelded, zeolitized; pumice, very pale orange, grayish-yellow to moderate-greenish-yellow, devitrified, zeolitized, commonly 5 mm to 2 cm; less than 1 percent phenocrysts; sparse grayish-red and black volcanic lithic fragments, commonly 2-3 mm, but as large as 2-5 cm	16.2	1,557.1
Tuff, bedded, reworked, and air-fall, moderate-orange-pink; pumice, white to moderate-orange-pink, 10-80 percent zeolitized, 1-10 mm; notable concentration of grayish-brown volcanic lithic fragments, commonly less than 2 mm	1.4	1,558.5
Tuff, ash-flow, light-brown to grayish-orange, nonwelded to partially welded, devitrified and zeolitized (slightly argillic); pumice, grayish-yellow to yellowish-gray and grayish-pink, zeolitized, comonly 1-3 cm in length; less than 1 percent phenocrysts (sanidine and plagioclase); sparse grayish-brown volcanic lithic fragments, commonly less than 2.0 mm, but as large as 1.0 cm	11.8	1,570.3
Tuff, reworked, brownish-gray to olive-gray, zeolitized; pumice, 2 mm to 1 cm, subrounded, conspicuous brownish-gray volcanic lithic fragments, 1-5 mm	.4	1,570.7
Tuff, ash-flow, light-red to moderate-reddish-brown, grayish-orange-pink, and light-brown (mottled grayish-black in places), nonwelded, zeolitized and slightly argillic; pumice, dusky-yellow, yellowish-gray, pale-yellowish-orange, grayish-orange-pink, grayish-orange, and very pale orange, commonly 5-10 mm, but as large as 6 cm, grayish-orange-pink pumice commonly argillic; less than 1 percent phenocrysts, rare grayish-brown volcanic lithic fragments, commonly less than 1.0 cm in size	122.1	1,692.8
Tuff, bedded, reworked and air-fall, moderate-reddish-brown, moderate-orange-pink, pale-olive, and yellowish-gray, zeolitized; pumice, commonly pale-greenish-yellow and grayish-orange-pink, 1-20 mm, subrounded, content within individual beds ranges from 5 to 80 percent; beds range in thickness from 1 to 10 cm; grayish-brown volcanic lithic fragments are conspicuous in some beds, commonly less than 2 mm	2.8	1,695.6

Table 3.--Lithologic log of drill hole USW-G1--Continued

Stratigraphic and lithologic description	Thickness of interval (feet)	Depth to bottom of interval (feet)
Tuffaceous beds of Calico Hills--Continued		
Tuff, ash-flow, pale-olive, light-brown, and grayish-orange-pink, nonwelded, zeolitized; pumice, very pale orange, grayish-pink, yellowish-gray, commonly less than 1 cm, but as large as 4 cm; less than 1 percent phenocrysts; sparse grayish-brown volcanic lithic fragments, commonly less than 1 cm, increase in size and abundance near base of unit, as large as 3 cm near base	40.8	1,736.4
Tuff, bedded, reworked, air-fall, and tuffaceous sandstone, pale-yellowish-brown, pale-olive, yellowish-gray, pale-greenish-yellow, moderate-greenish-yellow, and pale-reddish-brown, varying degrees of zeolitization and silicification; pumice, white, grayish-yellow, and pale-greenish-yellow, zeolitized; beds contain varying amounts of brownish-gray volcanic lithic fragments, commonly less than 1 cm; individual beds commonly 1-3 ft thick, some as thin as 2 cm, lower 2 ft of interval extremely zeolitic	65.1	1,801.5
Crater Flat Tuff		
Prow Pass Member		
Tuff, ash-flow, yellowish-gray, moderate-reddish-orange, light-gray, and light-olive-gray, partially welded, devitrified; pumice, very pale orange, pinkish-gray, and grayish-orange, devitrified (some vitric), commonly 2-10 mm, as large as 6 cm; 5-10 percent phenocrysts (quartz, sanidine, plagioclase, pyroxene pseudomorphs, and biotite); conspicuous moderate-reddish-brown mudstone lithic fragments, commonly 5-20 mm, as large as 3 cm, and moderate-brown volcanic lithic fragments, commonly 5-10 mm; upper 24 ft of interval zeolitized and argillic	61.5	1,863.0
Tuff, ash-flow, light-olive-gray to medium-light-gray, partially welded, devitrified; pumice, medium-gray, vapor-phase crystallization, some slightly argillic, commonly less than 1 cm; 5-10 percent phenocrysts (sanidine, quartz, plagioclase, and sparse biotite); rare moderate-reddish-brown mudstone lithic fragments, less than 0.5 m	3.6	1,866.6
Tuff, ash-flow, light-gray, light-brownish-gray, and grayish-orange-pink, partially to moderately welded, devitrified; pumice, medium-light-gray, light-brownish-gray, very light gray, and brownish-gray, devitrified (slightly argillic), mostly less than 1 cm, but as large as 6 cm; 5-10 percent phenocrysts of sanidine, quartz, plagioclase, biotite, and rare pyroxene; sparse moderate-reddish-brown mudstone lithic fragments, commonly less than 1 cm; part of interval from 1,962 to 1,976.5 ft discolored moderate orange pink due to slight iron oxide staining concentrated around mudstone lithics	109.9	1,976.5
Tuff, ash-flow, light-red and moderate-reddish-orange, partially welded, devitrified; pumice, yellowish-gray and moderate-orange-pink, commonly less than 2 cm (yellowish-gray pumice commonly contains a nucleus of opaque oxides), moderate-orange-pink pumice commonly vapor-phase crystallization; 5-15 percent phenocrysts of sanidine, plagioclase, quartz, pyroxene, and biotite; moderate-reddish-brown mudstone lithic fragments, commonly less than 1 cm, sparse grayish-brown rhyolitic lithic fragments, lower 4.3 ft contains yellow-gray pumice fragments altered to clay and zeolites	10.5	1,987.0

Table 3.--Lithologic log of drill hole USW-G1--Continued

Stratigraphic and lithologic description	Thickness of interval (feet)	Depth to bottom of interval (feet)
Crater Flat Tuff--Continued		
Prow Pass Member--Continued		
Tuff, ash-flow, yellowish-gray and light-olive-gray, partially welded, devitrified; pumice, very pale orange, grayish-yellow, yellowish-gray, devitrified, commonly 5-15 mm; 10-15 percent phenocrysts of sanidine, quartz, pyroxene, and biotite; 2-3 percent moderate-brown volcanic lithic fragments, commonly 2-20 mm, but as large as 3 cm (base of unit rests on 2 cm of air fall, very pale orange and moderate orange pink, 2-5 mm in size, subrounded, slightly argillic, dips about 14° relative to axis of core)	86.9	2,073.9
Tuff, ash-flow, yellowish-gray, grayish-orange-pink, partially to moderately welded, devitrified; pumice, moderate-orange-pink to light-brown, devitrified, 2-30 mm; 5-10 percent phenocrysts of quartz, sanidine, and plagioclase; sparse moderate-reddish-brown mudstone lithic fragments and brownish-gray volcanic lithic fragments, commonly range from 2 to 10 mm	78.1	2,152.0
Tuff, bedded, reworked, air-fall, and tuffaceous sandstone, grayish-orange, moderate-reddish-brown, grayish-yellow, light-brown, and moderate-yellowish-green, zeolitized, slightly argillic (some beds silicified); pumice, devitrified, zeolitized, and partially argillic, subrounded to rounded, content ranges from 1-90 percent, individual beds range in thickness from a few centimeters to a few feet; many contacts gradational; beds commonly dip from 9° to 12° relative to core axis	21.0	2,173.0
Bullfrog Member		
Tuff, ash-flow, moderate-reddish-brown to moderate-reddish-orange, and pale-red, nonwelded, devitrified; pumice, grayish-yellow and moderate-orange-pink, devitrified, 2-10 mm; 10-15 percent phenocrysts of sanidine, plagioclase, quartz, biotite, and hornblende; sparse volcanic lithic fragments; lower 2 ft of interval argillic	6.0	2,179.0
Tuff, ash-flow, grayish-orange-pink, light-brown, and grayish-orange, nonwelded, devitrified and argillic; pumice, grayish-orange-pink, grayish-yellow, and light-brown, devitrified and argillic, 2-30 mm; 10-15 percent phenocrysts of quartz, sanidine, plagioclase, hornblende, and biotite; sparse dark-gray and brownish-gray volcanic lithic fragments (base marked by 7 cm of reworked tuff)	30.5	2,209.5
Tuff, ash-flow, light-brown, and grayish-orange, nonwelded to partially welded, devitrified; pumice, grayish-orange-pink, light-brown, grayish-orange, devitrified and vapor-phase crystallization; 15-20 percent phenocrysts of quartz, sanidine, plagioclase, hornblende, and biotite; rare dark-gray and brownish-gray volcanic lithic fragments, commonly less than 5 mm, but as large as 3 cm; slightly zeolitized and argillic from 2,209.5 to 2,227 and 2,306.7 to 2,307 ft; partially silicified from 2,244.4 to 2,258 ft (gradational); base of unit dips 35° relative to core axis	107.9	2,317.4
Tuff, bedded, reworked, yellowish-gray, moderately indurated; pumice, pinkish-gray and light-brownish-gray, argillic; contains approximately 15-25 percent phenocrysts; sparse dark-gray volcanic lithic fragments	0.5	2,317.9

Table 3.--Lithologic log of drill hole USW-G1--Continued

Stratigraphic and lithologic description	Thickness of interval (feet)	Depth to bottom of interval (feet)
Crater Flat Tuff--Continued		
Bullfrog Member		
Tuff, ash-flow, grayish-orange, light-gray to medium-light-gray, partially welded, vapor-phase zone; pumice, white to medium-light-gray and light-brownish-gray, granophyric crystallization, commonly less than 1 cm, some as large as 2 cm; 10-15 percent phenocrysts of quartz, sanidine, plagioclase, hornblende, and biotite; sparse grayish-red, olive-gray, and brownish-gray mudstone and volcanic lithic fragments, commonly less than 1 cm in size, but as large as 4 cm (0.3-ft concentration of lithic fragments, 2-4 cm in length at 2,433.3 ft)	129.1	2,447.0
Tuff, ash-flow, light-brownish-gray, moderately welded, devitrified; pumice, pale-red, devitrified, some vapor phase, commonly 1-3 cm; 5-20 percent phenocrysts of quartz, sanidine, plagioclase, hornblende, and biotite; sparse pale-reddish-brown mudstone and brownish-gray volcanic lithic fragments (lower contact gradational)	20.0	2,467.0
Tuff, ash-flow, light-brown to moderate-brown, moderately to densely welded, devitrified; pumice, pale-yellowish-brown to pale-brown, devitrified, size ranges from 2 to 30 mm, commonly 1-3 cm; 10-15 percent phenocrysts of quartz, sanidine, plagioclase, hornblende, and biotite; sparse pale-brown volcanic lithic fragments and moderate-reddish-brown mudstone lithic fragments	80.1	2,547.1
Tuff, ash-flow, light-brown, moderately to partially welded, devitrified; pumice, light-brown, pale-yellowish-brown, and light-olive-gray, 5-20 mm, devitrified; 10-15 percent phenocrysts of quartz, sanidine, plagioclase, hornblende, and biotite; sparse brownish-gray mudstone and volcanic lithic fragments, commonly less than 1 cm in length (lower 2 ft of interval is light olive gray); base dips 10° relative to core axis	54.5	2,601.6
Tuff, bedded, reworked, light-brownish-gray, light-olive-gray, pale-green, brownish-gray, and pale-reddish-brown; beds range in pumice content from 5 to 80 percent; beds range in thickness from a few centimeters to several feet; contacts generally gradational; pumice fragments commonly zeolitized, a light-red to moderate-reddish-brown, thinly laminated, less than 2 mm, highly silicified unit 10 cm thick occurs at the base of the bedded interval	37.8	2,639.4
Tram unit (informal unit)		
Tuff, ash-flow, light-brown, light-brownish-gray, and grayish-orange-pink, partially to moderately welded, devitrified; pumice, very pale orange, grayish-orange-pink, moderate-orange-pink, light-brown, and light-brownish-gray, devitrified, commonly ranging from 2 to 20 mm; 10-15 percent phenocrysts of quartz, sanidine, plagioclase, hornblende, and biotite; sparse moderate-reddish-orange, brownish-gray, moderate-brown, and medium-dary-gray tuffaceous and rhyolitic lithic fragments, ranging from 2 to 30 mm, size and abundance increase from 2,751.0 to 2,828 ft (increase to 1-2 cm); a lithic-rich zone is present from 3,053 to 3,126.9 ft and contains 3 to 5 percent lithics, 1-3 cm in diameter, increasing downward; a light-red interval containing a concentration of light-brown pumice 3-7 cm in diameter, occurs from 2,643.6 to 2,645.9 ft; pumice fragments appear slightly altered to clay and zeolites from 3,005 feet to base of interval	443.6	3,083.0

Table 3.--Lithologic log of drill hole USW-G1--Continued

Stratigraphic and lithologic description	Thickness of interval (feet)	Depth to bottom of interval (feet)
Crater Flat Tuff--Continued		
Tram unit--Continued		
Tuff, ash-flow, light-olive-gray, light-brownish-gray (lower 24 ft altered to a grayish-orange and dark-yellowish-orange), partially welded, slightly to moderately zeolitized and argillic; pumice, grayish-orange, pink, white, and light-greenish-gray, argillic and zeolitized, commonly 2-20 mm; 10-15 percent sanidine, plagioclase, and biotite; 5-10 percent greenish-gray, light-gray to dark-gray, and brownish-gray rhyolitic and intermediate lava, and tuffaceous lithic fragments, commonly 5 mm to 4 cm, contains localized intervals (approximately 1 ft thick) containing as much as 50 percent lithics	38.0	3,121.0
Tuff, ash-flow, grayish-red (upper 7 ft slightly altered to pale-yellowish-brown), nonwelded to partially welded, argillic and zeolitized; pumice, white, light-greenish-gray, and grayish-orange-pink, devitrified, zeolitized, and argillic, commonly 2-10 mm, as large as 3 cm; 10-25 percent quartz, sanidine, plagioclase, and biotite; abundant (10-30 percent) very light gray, light-greenish-gray, light-brownish-gray, and brownish-gray rhyolitic and intermediate lava lithic fragments, commonly 5-30 mm	97.3	3,218.3
Tuff, ash-flow, grayish-yellow-green, yellowish-gray, and pale-olive, nonwelded to partially welded, argillic and zeolitized, weakly calcareous in places; pumice, dusky-yellow-green, grayish-yellow-green, grayish-olive-green, argillic (swelling) and zeolitized, occasionally calcareous, commonly 2-20 mm; 10-15 percent quartz, sanidine, plagioclase, biotite, hornblende, and pyroxene(?), sparse fine-grained disseminated pyrite mostly in lithic fragments, pyrite content increases downward; 5-25 percent grayish-yellow-green, brownish-gray, greenish-gray, light-brownish-gray, and light-gray to grayish-black rhyolitic and intermediate lava lithic fragments, commonly 1-6 cm, but as large as 8 cm; base of unit marked by a minor fault zone, 2 cm thick	303.7	3,522.0
Tuff, bedded, reworked, air-fall, and tuffaceous sandstone, light-olive, moderate-greenish-yellow, dusky-yellow-green, moderately indurated, bedding mainly gradational except within interval from 3,533.9 to 3,534.3 ft where distinct laminations, 1-10 cm thick, occur; pumice, dusky-yellow-green and light-olive, argillic and zeolitized, commonly less than 5 mm in length; less than 3 percent dark-gray and brownish-gray volcanic lithic fragments, commonly less than 5 mm, lower 0.8 ft altered to grayish-yellow-green swelling clay; base of unit marked by a fault	36.2	3,558.2
Flow breccia		
Breccia, tuff, dusky-yellow-green and medium-gray, slightly welded, well-indurated, devitrified; pumice, pale-greenish-yellow, grayish-yellow-green, dusky-yellow-green, moderate-yellow-green, argillic; 10 percent plagioclase, hornblende, and biotite phenocrysts, groundmass appears granulated medium-dark-gray, brownish-gray, and greenish-gray dacitic and tuffaceous lithic fragments, poorly sorted, commonly range from 1 to 14 cm in length, subrounded to well-rounded, many of which show crackling; fine to coarse pumiceous matrix	9.8	3,568.0

Table 3.--Lithologic log of drill hole USW-G1--Continued

Stratigraphic and lithologic description	Thickness of interval (feet)	Depth to bottom of interval (feet)
Flow breccia--Continued		
Breccia, flow, light-olive-gray, medium-dark-gray, and grayish-red, devitrified to glassy, poorly sorted; 50-60 percent brownish-gray and dark-gray volcanic dacitic lithic fragments, commonly 2-9 cm in length, angular to subangular, crackled; devitrified groundmass, lower 0.5 ft argillic	56.3	3,624.3
Lava, dacite, medium-gray and light-olive-gray to olive-gray, 10-15 percent phenocrysts (plagioclase and hornblende, which accounts for as much as 10 percent of total phenocryst content)	24.6	3,648.9
Breccia, flow autoclastic, light-olive-gray, olive-gray, and light- to mediumm-bluish-gray, moderately indurated, poorly sorted; dacite fragments, commonly grayish-black and olive-gray, devitrified to glassy, partially argillic, crackled, commonly 2-10 cm in length; groundmass, granular, clayey and (or) calcitic in places; fragments contain plagioclase and hornblende	74.1	3,723.0
Flow, dacitic, greenish-black, devitrified, phenocrysts include plagioclase, biotite and hornblende	3.0	3,726.0
Breccia, flow, autoclastic, light-olive-gray and olive-gray, moderately to well-indurated, abundant (40-50 percent) fragments, olive-black, olive-gray, brownish-gray, and medium-gray, dacitic, slightly argillic, commonly range from 2 to 10 cm in length, contains blocks as large as 2 ft; matrix commonly contains clay and calcite	99.1	3,825.1
Lava, flow, dacitic, dark-greenish-gray, well-indurated, devitrified, slightly argillic; phenocrysts include plagioclase, biotite, and hornblende, slightly brecciated in places	56.4	3,881.5
Breccia, flow, autoclastic, light-olive-gray, olive-gray, olive-black, greenish-black, and grayish-black, poorly sorted, devitrified and glassy; fragments, dacitic, glassy (some devitrified), range in size from 1-60 cm; matrix is slightly argillic	38.5	3,920.0
Tuff, bedded, reworked, air-fall, dark-greenish-gray, moderately indurated, fused(?), devitrified; sparse pumice, grayish-yellow-green and moderate-yellow-green, argillic, commonly less than 1 cm; brownish-black rhyolitic to intermediate lithic fragments, generally less than 1 cm in length	3.9	3,923.9
Tuff, bedded, reworked, greenish-gray, well-indurated, fused, calcitic; pumice, dusky-yellow-green, argillic, generally less than 2 cm; approximately 40 percent dark-greenish-gray and brownish-gray volcanic lithic fragments, commonly 5-30 mm	1.2	3,925.1
Tuff, ash-fall, dark-greenish-gray, partially welded, argillic, calcitic; abundant pumice, dark-greenish-gray, argillic and zeolitized, commonly 1-3 cm, 5-10 percent phenocrysts of sanidine, quartz, plagioclase, and rich in biotite; sparse brownish-gray intermediate lithic fragments, commonly less than 5 mm	17.3	3,942.4
Tuff, bedded, reworked, dusky-yellow-green, well-indurated, zeolitic; pumice, dusky-yellow-green, argillic, commonly less than 5 mm, abundant brownish-gray and dark-gray volcanic lithic fragments, commonly less than 2 mm; distinctive bedding, 1-3 cm thick from 3,942.5 to 3,943.2 ft	3.4	3,945.8

Table 3.--Lithologic log of drill hole USW-G1--Continued

Stratigraphic and lithologic description	Thickness of interval (feet)	Depth to bottom of interval (feet)
Lithic-rich tuff		
Tuff, ash-flow, grayish-yellow-green, light-brownish-gray, dusky-yellow, greenish-gray, brownish-gray, light-olive-gray, and yellowish-gray, partially welded, well-indurated, argillic and zeolitic; pumice, moderate-yellow-green, grayish-green, grayish-yellow, yellowish-gray, and white, argillic (swelling), zeolitic, generally 5 mm to 4 cm (pumice in upper 100 ft is intensely argillic, grades downward into slight to moderate alteration); 5-10 percent phenocrysts of quartz, sanidine, plagioclase, biotite, and conspicuous sphene; interval contains from 5 to 15 percent rhyolitic to intermediate lava lithic fragments, brownish-gray, greenish-gray, olive-black, grayish-black, and brownish black, range in size from 5 mm to 9 cm, commonly 2-4 cm; lithics decrease in size and abundance in lower 40 ft of interval	974.9	4,920.7
Tuff, bedded, reworked, air-fall, yellowish-gray, grayish-yellow-green, and moderate-yellow-green, moderately indurated, individual beds range from 4 cm to 5.0 ft; pumice, grayish-yellow-green, moderate-yellow-green, and grayish-green, devitrified, zeolitized and argillic, subrounded, well-sorted; varying amounts of grayish-brown volcanic lithic fragments, commonly less than 5 mm in length, but range from 2 mm to 2 cm; lowermost bed (1.2 ft thick) is rich in brownish-gray volcanic lithic fragments, constituting 30-40 percent of interval	19.5	4,940.2
Ash-flow and bedded tuff (undivided)		
Unit A		
Tuff, ash-flow, grayish-yellow-green, light-olive-gray, and yellowish-gray, partially welded, well-indurated, devitrified (partially silicified); pumice, pale-greenish-yellow, grayish-yellow-green, and moderate-yellow-green, devitrified, zeolitized, and argillic, vary in size from 5 mm to 5 cm; 10-20 percent phenocrysts of sanidine, quartz, plagioclase, biotite, and sphene; 3-4 percent brownish-gray rhyolitic and intermediate lithic fragments, commonly 5 mm to 2 cm in length	50.6	4,990.8
Tuff, bedded, reworked, air-fall, grayish-yellow-green, grayish-green, and light-olive-gray, devitrified and zeolitized; pumice, moderate-yellow-green, grayish-yellow-green, and grayish-green, slightly zeolitized, partially argillic, rounded fragments; brownish-gray rhyolitic and intermediate lithic fragments, commonly less than 1 cm, some individual beds contain fragments as large as 2 cm; individual beds commonly range from 2 to 14 cm thick; beds dip from 8° to 13° relative to core axis	10.3	5,001.1
Tuff, ash-flow, light-brown, light-brownish-gray, pale-red, grayish-orange-pink, and grayish-orange, moderately welded, partially silicified, devitrified; pumice, grayish-orange-pink, pale-green, light-brown, moderate-brown, pale-brown, and light-olive-gray, argillic and zeolitic, commonly range in size from 2 to 3 mm; 10-20 percent phenocrysts of quartz, sanidine, plagioclase, biotite, hornblende, sphene, and magnetite; 1-3 percent brownish-gray and pale-reddish-brown volcanic lithic fragments, generally less than 2 cm in length	108.9	5,110.0
Tuff, ash-flow, greenish-gray, moderately welded, devitrified, partially silicified and slightly argillic; pumice, greenish-gray, dark-greenish-gray, and dusky-yellow-green, slightly argillic, silicified, commonly less than 2 cm in size; 10-20 percent phenocrysts of quartz, sanidine, plagioclase, biotite, and sphene; light-brownish-gray and brownish-gray intermediate lithic fragments, commonly 5-10 mm	40.0	5,150.4

Table 3.--Lithologic log of drill hole USW-G1--Continued

Stratigraphic and lithologic description	Thickness of interval (feet)	Depth to bottom of interval (feet)
Ash-flow and bedded tuff (undivided)--Continued		
Unit A--Continued		
Tuff, ash-flow, brownish-gray, moderately to densely welded, devitrified (partially vitric and (or) silicified); pumice, dark-greenish-gray, and moderate-yellow-green, zeolitized, commonly less than 1 cm; 10-20 percent phenocrysts of quartz, sanidine, plagioclase, and biotite; less than 5 percent brownish-gray volcanic lithic fragments, commonly 5-50 mm	2.2	5,152.6
Tuff, ash-flow, greenish-gray, light-brownish-gray, and moderate-yellow-green, partially to moderately welded, devitrified; pumice, grayish-yellow-green, and dusky-yellow-green, zeolitized; 10-20 percent phenocrysts of quartz, sanidine, plagioclase, sphene, and biotite; sparse brownish-gray and moderate-reddish-brown volcanic lithic fragments, commonly 5-30 mm	156.7	5,309.3
Tuff, ash-fall and tuffaceous sandstone, pale-greenish-yellow, grayish-green, light-brownish-gray, and yellowish-gray, moderately to well-indurated, dominant rock type is tuffaceous sandstone, well-sorted, grains well-rounded, commonly less than 1 mm in size; basal 0.5 ft consists of argillic ash-fall tuff; beds range from 2 cm to 5.2 ft in thickness, beds dip 3°-4° relative to core axis	10.7	5,320.0
Unit B		
Tuff, ash-flow, grayish-yellow-green, partially welded, argillic; pumice, grayish-yellow-green and moderate-yellow-green, altered to clay, commonly less than 2 cm in length; 5-15 percent phenocrysts of quartz, sanidine, plagioclase, biotite, and sphene; rare brownish-gray volcanic lithic fragments, commonly 5-10 mm	16.6	5,336.6
Tuff, bedded, reworked, pale-green and brownish-gray, moderately indurated, beds range in thickness from 1 cm to 8 ft; lower 8 ft consists of reworked tuff containing abundant moderate-yellow-green subrounded pumice fragments	13.0	5,349.6
Tuff, ash-flow, grayish-yellow-green to moderate-greenish-yellow, nonwelded to partially welded, zeolitic and argillic (partially silicified); pumice, grayish-green, moderate-yellow-green, and grayish-orange, zeolitic and argillic, commonly range in size from 2 to 20 mm; 5-10 percent phenocrysts of quartz, sanidine, plagioclase, biotite, and rare sphene; rare brownish-gray volcanic lithic fragments, commonly 1-2 cm in length; lower 4.5 ft of unit contains ash-flow blocks, grayish-orange, argillic, 8-16 cm in size	18.7	5,368.3
Tuff, bedded, reworked, air-fall, and tuffaceous sandstone, grayish-yellow-green, grayish-green, moderate-orange-pink, and brownish-gray, well-indurated, partially silicified; beds commonly 5 mm to 10 cm in thickness, abundant rounded to subrounded, well-sorted pumice fragments, conspicuous biotite	1.7	5,370.0
Tuff, ash-flow, greenish-gray and grayish-yellow-green, partially welded, zeolitic and argillic, partially silicified; pumice, moderate-yellow-greeen to grayish-green, commonly zeolitic and argillic, commonly ranges from 2 to 20 mm; 5-15 percent phenocrysts of quartz, sanidine, plagioclase, biotite, and sphene; rare brownish-gray rhyolitic to intermediate lithic fragments, commonly less than 5 mm in size; moderate-orange-pink clay alteration occurs from 5,377.6 to 5,380.9 ft; a bed of air-fall tuff occurs from 5,388.0 to 5,388.1 ft; pumice, grayish-yellow-green, subrounded, less than 5 mm in size; contains brownish-gray volcanic lithics, less than 5 mm in size	28.2	5,398.2

Table 3.--Lithologic log of drill hole USW-G1--Continued

Stratigraphic and lithologic description	Thickness of interval (feet)	Depth to bottom of interval (feet)
Ash-flow and bedded tuff--Continued		
Unit B--Continued		
Tuff, air-fall, grayish-yellow-green, moderately indurated, zeolitic and argillic; pumice, yellowish-gray, grayish-yellow, and green, moderately sorted, subrounded, commonly less than 5 mm in size; sparse brownish-gray volcanic lithic fragments, commonly 2-5 mm in length; bed dips 12° relative to core axis	.4	5,398.6
Tuff, ash-flow, light-olive-gray and pale-green, partially to moderately welded, zeolitic and argillic; pumice, moderate-yellow-green, yellowish-gray, light-brownish-gray, and grayish-yellow-green, zeolitic and argillic, commonly less than 1 cm; 5-15 percent phenocrysts of quartz, sanidine, plagioclase, and biotite; sparse brownish-gray rhyolitic lithic fragments, commonly range in size from 5 to 20 mm; two thin air-fall deposits occur within unit from 5,411.2 to 5,411.6 and 5,419.1 to 5,419.6 ft; pumice and brownish-gray lithic fragments commonly less than 5 mm in size	23.4	5,422.0
Tuff, bedded, reworked, air-fall, thick-bedded, grayish-yellow-green to grayish-green and mottled light-red in places, well-indurated, silicified; individual beds commonly range from 1.0 to 5.0 ft; upper 3.0 ft contains abundant pumice fragments (5 mm) and brownish-gray rhyolitic lithic fragments (5 mm); bed from 5,425 to 5,430.0 ft is fine grained, reworked, low in pumice and lithic fragments; beds dip from 9° to 11° relative to core axis	12.0	5,434.0
Unit C		
Tuff, ash-flow, grayish-green, partially welded, zeolitic and argillic, commonly 5-30 mm; 5-10 percent phenocrysts of quartz, sanidine, plagioclase, biotite, and sphene; rare brownish-gray volcanic lithic fragments, commonly less than 5 mm	15.2	5,449.2
Tuff, bedded, reworked, air-fall and tuffaceous sandstone, pale-green, light-olive-gray, grayish-green, moderate-yellow-green, grayish-orange, and brownish-gray; individual beds commonly 1.5-5 ft thick, vary in degree of zeolitization and clay alteration; lithic fragments commonly brownish gray, rhyolitic and less than 1 cm in size; beds dip from 7° to 8° relative to core axis	42.5	5,491.7
Tuff, ash-flow, pale-green to greenish-gray, nonwelded to partially welded, zeolitic and argillic; pumice, yellowish-gray, moderate-yellow-green, and grayish-green, zeolitic and argillic, commonly range in size from 5 to 20 mm; 15-20 percent phenocrysts of sanidine, plagioclase, biotite, sphene, and hornblende; conspicuous amount of brownish-gray rhyolitic lithic fragments varying in size from 5 mm to 6 cm	18.6	5,510.3
Tuff, bedded, reworked, air-fall, light-olive-gray and brownish-gray, moderately indurated, thin-bedded, zeolitic and argillic, fine-grained, individual beds range in thickness from 5 mm to 0.8 ft; beds dip 0°-5° relative to core axis	3.2	5,513.5
Tuff, ash-flow, greenish-gray, nonwelded to partially welded, zeolitic and argillic; pumice, light-greenish-gray, pale-yellowish-green, zeolitic and argillic, commonly 5-20 mm; 15-20 percent phenocrysts of sanidine, plagioclase, biotite, sphene, and hornblende; conspicuous amount of brownish-gray and medium-dark-gray rhyolitic lithic fragments which vary in size from 5 mm to 10 mm	13.0	5,526.5

Table 3.--Lithologic log of drill hole USW-G1--Continued

Stratigraphic and lithologic description	Thickness of interval (feet)	Depth to bottom of interval (feet)
Ash-flow and beded tuff--Continued		
Unit C--Continued		
Tuff, bedded, reworked, air-fall, greenish-gray, brownish-gray, and pale-yellowish-green, zeolitic, argillic, and silicified, moderately indurated; individual beds range from 0.3 to 3.3 ft; lithics are commonly brownish-gray rhyolites, mostly less than 1 cm in size; beds are horizontal relative to core axis	12.3	5,538.8
Tuff, ash-flow, light-olive-gray, nonwelded to partially welded; pumice, yellowish-gray, grayish-yellow-green, and pale-yellowish-green, zeolitic and argillic, commonly 5 mm to 20 cm; 15-20 percent phenocrysts of sanidine, plagioclase, and biotite; sparse brownish-gray rhyolitic lithic fragments, commonly 5 mm to 2 cm	4.0	5,542.8
Tuff, bedded, reworked, and air-fall, greenish-gray, light-olive-gray, grayish-orange, moderately indurated, zeolitic and argillic; thickness of bedding ranges from 1 to 4 ft; beds dip 6°-7° relative to core axis	12.4	5,555.2
Tuff, ash-flow, greenish-gray and light-olive-gray, nonwelded to partially welded, zeolitic and argillic; pumice, pale-green, grayish-green, and pale-yellowish-orange, zeolitic and argillic; commonly 5 mm to 4 cm; 15-20 percent phenocrysts of sanidine, plagioclase, and biotite; medium-dark-gray, brownish-gray, pale-yellowish-green rhyolitic and tuffaceous lithic fragments, commonly 5 mm to 3 cm in size	6.9	5,562.1
Tuff, reworked, greenish-gray and mottled moderate-orange-pink, moderately indurated, moderately argillic; conspicuous amount of brownish-gray rhyolitic to intermediate lithic fragments, 2-10 mm	1.3	5,563.4
Tuff, ash-flow, light-olive-gray and greenish-gray, nonwelded to partially welded; pumice, yellowish-gray, grayish-yellow-green, and moderate-yellow-green, zeolitic and argillic, commonly 5-10 mm; 10-15 percent phenocrysts of sanidine, plagioclase, biotite, and rare sphene; 2-3 percent brownish-gray rhyolite to lithic intermediate fragments, commonly 5 mm to 4 cm in size (abundant biotite occurs in pumice fragments, matrix, and lithic fragments)	18.9	5,582.3
Tuff, ash-flow, greenish-gray and light-olive-gray, moderately to densely welded, devitrified; pumice, dusky-greenish-gray and grayish-green, zeolitic, range in size from 5 mm to 4 cm; 15-20 percent phenocrysts of sanidine, plagioclase, and biotite (in both the matrix and lithic fragments); sparse medium-gray and brownish-gray rhyolitic and intermediate lithic fragments, commonly 5-10 mm, noticeable decrease in size and abundance compared to overlying unit; ash partings less than 2.5 cm thick occur at 5,595.0 and 5,619.2 ft	64.0	5,646.3
Tuff, bedded, reworked, light-greenish-gray, brownish-gray, moderately indurated, zeolitic; beds range in thickness from 5 mm to 1.4 ft; beds commonly pumice rich and contain abundant medium-gray and brownish-gray rhyolitic and intermediate lithic fragments, commonly ranging in size from 5 mm to 2 cm, but as large as 4 cm	2.1	5,648.4
Tuff, ash-flow, grades from brownish-gray to light-olive-gray, partially welded, devitrified, slightly zeolitic; pumice, grayish-yellow, grayish-orange, and light-greenish-gray, zeolitic, commonly 5 mm to 3 cm; 10-15 percent phenocrysts of sanidine, plagioclase, and abundant biotite; sparse rhyolitic to intermediate lithic fragments, brownish-gray, 2-20 mm	10.6	5,659.0

Table 3.--Lithologic log of drill hole USW-G1--Continued

Stratigraphic and lithologic description	Thickness of interval (feet)	Depth to bottom of interval (feet)
Ash-flow and bedded tuff--Continued		
Unit C--Continued		
Tuff, ash-flow, greenish-gray and light-olive-gray (mottled), moderately welded, devitrified, slightly zeolitic, commonly less than 1 cm in size; 15-20 percent phenocrysts of sanidine, plagioclase, and biotite; conspicuous amount of brownish-gray and light-olive-gray rhyolitic and intermediate lithic fragments, commonly 5-25 mm	8.7	5,667.7
Tuff, ash-flow, mottled greenish-gray and light-olive-gray, partially welded, devitrified and slightly zeolitic; pumice, light-greenish-gray, zeolitic, commonly 5-20 mm; 15-20 percent phenocrysts of sanidine, plagioclase, and biotite; sparse brownish-gray and light-olive-gray rhyolitic to intermediate lithic fragments, commonly 5 mm to 2 cm	3.7	5,671.4
Tuff, bedded, reworked, air-fall, and tuffaceous sandstone, light-olive-gray, greenish-gray, and brownish-gray, moderately to highly indurated, zeolitized and silicified, beds commonly range in thickness from 1 cm to 1.5 ft; both pumice-rich and pumice poor beds present; pumice, varying shades of green; pumice-rich beds commonly associated with an abundance of lithic fragments, commonly brownish-gray, rhyolitic to intermediate in composition, commonly range from 2 mm to 2.5 cm; beds dip from 7° to 10° relative to core axis	14.4	5,685.8
Tuff, ash-flow, light-brownish-gray, partially welded, devitrified (partially silicified); pumice, light-greenish-gray, zeolitized, commonly less than 1.5 cm in size; 15-20 percent phenocrysts of sanidine, plagioclase, and abundant biotite; sparse brownish-gray and dark-reddish-brown rhyolitic to intermediate lithic fragments, 2-15 mm	2.4	5,688.2
Tuff, ash-flow, light-olive-gray to greenish-gray, moderately welded, devitrified; pumice, very pale green, grayish-green, and greenish-gray, zeolitized, commonly less than 1 cm; 15-20 percent phenocrysts of sanidine, plagioclase, and conspicuous biotite; 2-3 percent lithic fragments, dark-reddish-brown, brownish-gray, medium-gray, and medium-dark-gray, 2 mm to 4 cm in size, rhyolitic to intermediate in composition, commonly contains biotite	202.8	5,891.0
Tuff, ash-flow, light-brownish-gray, brownish-gray, and greenish-gray, densely welded, devitrified, silicified, and slightly zeolitic; pumice, light-greenish-gray, greenish-gray, light-brownish-gray, and brownish-gray, zeolitic, commonly 1-4 cm; 15-20 percent phenocrysts of sanidine, plagioclase, and biotite; 1-3 percent lithic fragments, dark-reddish-brown and brownish-gray, rhyolitic to intermediate in composition, commonly 5 mm to 3 cm	7.0	5,898.0
Tuff, reworked, greenish-gray to dark-greenish-gray, slightly to moderately indurated, zeolitized; abundant grayish-green subrounded pumice fragments; sparse lithic fragments, brownish-gray, rhyolitic to intermediate, 5 mm to 3.5 cm	.9	5,898.9
Tuff, ash-flow, light-brownish-gray, brownish-gray, and greenish-gray, partially welded, devitrified, slightly zeolitic; pumice, pale-green, greenish-gray, and brownish-gray, slightly zeolitic and argillic, commonly less than 1 cm; 15-20 percent phenocrysts of sanidine, plagioclase, and biotite; 1-2 percent lithic fragments, dark-reddish-brown and brownish-gray, rhyolitic to intermediate lava, 5 mm to 1.5 cm	12.1	5,911.0

Alluvium and Colluvium

Alluvial deposits of Quaternary age, composed of fragments of moderately to densely welded Tiva Canyon and Yucca Mountain Members of the Paintbrush Tuff, extend to a depth of 60 ft below the surface. A noticeable proportion of bit-cutting fragments were coated with a thin, soft veneer of calcium carbonate which aided in distinguishing alluvium from the underlying bedrock.

Paintbrush Tuff

A total of 1,366 ft of ash-flow and bedded tuff designated as the Paintbrush Tuff underlies the central portion of the area of interest. The formation includes, in descending order, the Tiva Canyon, Yucca Mountain, Pah Canyon, and Topopah Spring Members. All four members represent ash-flow tuff sheets separated by thin air-fall tuff and tuffaceous sediments. The upper and lowermost members are compound cooling units compositionally zoned upward from crystal-poor rhyolite to crystal-rich quartz latite, whereas, the intervening Yucca Mountain and Pah Canyon Members represent simple cooling units, crystal poor and rhyolitic in composition.

Tiva Canyon Member

The Tiva Canyon was the only member of the Paintbrush Tuff that was not encountered beneath the alluvial cover at USW-G1. Most of the member is exposed along relatively steep canyon walls surrounding the drill-hole location. This exposed section is densely welded and contains an abundance of lithophysal cavities. The nonwelded, vitric basal unit of the member probably occurs 20-30 ft below ground level along the flanks of the canyon.

Table 3.--Lithologic log of drill hole USW-G1--Continued

Stratigraphic and lithologic description	Thickness of interval (feet)	Depth to bottom of interval (feet)
Ash-flow and bedded tuff--Continued		
Unit C--Continued		
Tuff, ash-flow, light-olive-gray to greenish-gray, moderately welded, devitrified, slightly zeolitic and silicified; pumice, grayish-green, greenish-gray, and dark-greenish-gray, zeolitic, commonly less than 1 cm; 15-20 percent phenocrysts of sanidine, plagioclase, and biotite; sparse lithic fragments, dark-reddish-brown and brownish-gray, rhyolitic to intermediate in composition, commonly 5 mm to 2.5 cm; lower 0.4 ft contains pumice altered to clay and zeolites	24.2	5,935.2
Tuff, bedded, air-fall, light-greenish-gray, grayish-green, light-brownish-gray, and brownish-gray, well-indurated, beds commonly 5 mm to 3.0 cm in thickness; pumice and lithic fragments, commonly less than 5 mm; beds dip 8°-9° relative to core axis	.4	5,935.6
Tuff, ash-flow, brownish-gray, moderately welded, devitrified; pumice, dark-greenish-gray and brownish-gray, zeolitic, commonly 5 mm to 2.5 cm; 20 percent phenocrysts of sanidine, plagioclase, and biotite, phenocrysts, very fine to fine-grained; sparse lithic fragments, dark-reddish-brown and brownish-gray, rhyolitic to intermediate, 2 mm to 2.5 cm	5.4	5,941.0
Tuff, ash-flow, brownish-gray, densely welded, devitrified, silicified; pumice, brownish-gray, greenish-gray, dark-greenish-gray, and moderate-yellow-green, zeolitic, 5 mm to 4 cm; 15-20 percent phenocrysts of sanidine, plagioclase, and biotite, fine-grained; sparse lithic fragments, brownish-gray and medium-dark-gray, rhyolitic to intermediate in composition, 5 mm to 2.0 cm	9.0	5,950.0
Tuff, ash-flow, greenish-gray, moderately welded, devitrified, silicified; pumice, dark-greenish-gray, zeolitized, 5 mm to 3 cm; 20 percent phenocrysts of sanidine, plagioclase, and altered biotite; conspicuous increase in lithics relative to unit above, 2-3 percent, brownish-gray and dark-gray, rhyolitic to intermediate in composition, commonly 1-6 cm in size	50.0	6,000.0
Total Depth		6,000.0

Yucca Mountain and Pah Canyon Members

As in previous subsurface studies (Spengler and Rosenbaum, 1980), both the Yucca Mountain and Pah Canyon Members in the drill hole are nonwelded, vitric ash-flow tuffs. In USW-G1, the Yucca Mountain and Pah Canyon attain thicknesses of 75 and 100 ft, respectively. Approximately 35 ft of bedded tuffs were noted between the Yucca Mountain and Pah Canyon. However, only bit-cutting samples were obtained through these units, and therefore, depths and thicknesses should be regarded as approximate. For purposes of this report the bedded tuffs are included in the Yucca Mountain Member (pl. 1). Near their distal edges, these tuffs are underlain by 5.5 to as much as 19 ft of reworked pumiceous sediments (Spengler and Rosenbaum, 1980).

Topopah Spring Member

The Topopah Spring is the thickest and most widespread member of the Paintbrush Tuff (Lipman and others, 1966). As noted earlier, this member is a compound cooling unit, although deviations from simple cooling are slight. In general, the member represents a typical ignimbrite sheet, wherein nonwelded basal and uppermost parts grade inward through zones of partial welding into a densely welded center part, which in the case of the Topopah Spring Member contains an innermost zone characterized by lithophysae. Superposed on the welding characteristics are intervals of devitrification and vapor-phase crystallization.

Core samples obtained from USW-G1 show that the Topopah Spring attains a total thickness of almost 1,191 ft in USW-G1. The upper 35 ft is nonwelded, vitric, and rests on a reddish-brown vitrophyre approximately 10 ft thick. Directly beneath the vitrophyre, the member contains a zone, about 12.5 ft thick, commonly referred to as "caprock" where the rock is grayish red, quartz latitic, and densely welded.

Below the caprock, the member progressively grades downward into about 146 ft of rhyolitic, densely welded tuff containing a mixture of high- and low-silica pumice. Pumice fragments commonly show evidence of vapor-phase crystallization and typically display a subparallel alinement in the plane of flattening and welding.

A depth of 438 ft marks the initial appearance of four subzones within the densely welded, devitrified zone where the core contains an abundance of lithophysal cavities. These lithophysal zones range in thickness from 17 to as much as 384 ft. Contacts separating the subzones are gradational. Commonly, there is a relative decrease in size and abundance of cavities away from the center of each subzone, except in the uppermost lithophysal zone where a poorly consolidated ash bed abruptly dissects the unit at a depth of 466.5 ft (pl. 1).

Lithophysae are either roughly spherical or slightly flattened perpendicular to the core axis. Many are lined and some are completely filled with secondary minerals such as alkali feldspar, quartz, cristobalite, calcite, and traces of pseudobrookite, montmorillonite, illite, clinoptilolite, hematite, dolomite, and siderite (Spengler and others, 1979).

Near the base, the member consists of a distinct dark-gray to black, densely welded vitrophyric layer about 55 ft thick. Below the vitrophyre, welding progressively decreases although the rock remains glassy. The ash-flow tuff rests on 22 ft of bedded ash-fall and reworked tuff. For convenience, the ash layers found below most major flow units described herein are included as part of the stratigraphic unit of the overlying ash-flow tuff deposit, though they may not always be composed of coignimbrite ash.

Tuffaceous Beds of Calico Hills

Tuffs occupying the stratigraphic interval between the Paintbrush and Crater Flat Tuffs at Yucca Mountain have been assigned to the tuffaceous beds of Calico Hills. In USW-G1, this informal unit consists almost entirely of relatively massive, homogeneous, nonwelded ash-flow tuff separated at four horizons by thin reworked tuff beds. The nonwelded ash-flow tuffs are commonly rich in accidental lithic fragments, most of which are of volcanic origin. Clasts as large as 6 cm in diameter are not uncommon. The entire stratigraphic interval has undergone pervasive zeolitization as indicated by X-ray analyses of five samples collected from both ash-flow tuff and bedded intervals. Zeolites (clinoptilolite and mordenite) constitute 60 to as much as 80 percent of the rock (samples 2-6, table 4).

A 65-ft zone of reworked tuff, air-fall tuff, and tuffaceous sandstone lies directly beneath the ash-flow tuff deposits.

Table 4.--X-ray analyses of selected samples from drill hole USW-G1

[Analyst: P. D. Blackmon, U.S. Geological Survey. Estimated amounts of minerals present are reported as parts of 10; TR, trace (<5 percent) <, less than; > more than; leaders (---) indicate minerals not identified; NWT nonwelded ash-flow tuff; PWT, partially welded ash-flow tuff; MWT, moderately welded ash-flow tuff; RWT, reworked tuff; RFB, dacite flow breccia (matrix filling); AFT, air-fall tuff; stratigraphic symbols defined on pl. 1]

Sample No.	Depth (feet)	Stratigraphic unit	Rock type	Mineral Content										
				Montmorillonite	Illite-mica	Quartz	Feldspar (potassium)	Cristobalite--opaline silica	Amorphous (ash)	Carbonate (acid reaction)	Calcite	Clinoptilolite	Analcime	Chlorite
1	456.5-456.7	Tpt	Ash bed[1]	TR	TR	TR	5	>2	<1	TR	---	---	---	---
2	1,450.5		NWT	[2]TR	---	TR	TR	TR	1	TR	---	[3]8	---	---
3	1,586.5	Tcb	NWT	TR	---	TR	<1	<1	TR	TR	---	[3]8	---	---
4	1,636.0		NWT	TR	---	TR	<1	<1	TR	TR	---	[3]8	---	---
5	1,747.0		NWT	---	TR	<1	<1	<1	<1	TR	---	[3]7	---	---
6	1,799.1		RWT	[4]1	---	---	<1	>1	<1	TR	---	6	---	---
7	1,811.7	Tcfp	NWT	[5]TR	---	TR	>1	1	<1	---	---	>6	---	---
8	1,863.2		NWT[6]	TR	TR	TR	5	4	<1	---	---	---	---	---
9	1,921.7		MWT	TR	TR	3	6	TR	TR	---	---	---	---	---
10	1,985.7		PWT	[5]<1	TR	TR	>4	3	1	---	---	<1	---	---
11	2,190.0	Tcfb	NWT	[2]1	TR	TR	1	TR	<1	TR	---	[3]>6	---	---
12	2,190.5		NWT	[2]1	TR	TR	1	1	<1	TR	---	[3]6	---	---
13	2,207.7		NWT	TR	TR	---	>2	TR	1	TR	---	[3]>5	---	---
14	2,265.4		NWT	---	TR	TR	>3	TR	1	TR	---	[7]>4	---	---
15	2,347.0		PWT	TR	TR	3	6	---	<1	TR	---	---	---	---
16	2,798.0	Tcft	PWT	---	1	>3	5	---	TR	TR	---	---	---	---
17	3,179.2		PWT	[8]>1	TR	>1	>3	---	<1	TR	---	[3]>1	<1	---
18	3,284.5		PWT[9]	[5]<1	TR	>2	2	---	>1	TR	---	[3]3	---	---
19	3,370.9		PWT[10]	[2]>1	TR	>2	>3	---	<1	TR	---	TR	1	---
20	3,708-3,800	Tfb	RFB	2	---	TR	>1	TR	---	TR	---	[3]6	TR	---
21	3,938.5		AFT[11]	[2]>1	TR	2	>4	---	TR	---	TR	TR	TR	<1
22	4,049.0	Trt	PWT	[2]1	TR	>2	3	---	TR	TR	---	---	3	TR
23	4,205.1		PWT	[2]1	TR	>2	>3	---	TR	TR	---	---	>2	TR
24	4,563.0		PWT	[12]>3	TR	3	>2	---	TR	TR	---	---	<1	---
25	4,787.0		PWT	[12]1	TR	3	>3	---	TR	TR	---	---	>1	---
26	4,870.3		PWT	[8]<1	TR	3	4	---	TR	---	TR	---	2	---
27	4,990.0	Tt	PWT	[4]2	---	3	3	---	TR	TR	---	---	2	TR
28	5,066.0		MWT	[4]1	TR	>3	>3	---	TR	---	TR	---	>1	---
29	5,142.2		MWT	TR	>1	3	2	---	TR	TR	---	---	3	---
30	5,239.0		PWT	TR	<1	3	>2	---	TR	---	TR	---	3	---
31	5,378.0		PWT	[12]>2	TR	>1	>2	---	1	TR	---	[3]2	---	---
32	5,436.4		PWT	[12]<1	>1	2	3	---	TR	---	TR	---	>2	TR
33	5,517.3		PWT	[12]>1	<1	>2	>3	---	<1	---	TR	---	<1	TR
34	5,632.2		MWT	[12]<1	<1	>2	>3	---	<1	---	TR	---	1	TR
35	5.871.0		MWT	[12]<1	TR	>2	>4	---	<1	---	TR	TR	TR	<1
36	5,898.7		RWT	[8]>3	<1	<1	3	---	>1	---	TR	<1	---	TR

[1]Contains >10 percent tridymite and traces of hematite.

[2]10-20 percent illite mixed layers.

[3]Contains mordenite.

[4]25-35 percent illite mixed layers.

[5]5-15 percent illite mixed layers.

[6]Contains 10 percent hematite.

[7]1:3 ratio of clinoptilolite/mordenite.

[8]20-30 percent illite mixed layers.

[9]Contains trace of kaolinite.

[10]Contains trace of pyrite.

[11]Contains trace of amphibole.

[12]15-25 percent illite mixed layers.

Crater Flat Tuff

On the basis of similar petrographic features and chemical compositions, suggesting a genetic linkage, three separate, rhyolitic ash-flow tuff sheets found in USW-G1 have been assigned to the Crater Flat Tuff. They include, in descending order, the Prow Pass Member, the Bullfrog Member and a lowermost ash-flow tuff, herein informally designated as the Tram unit. Chemical analyses and calculations of 13 samples taken from all three units indicate that normative percentages of essential minerals include the following: quartz ranges from 32.5 to 40.9 percent; orthoclase, 27 to 31.1 percent; albite, 23.1 to 34.3 percent; and anorthite, 2.6 to 7.2 percent (table 5, fig. 4).

Prow Pass Member

Unlike other stratigraphic units found in USW-G1, the Prow Pass is readily distinguishable based on the presence of orthopyroxene relicts and the abundance of conspicuous reddish-brown mudstone lithic fragments incorporated throughout the ash-flow tuff portion of the member. Examination of four thin sections indicates an average phenocryst content of about 10 percent. Of the total phenocrysts, approximately 11 percent were identified as quartz, 46 percent as potassic feldspar, and 40 percent as plagioclase (fig. 4).

On the basis of gross lithologic features as well as welding characteristics of core specimens, the member can be divided into three subunits. The uppermost subunit, extending from a depth of 1,801.5 to 1,987 ft, is commonly light olive gray to light gray and partially welded, but welding increases from 1,866.6 to 1,976.5 ft. Although predominantly devitrified, pumice lapilli show evidence of vapor-phase crystallization directly above and below the zone of moderate welding. In addition to these zones of primary alteration, conspicuous intervals showing a marked degree of secondary alteration to zeolites and clay minerals were evident at the top and lowermost part of this subunit (pl. 1, col. 1, 2). Analysis by X-ray diffraction methods of one sample collected from the uppermost altered zone indicates that the alteration products are principally clinoptilolite and mordenite and constitute as much as 60 percent of the rock (sample 7, table 4). X-ray analysis of a sample taken at a depth of 1,985.7 ft, within the lowermost altered zone, indicates that the rock contains less than 10 percent clinoptilolite and less than 10 percent montmorillonite (sample 10, table 4). The basal 10 ft has been altered to a light-red color, presumably caused by oxidation of iron-bearing mineral constituents.

The subunit occupying a stratigraphic position near the central portion of the member at depths between 1,987.0 and 2,073.9 ft is relatively homogeneous and nondescript. The ash-flow tuff is light olive gray and partially welded. The only observable criterion believed to be useful in distinguishing this subunit from both the upper and lower subunits is, perhaps, the noticeable increase in size and abundance of mudstone lithic inclusions. A similar subunit was noted in drill hole UE25a-1 (Spengler and others, 1979). In USW-G1, a rather thin, extremely indurated air-fall tuff, less than 4 cm in thickness, separates this subunit from the underlying ash-flow tuff.

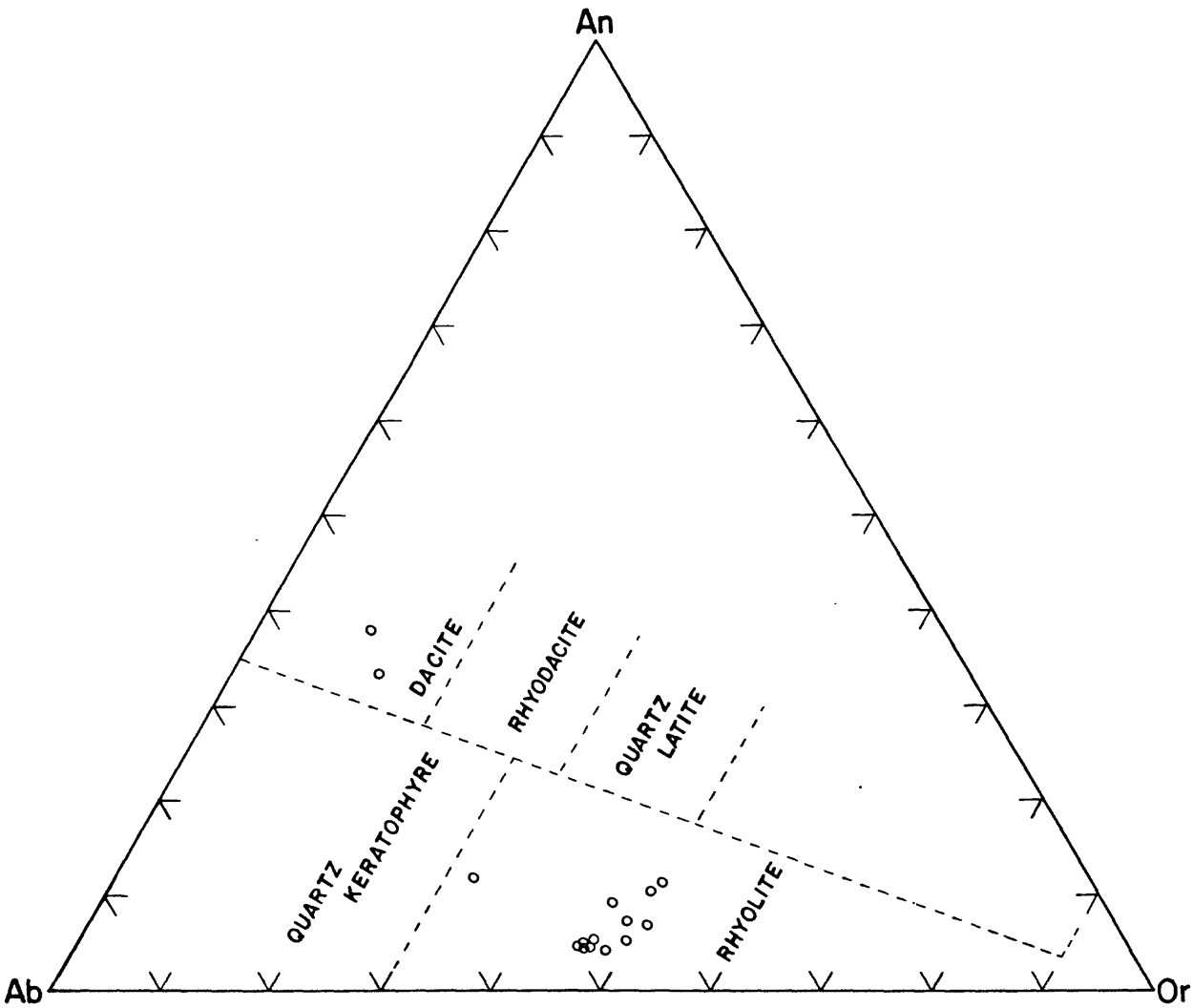


Figure 4.--Normative feldspar ratios of selected samples from the Crater Flat Tuff and flow breccia, and normative classification for silicic volcanic rocks from O'Connor (1965). (Normative Ab, An, and Or are plotted in weight percent recalculated to 100 percent.)

The lowermost subunit of the Prow Pass Member is distinguished by the presence of moderate-orange-pink to light-brown collapsed pumice lapilli. These pumice fragments often display a sufficient degree of parallelism to warrant further study of their preferred orientation; the details of which are presented under "Structural Properties of the Core." The entire subunit is partially to moderately welded and rests on 21 ft of intercalated air-fall tuff, reworked tuff, and tuffaceous sandstone.

Bullfrog Member

The Bullfrog and Prow Pass Members generally resemble one another in regard to having similar percentages of phenocrysts and containing notable concentrations of mudstone lithic fragments

Observations that aid in differentiating the two members at Yucca Mountain include the following: (1) Although mudstone lithics are present, they are markedly smaller and less abundant within the Bullfrog and commonly occur along with a subequal quantity of rhyolitic lithic fragments. (2) Thin-section analysis indicates a conspicuous increase in mafic minerals within the Bullfrog, of which biotite and hornblende relicts represent a significant proportion (fig. 4), and (3) The Bullfrog Member identified in USW-G1 shows a zonal pattern similar to that of simple cooling (Smith, 1960), whereas zonations in the Prow Pass suggest a more complex cooling history.

The upper 36.5 ft of the member is described as nonwelded but grades downward into a zone of partial welding about 108 ft thick. Within this zone, pumice lapilli exhibit vapor-phase crystallization as indicated, megascopically by the preservation of pumice-tube structure, and microscopically by the appearance of tridymite and drusy feldspar.

Within the upper 138 ft, a moderate degree of secondary alteration is evident, particularly within the uppermost 50 ft, and within the 59-ft interval between 2,258 and 2,317 ft (pl. 1, col. 2). Samples collected within each of two intervals at depths of 2,207.7 and 2,265.4 ft, were submitted for analysis by X-ray diffraction methods. Results indicate that clinoptilolite constitutes more than 50 percent of the rock from the upper interval and 40 percent of the rock from the lower interval (samples 13, 14, table 4).

The zone of nonwelding to partial welding is interrupted at depths of 2,209.5 and 2,317.4 ft by two thin, crystal-rich, reworked-tuff intervals (table 3); these partings do not appear to have influenced zonal patterns typical of simple cooling (table 3). The zone of partial welding persists below the lower parting, but the color of core samples changes to light gray and the rock shows evidence of granophyric crystallization in which the vitroclastic texture is almost completely obliterated by the conversion of groundmass to quartz and alkali-feldspar intergrowths. This zone persists downward for about 130 ft and then gradually increases in welding. A depth of 2,467 ft marks the top of an 80-foot zone characterized as moderately to densely welded, and devitrified. It should be noted that, although plate 1 graphically depicts this interval as a zone of dense welding, welding is noticeably less than that found in the densely welded Topopah Spring Member. Below 2,547.1 ft the rock remains devitrified but progressively decreases in the degree of welding.

The base of the ash-flow tuff rests on about 38 ft of bedded and reworked tuff. Bedding within this sequence is predominantly gradational except for the lowermost 10 cm where a distinctive light-red, thinly laminated, highly siliceous, interval occurs.

Tram Unit

The designation Tram unit is informally applied to a thick section of ash-flow tuff that includes some zeolitized bedded tuff at its base. The Tram unit underlies the Bullfrog Member of the Crater Flat Tuff at Yucca Mountain. The term has been applied by P. P. Orkild (USGS) to a tuff exposed in the northern Crater Flat-Beatty Wash area and several other localities in the southwest NTS region. Our present understanding of this ash-flow tuff unit is based partly on core recovered from USW-G1.

The Bullfrog Member and parts of the Tram unit closely resemble one another lithologically and petrographically. Both tuffs are similar in color, varying from light brown to shades of gray; both display similar welding characteristics and phenocryst assemblages. For example, the average phenocryst contents for the Bullfrog and Tram unit average 11.3 and 10.9 percent, respectively (fig. 5).

Despite their similarities, the Bullfrog and Tram have distinctive magnetic and petrographic properties. Measurement of magnetic properties with a portable fluxgate magnetometer has indicated that the remanent magnetization direction is normal for the Bullfrog, but reversed for the Tram unit. The principal petrographic feature differentiating the two tuffs is their quartz content. Within the Tram unit, the average quartz phenocryst content slightly exceeds 31 percent of the total, but is noticeably less in the overlying Bullfrog where it accounts for slightly more than 16 percent of the total phenocryst content (fig. 4). One other feature which may be helpful in distinguishing the two units is the apparent absence of mudstone lithic fragments in the Tram unit.

From the upper surface of the unit to a depth of about 3,005 ft in USW-G1, the Tram exhibits partial to moderate welding and is composed of matrix material which is generally microcrystalline. Below about 3,000 ft, the rock has characteristics suggesting a slight increase in secondary alteration products. X-ray analysis of a sample collected at 3,179.2 ft indicates that the rock contains a little more than 10 percent montmorillonite and a little more than 10 percent mixture of clinoptilolite and mordenite (table 4). In addition to these secondary mineral components, less than 10 percent analcime was identified, which is the highest stratigraphic occurrence of this zeolite in USW-G1 (sample 17, table 4). Size and abundance of lithic fragments increase rather abruptly below about 3,000 ft. In one thin section, lithic inclusions constitute as much as 33 percent of the rock (fig. 4). Most of the lithics consist of rhyolite and intermediate lava.

An abrupt increase in the intensity of alteration, presumably caused by hydrothermal solutions, is evident below a depth of 3,218.3 ft. From this depth to the base of the ash-flow tuff, practically all the rocks are yellowish gray and pale olive in color and have a "bleached" appearance. Alteration products include not only montmorillonite, clinoptilolite,

mordenite, and analcime, but secondary calcite, kaolinite, and pyrite as well (samples 18, 19, table 4). Most of the pyrite appears to be finely disseminated within the abundant rhyolitic lithic fragments, but occasionally pyrite is detectable within the groundmass. A sample was collected from a depth of 3,515.1 ft and submitted for analysis by atomic absorption methods. Results indicated the content of silver and gold to be 20.0 and 0.5 ppm, respectively (P. H. Briggs and V. E. Shaw, USGS written commun., 1980).

The ash-flow tuff is in fault contact with the underlying bedded and reworked tuff interval. This intensely argillic and zeolitic strata is 36.2 ft thick; the base of which is also marked by a fault zone several feet in thickness separating it from the underlying flow breccia (pl. 1).

Flow Breccia

Approximately 362 ft of dacite was identified in the drill hole, most of which is described as flow breccia. In the upper 9.8 ft the unit contains sufficient quantities of pyroclastic material to be catergorized as a tuff breccia (table 3).

Much of the flow breccia is light olive gray to olive black and composed of angular to subangular fragments of dacite, commonly 2-10 cm in diameter along their maximum dimension. Incorporated at various levels, are large blocks of lava from 3 to more than 55 ft in thickness. These blocks are commonly dark greenish gray to greenish black and devitrified, although glassy fragments were identified near the base of the unit. The breccia is autoclastic, suggesting its formation is largely due to fragmentation of semisolid and solid lava during relatively slow movement of the lava flow (Fisher, 1960).

Modal analysis of the rock indicates the complete absence of quartz and potassium feldspar phenocrysts, and an abundance of mafic phenocrysts (fig. 5). The total crystal content is generally less than 15 percent. Mafics, mostly hornblende and clinopyroxene, make up 19.5-28.1 percent of the phenocrysts. Hornblende is commonly uralitized. In two thin sections collected at depths of 3,837 and 3,876 ft, conspicuous amygdules were noted. These cavities are approximately 3 mm in length and 1 mm in width and are commonly filled with chalcedony and calcite. In places, the flow breccia and incorporated lava blocks are moderately altered to clay minerals and zeolites.

Because the rock contains a relatively low percentage of phenocrysts in addition to an appreciable quantity of altered glass, an accurate determination of the rock type is not feasible based on modal analysis alone. Two samples at depths of 3,724.0 and 3,908.2 ft were submitted for chemical analyses. Calculations of normative minerals, Barth's cations, Niggli values, and color index were made by computer methods developed by Stuckless and VanTrump (1979). Calculations suggest an average normative quartz content of 17.2 percent. A quartz content greater than 10 percent allows the use of a normative classification for silicic volcanic rocks based on feldspar ratios (O'Connor, 1965). A plot of the normative albite, anorthite, and orthoclase indicates that the two samples fall well within the dacite field boundary (fig. 4). (It should be noted that, although O'Connor's

classification is based on normative mineralogy in molecular percent as opposed to our use of weight percent, field boundaries are not significantly altered.)

Approximately 26 ft of ash-fall, reworked, and bedded tuff underlies the flow breccia. Similar mineral constituents suggest a genetic link between these tuffs and the overlying flow breccia and most of the upper part of the bedded interval has a volcanic texture suggesting postemplacement fusion. X-ray analyses of one sample, collected at a depth of 3,938.5 ft, indicate that the rock contains more than 10 percent montmorillonite and traces of calcite, clinoptilolite, and analcime (sample 21, table 4).

Lithic-Rich Tuff

The ash-flow tuff sheet below the flow breccia is about 975 ft thick in drill hole USW-G1. Unlike overlying tuff units in USW-G1, this unit, herein referred to as the "lithic-rich tuff", displays a remarkable degree of uniformity and homogeneity with respect to welding characteristics, percentage of phenocrysts, and extent of secondary alteration. This thick section of tuff varies only slightly in color and relative abundance of lithic inclusions. Lithics are commonly rhyolitic and intermediate in composition.

As indicated in the lithologic log (table 3), the lithic-rich tuff is generally green and gray, consistently displays partial welding, and exhibits a moderate secondary alteration in the form of clay minerals and zeolites. X-ray analyses of five samples show that montmorillonite constitutes from 10 to as much as 30 percent of the whole rock. Analcime ranges from less than 10 to 30 percent. Traces (less than 5 percent) of calcite and chlorite were also detected (samples 22-26, table 4).

Lithic inclusions constitute 5 to as much as 15 percent of the rock; sizes commonly range from 5 mm to 9 cm. The abundance of lithics is a diagnostic feature of the tuff. The Tram unit is the only other rock unit found in the drill hole than contains a similar concentration of lithic fragments. Total lithic content determined from thin sections ranges from as low as 6 to as high as 43 percent of the rock (fig. 4). Although the rock contains lithics ranging in composition from rhyolite to rhyodacite, a predominant number possess a conspicuous "spherulitic" texture. These spherulitic lithics are composed of alternating intergrowths of quartz and feldspar radiating outward from a central part of the fragment. Similar types of lithics are present in other tuffs but not in the abundance found in the this unit.

Crystal content is low within the lithic-rich tuff (fig. 4). The phenocryst content of 10 thin sections from this unit ranges from 18.3 percent near the extreme top to a low of 5.5 percent near the center of the unit and averages about 9.5 percent. Quartz, potassium feldspar, and plagioclase average 5.6, 34.3, and 54.7 percent of the phenocryst content, respectively. Two of the more diagnostic features helpful in distinguishing the lithic-rich tuff from other tuffs found in USW-G1 include (1) a conspicuously low quartz content, and (2) the presence of notable amounts of sphene as an accessory mineral.

About 20 ft of bedded and reworked tuffs separate this unit from the underlying tuffs.

Older Ash-Flow and Bedded Tuffs

A rock sequence, dominantly composed of ash-flow tuffs with subordinate interbedded ash-fall and moderately reworked pumiceous sediments, occupies a stratigraphic position in USW-G1 between 4,946.4 ft and the bottom of the drill hole (6,000 ft). Informally referred to as "older ash-flow and bedded tuffs", these tuffs have not been correlated with any previously mapped units in the region. These tuffs vary in color from shades of green to gray, are partially to moderately welded and (or) moderately indurated and, for the most part, show evidence of sporadic zeolitization and silicification. X-ray analyses coupled with thin section studies indicate that these rocks contain as much as 30, 20, and 30 percent montmorillonite, clinoptilolite, and analcime, respectively. Traces (less than 5 percent) of calcite and chlorite have also been detected (samples 27-36, table 4).

On the basis of the relative abundance of essential minerals in these ash-flow tuff deposits, three units, A, B, and C, have been identified. These subdivisions occupy intervals between 4,940.2 and 5,320 ft; 5,320 and 5,434 ft; and 5,434 ft and the total depth of the drill hole, respectively. It is not yet known whether or not these units are continuous over the entire area of interest.

Unit A is almost entirely composed of one thick, uniform ash-flow tuff varying from grayish yellow green to light brown gray. The rock is commonly partially to moderately welded, devitrified, and partially silicified. Near the uppermost part of the flow, a zone of partial welding is separated from the thicker zone of moderate welding by 10 ft of bedded tuff (pl. 1). The rock averages about 17 percent phenocrysts, of which quartz is 26.2 percent, potassium feldspar 33.5 percent, plagioclase 36.9 percent, and biotite 2.1 percent. Accessory apatite, zircon, and sphene also occur as phenocrysts in the groundmass. Except for a slightly higher phenocryst content, fewer lithic fragments, and the presence of sphene, this unit could easily be mistaken for Tram unit. Approximately 10 ft of bedded tuff occurs at the base of this unit.

A noticeable decrease in quartz and potassium feldspar marks the boundary between units A and B. Unit B is principally made up of alternating partially to moderately welded zones. All contacts between welded units are marked by bedded tuff horizons (pl. 1). This unit apparently represents a transition zone between quartz-rich unit A and quartz poor unit C, as indicated by modal analyses, showing from top to bottom, a progressive decrease in quartz from 26.7 to 10.5 percent and potassium feldspar from 35 to 25.6 percent. Thin sections also reveal a corresponding increase in plagioclase from 36.3 to 58.8 percent (fig. 5).

Unit C is predominantly made up of brownish-gray and greenish-gray, moderately welded ash-flow tuffs separated by reworked tuffaceous sediments. One of the more conspicuous zones within this unit occurs within the upper 148 ft where bedded tuffs are thicker and more frequent. This zone probably reflects a period of increased subsidence during continual volcanism. The

magnitude of regional subsidence is indicated by the occurrence of these continental deposits of Tertiary age at elevations more than 960 ft below sea level.

Plagioclase averages about 83 percent of the phenocryst content in subunit C. Quartz and potassium feldspar are relatively low, averaging 1.2 and 3.3 percent, respectively. Accessory hornblende, biotite, sphene, and rare pyroxene are also present.

STRUCTURAL PROPERTIES OF THE CORE

Considerable attention was devoted to examining the structural characteristics of core recovered from the drill hole. Of the 5,708 ft continuously cored in USW-G1, 5,513.7 ft (96.6 percent) were successfully recovered. At the drill site, 21 percent of the recovered core was wrapped in heavy-gauge aluminum foil, labelled, and sealed with beeswax to preserve "in situ" moisture content of the core. The remaining 4,353.9 ft of core was carefully examined for structural features which include layering attitudes, evidence of faulting, frequency of occurrence and inclinations of shear fractures and joints, and types of fracture coatings.

Foliation and Layering

It is difficult to control the direction and amount of horizontal deviation in deep exploratory holes, as exemplified in USW-G1 where the hole ultimately deviated by more than 14° in a southwesterly direction (fig. 3). In table 3 of this report, information was presented on the inclinations of pseudo-bedding planes relative to the axis of the recovered core. The range is from 0° to 35°, but some of the dips may be misleading particularly below 3,000 ft, because the deviation from vertical of the drill hole was not taken into account. In an attempt to gain information about the "true" attitude of structural features with a reasonable degree of precision, approximately 11 percent of the core was collected using oriented coring techniques. The method employs the use of an orienting core barrel, similar to conventional core barrels, except that three triangular scribes are mounted in the shoe at the base of the inner barrel. A survey instrument, which includes a compass and multishot camera is enclosed within a nonmagnetic drill collar and mounted on top of the inner core barrel, alined with the orienting scribe. The recording of the drift direction and reference groove orientation allows core segments to be spatially reoriented to their original position.

Primary intervals targeted for the recovery of oriented core include bedded intervals, which occur between major ash-flow units and densely welded zones of ash-flow tuffs where the parallel alinement of pumice fragments is moderately to well developed. Difficulties associated with the collection of oriented core from these target horizons include the following: (1) bedded intervals were commonly thin and poorly stratified and (2) well-developed eutaxitic structure (foliation shown by flattened pumice) rarely was seen below the Topopah Spring Member of the Paintbrush Tuff.

Figure 6 shows the location of stratigraphic intervals where meaningful measurements were taken. These intervals include portions of (A) the Topopah

Spring Member of the Paintbrush Tuff, (B) the Prow Pass Member of the Crater Flat Tuff, (C) the Bullfrog Member of the Crater Flat Tuff, and (D) selected bedded intervals occuring at depths between 4,293 and 5,899 ft. Within the Topopah Spring, data points were collected between the intervals of 638 and 654 ft, 729 and 738 ft, and 1,169 and 1,178 ft. The most pronounced foliation occurred within the lowermost of the three intervals. As shown, the direction of dip of the foliation ranges from N. 73° E. to S. 13° E. by 4° to as much as 19°. The average dip and direction is 10.5° S. 74° E.

Although not as pronounced as in the Topopah Spring, foliated pumice fragments are also present within the Prow Pass Member at depths between 1,952 and 1,957 ft and between 2,092 and 2,111 ft, correlative with subunits B and C, respectively (on fig. 6, symbols which correspond to the upper and lower intervals point north and south, respectively). Foliation trends dip toward directions ranging from N. 46° E. to S. 55° E. by amounts varying from 5° to 17°.

Only five structural attitude observations were made within the Bullfrog Member, at depths of 2,181.8, 2,183.3, 2,457.6, 2,462.0, and 2,463.0 ft, of which the upper two are inclined toward N. 85° E. and the latter three between S. 29° E. and S. 38° E. Dips range from 5° to 13°.

In contrast to foliation trends, bedding planes below a depth of 4,293 ft are commonly inclined less than 10° in a preferred south to southwesterly direction.

Fractures

Fracture frequencies, represented in columns 4 and 5 of plate 1, are segmented into two discrete subsets: joints and shear fractures. As in earlier studies (Spengler and others, 1979; Spengler and Rosenbaum, 1980) joints are defined as fracture planes along which differential movements were not apparent during megascopic examination of the core. Although similar in relative distribution and types of coatings, shear fractures, by definition, show evidence of movement in the form of minor offsets of pumice fragments and (or) striations and slickenside grooving on fracture faces.

Shear Fractures and Fault Zones

A total of 61 shear fractures were recognized in core samples from USW-G1 between depths of 324.8 and 5,468.4 ft (col. 5, pl. 1). Examination revealed that most shears are preferentially associated with particular rock types as well as with conspicuous fault zones. Shears predominantly occur within the extensive densely welded zone of the Topopah Spring Member and in flow breccia, which contains the highest proportion. This distribution undoubtedly reflects the behavior of highly brittle rock masses intercalated with softer, more pliable partially welded and nonwelded tuff units.

Examination of shear-fracture inclinations revealed that 39 percent of the shears are preferentially inclined between 60° and 80° relative to the axis of the core (fig. 7). Where obtainable, the rake of striations measured along these fracture faces suggests a sizable component of lateral movement

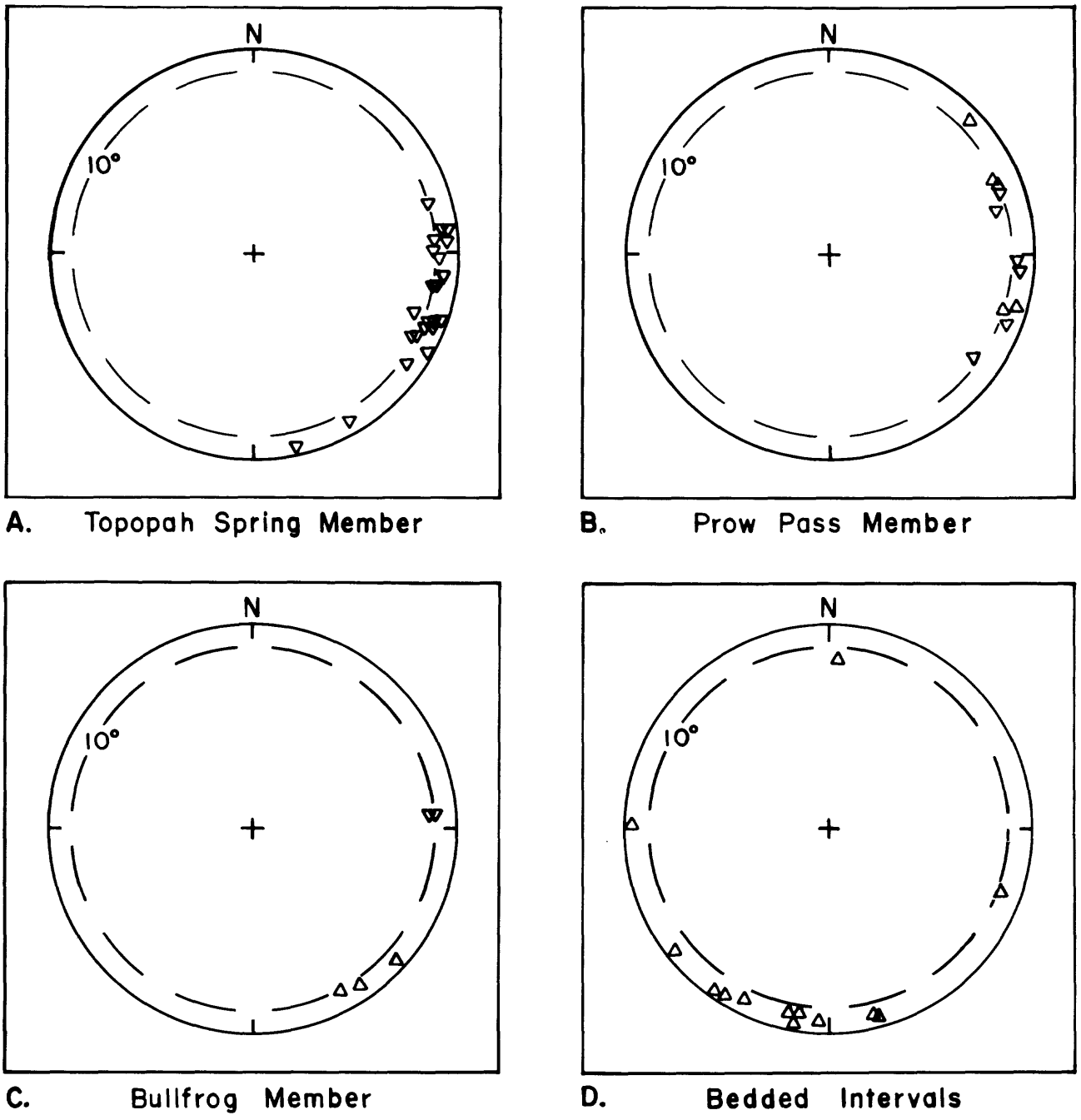
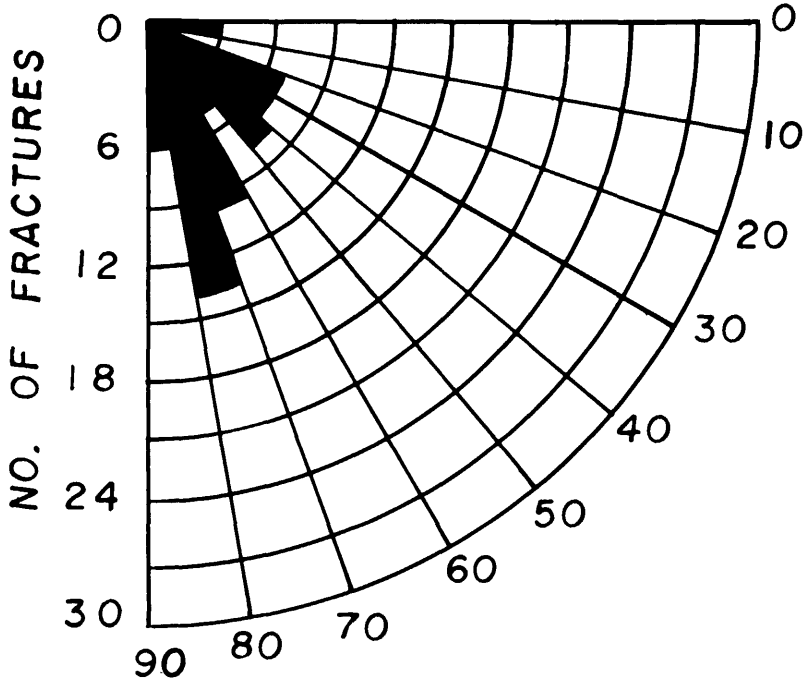


Figure 6.--Orientation of (A) foliation in Topopah Spring Member; (B) foliation in Prow Pass Member; (C) foliation in Bullfrog Member; and (D) bedding in bedded intervals between 4293 and 5899 feet, USW-G1. (Amount and direction of dip plotted on lower hemisphere of equal-area projection.)

INCLINATION OF SHEAR FRACTURES



INCLINATION OF STRIATIONS ON FRACTURE FACES (RAKE)

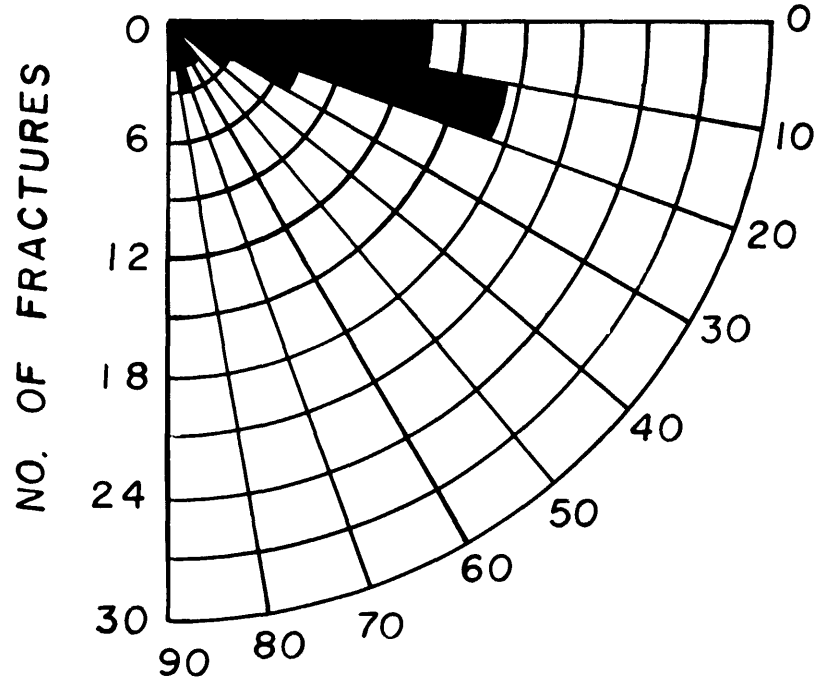


FIGURE 7.-- STRUCTURAL DIAGRAMS SHOWING INCLINATIONS OF SHEAR FRACTURES AND CORRESPONDING RAKE OF STRIATIONS

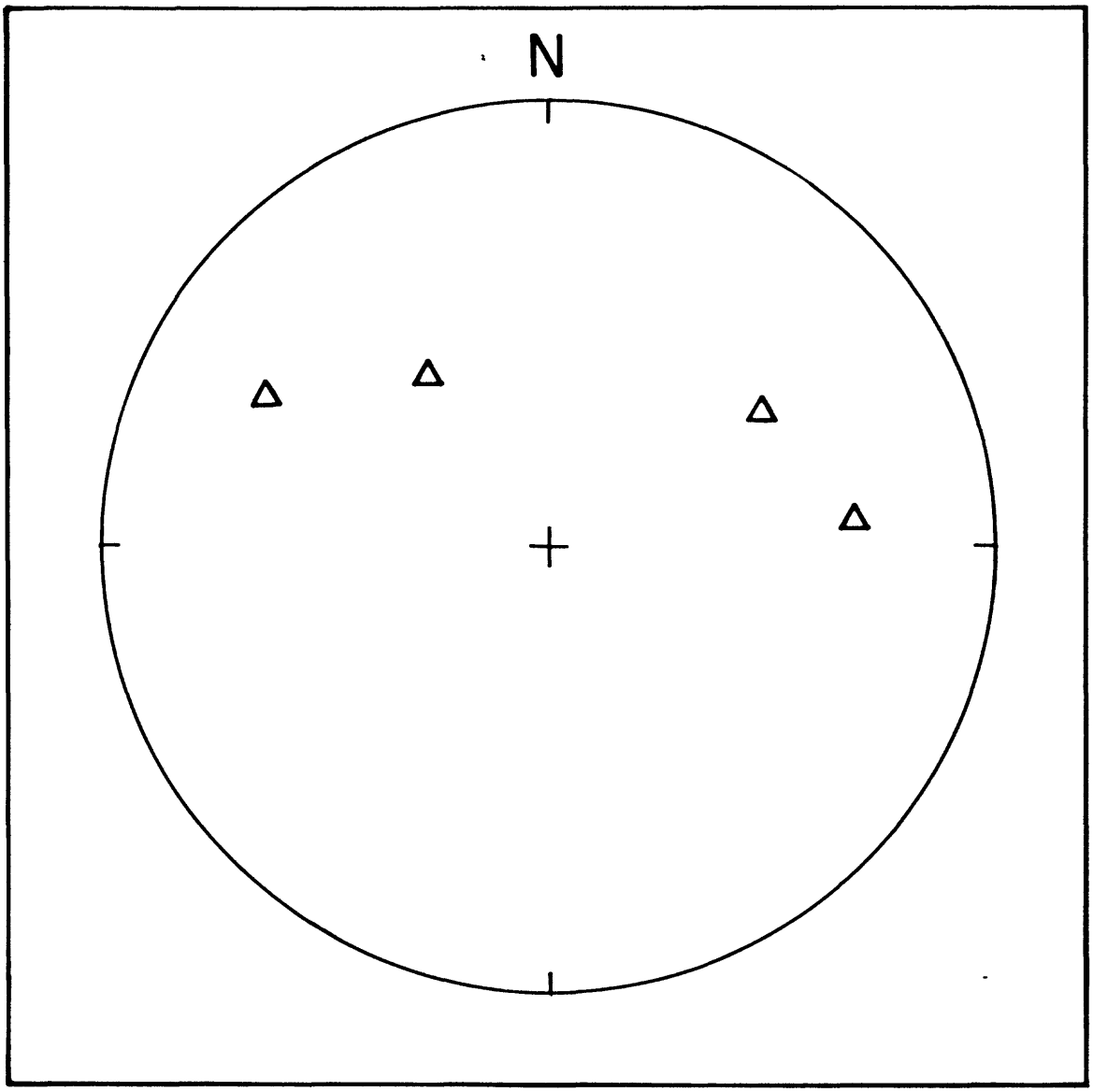


Figure 8.--Orientation of shear-fracture poles between 3552.5 and 3558.2 feet in USW-G1

similar to observations made from core derived from UE25a-1 (Spengler and others, 1979).

Although prominent fault zones found in USW-G1 can easily be recognized by the relative increase in the number of shear fractures, the magnitude of displacement along any of the zones could not be determined. Four of the more conspicuous fault zones, two of which occur within the flow breccia, are clearly illustrated on plate 1. These zones, arbitrarily selected on the basis of a thickness of 5 ft or more, not only contain an abundance of shears, but also display a combination of other structural features which include the presence of (1) clay gouge, (2) fault breccia, and (3) highly granulated core segments. Minor zones, most of which occur in the Topopah Spring Member are reported in table 6.

Acquisition of oriented core between 3,551.5 and 3,558.2 ft afforded a rare opportunity to study the subsurface trend of one of these fault zones, occurring in the bedded interval between the Tram unit and flow breccia. Unfortunately, a preferred orientation is not apparent, as illustrated on figure 8 where the attitudes of four measurable shear planes are N. 28° E. 64° SE., N. 5° W. 61° SW., N. 55° E. 41° SE., and N. 33° W. 50° SW. Fractures striking N. 5° W. and N. 55° E. show oblique slip with a strong component of right-lateral horizontal movement.

Joints

A total of 528 joints were identified and their inclinations recorded with respect to the axis of the core. Cursory examination of column 4, plate 1, suggests a close association of joint frequency with degree of welding. Similar to previous studies (Spengler and others, 1979), the ocurrence and distribution of jointing suggest that densely welded ash-flow tuffs generally are highly fractured at Yucca Mountain, whereas, bedded tuffs and nonwelded to moderately welded ash-flow tuffs are less fractured. Three exceptions to this generalization include: (1) zones showing secondary silicification, (2) the moderately to densely welded zone in the Bullfrog Member, and (3) the flow breccia.

Pronounced joint development is largely confined to the Topopah Spring Member and the Tram unit where 49.6 and 22.2 percent of the total joints occur, respectively (fig. 9a). Very few joints occur within the tuffaceous beds of Calico Hills where only five joints were noted near the top and base.

Figure 9a illustrates the distribution of joint inclinations (percent age of joints in each 10° increment) for each of the eight major stratigraphic intervals. Inclinations are expressed in degrees of dip as measured from the horizontal, assuming a near-vertical drill hole.

Similar to observations made in UE25a-1 (Spengler and others, 1979), the majority of joints in the Topopah Spring show a near-vertical joint trend preferentially inclined between 70° and 90°. These joints were probably formed in response to tensional forces active during cooling of the thick densely welded zone. Even though joints found in the Topopah Spring represent about 50 percent of the total, considerably less jointing occurs within the

Table 6.--Intervals less than 5 ft thick showing evidence of faulting

Interval (ft)	Stratigraphic unit	Characteristics
926.9- 927.1	Topopah Spring Member	Fault breccia
931.6- 932	Topopah Spring Member	Fault breccia
1,122.8-1,134.1	Topopah Spring Member	Fault breccia
1,199.7-1,199.8	Topopah Spring Member	Fault breccia
1,267.0-1,269.3	Topopah Spring Member	Fault breccia minor offset at 1,269.3 ft
2,281.4-2,282.1	Bullfrog Member	Slickensides and clay gouge
3,522.0	Tram unit	Offset
5,338- 5,340	Older ash-flow and bedded tuffs	Slickensides and clay gouge
5,348.6-5,349.1	Older ash-flow and bedded tuffs	Fault breccia, slickensides

Topopah Spring at USW-G1 than at UE25a-1 (Spengler and others, 1979). The average number of joints per 10-ft interval within the Topopah Spring Member at USW-G1 and UE25a-1 is 2.2 and 4.5, respectively.

Compilation of joint inclinations within the tuffaceous beds of Calico Hills and the three tuff sheets comprising the Crater Flat Tuff show the presence of two discrete joint sets, although inspection of their occurrence did not reveal any distinct vertical separation of the two sets within any of the ash-flow tuff units. Within the Prow Pass Member and Tram unit, low-angle jointing represents the master of the two sets, ranging in inclination from 0° to 30°.

Jointing in major stratigraphic units subjacent to the Tram unit accounts for about 19 percent of the total joints and indicate similar preferred inclinations to one another. The flow breccia displays the widest range of joint inclinations, showing a subequal number of joints occupying increments between 40° and 80°. More than 70 percent of the joints identified in the lithic-rich tuff dip between 70° and 90°. Most of the 29 joints measured below lithic-rich tuff are inclined between 50° and 80° (fig. 9a).

Fracture Coatings

About 88 percent of the joint and shear surfaces showed evidence of at least a partial coating of secondary minerals. Coatings or lack of coatings are discussed for 516 of the 589 fractures. The remaining 73 fractures were excluded mainly because they occurred in wrapped samples, and therefore, verification of their surface features was not possible. Because these fractures account for only 12 percent of the total and appear evenly distributed throughout most of the major stratigraphic intervals, their elimination from the study probably does not significantly alter any preliminary trends drawn from the remaining data.

Approximately 40 percent of the 516 fractures were described as "healed". This term applies to fractures along which secondary minerals have completely filled any void space, and breakage along fracture planes did not occur during core recovery. The percentage of "healed" fractures should be viewed as conservative, because only those fractures that contain bonding material strong enough to withstand breakage during core recovery were counted. For example, several fracture faces were completely covered with secondary minerals but were not counted as healed based on the above criteria. Stratigraphic units where more than 70 percent of the fractures are healed, include: (1) tuffaceous beds of Calico Hills, (2) Bullfrog Member, (3) Tram unit, and (4) lithic-rich tuff.

Fracture coatings and fillings found in USW-G1 commonly range in thickness from 1 to 3 mm, although some fractures contain coatings as thick as 4 and 5 mm. In most cases the principal type of coating was recorded. Where more than one type of coating occurred in approximately subequal proportions, a footnote is provided on figure 9b to describe its significance. In decreasing order of abundance, the types of fracture coatings observed are as follows: silica (35 percent), manganese and iron oxides (24 percent), calcite (22 percent), and clay (6.6 percent). These percentages are similar to those reported in UE25a-1 (Spengler and others, 1979). Coatings were absent along

12.3 percent of the examined fractures, most of which occur within the Topopah Spring Member and the flow breccia.

The stratigraphic column can be subdivided into three discrete zonations based on the type of fracture coatings. Histograms (fig. 9b) display the relative abundance of coatings in each major stratigraphic interval. Silica, found along 67 percent of the fractures, is the dominant coating within the Topopah Spring Member. On the other hand, fractures occurring within the interval extending from the base of the Topopah Spring to the top of the flow breccia, are dominated by manganese and iron oxide coatings. More than 66 percent of the fractures in this zone contain this coating. Below the Tram unit, calcite was identified along 60 percent of the fractures.

Core Index

The CI (core index) number represents a summation of the joint frequency, core loss, and broken core (core less than 4 in. in length) into one significant number (J. R. Ege, written commun., 1975). The equation used to compute the CI is expressed as:

$$CI = \frac{(\text{ft broken}) + (\text{ft core loss}) + (1/3 \text{ joints})}{(\text{drilled interval, ft})} X100$$

An increase in the CI corresponds to an increase in joint frequency, core loss, and (or) broken core and, therefore, relates to structural competency. As shown on plate 1, a decrease in the competency of the rock is commonly associated with (1) densely welded zones, (2) silicified zones, and (3) fault zones. Broken lines indicated on plate 1 denote intervals where an increase in CI can be attributed to mechanical difficulties during core recovery and, therefore, these values do not accurately reflect the competency of the rock.

SUMMARY

A few of the more salient geologic features recognized in core recovered from USW-G1 include the following:

1. Stratigraphic units found in USW-G1 include, in descending order: The Paintbrush Tuff (Tiva Canyon, Yucca Mountain, Pah Canyon, and Topopah Spring Members), tuffaceous beds of Calico Hills, the Crater Flat Tuff (Prow Pass and Bullfrog Members, and Tram unit), flow breccia, lithic-rich tuff, and older ash-flow and bedded tuffs.

2. Individual ash-flow tuff units vary in thickness from 25 to as much as 994 ft. Intervening volcaniclastic tuff intervals vary from less than 1 ft to as much as 42.5 ft.

3. The ash-flow tuff units are generally nonwelded to moderately welded, except near the middle of the Bullfrog and in most of the Topopah Spring where moderate to dense welding is dominant.

4. Above 3,005 ft, ash-flow tuffs are commonly devitrified to locally vitric, except in the tuffaceous beds of Calico Hills where the rock is altered to as much as 80 percent zeolites (clinoptilolite and mordenite). Rock units below 3,005 ft show a marked increase in secondary alteration to clay (montmorillonite, illite, kaolinite), zeolites (clinoptilolite, mordenite, analcime), and chlorite.

5. Finely disseminated pyrite occurs within the lower portion of the Tram unit from 3,218.3 ft to its base. This iron sulfide occurs mainly in abundant rhyolite lithic fragments, although on occasion it is also present within the groundmass.

6. In ash-flow tuffs where eutaxitic structure is moderately developed, pumice fragments commonly dip less than 10° in directions varying from northeast to southeast. Bedded intervals below 4,293 ft commonly are inclined less than 10° toward the southwest.

7. A total of 61 shear fractures were recognized in USW-G1; the majority are distributed throughout the flow breccia and within the four conspicuous fault zones. The rake of striations along these shears suggests a dominant component of lateral slip.

8. A total of 528 joints were found in USW-G1, corresponding to an average frequency of 0.90 joints per 10-ft interval. This frequency is notably less than that reported in UE25a-1, where the average frequency was 3.8 joints per 10-ft interval (Spengler and others, 1979). Increases in joint occurrences are commonly associated with an increase in the degree of welding. Deviations from this pattern occur in (1) densely welded Bullfrog, (2) flow breccia, and (3) silicified zones. High joint frequencies occur mainly in the Topopah Spring, Tram unit, and flow breccia where 49.6, 22.2, and 7.9 percent of the total joints occur, respectively.

9. Similar to fracture distribution, increases in the CI index are closely associated with (1) densely welded zones, (2) highly silicified intervals, and (3) fault zones.

REFERENCES CITED

Byers, F. M. Jr., Carr, W. J., Orkild P P., Quinlivan, W D., and Sargent, K. A., 1976, Volcanic suites and related cauldrons of Timber Mountain-Oasis Valley caldera complex, southern Nevada U.S. Geological Survey Professional Paper 919, 70 p.

Christiansen, R. L., and Lipman, P. W., 1965, Geologic map of the Topopah Spring NW quadrangle, Nye County, Nevada: U S Geological Survey Geologic Quadrangle Map GQ-444, scale 1:24,000.

Christiansen, R L., Lipman, P. W., Carr, W J., Byers, F M. Jr. Orkild, P. P., and Sargent, K. A., 1977, Timber Mountain-Oasis Valley caldera complex of southern Nevada: Geological Society of America Bulletin, v.88, p. 943-959.

Fisher, R. V., 1960, Classification of volcanic breccias: Geological Society of America Bulletin, v. 71, p. 973-982.

Goddard, E. N., chm., and others, 1948, Rock-color chart: Washington, National Research Council (reprinted by Geological Society of America, 1975).

Lipman, P. W., Christiansen, R. L., and O'Connor, J. T., 1966, A compositionally zoned ash-flow sheet in southern Nevada: U.S Geological Survey Professional Paper 524-F, p. F1-F47.

Lipman, P W., and McKay, E. J., 1965, Geologic map of the Topopah Spring SW quadrangle, Nye County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-439, scale 1:24,000.

O'Connor, J. T., 1965, A classification for quartz-rich igneous rocks based on feldspar ratios: U.S. Geological Survey Professional Paper 525-B, p. B79-B84.

Orkild, P. P., 1965, Paintbrush tuff and Timber Mountain Tuff of Nye County, Nevada, in Changes in stratigraphic nomenclature by the U.S. Geological Survey: U.S. Geological Survey Bulletin 1224-A, p. A44-A51.

Smith, R L, 1960, Zones and zonal variations in welded ash flows: U S. Geological Survey Professional Paper 354-F, p. F149-F159.

Spengler, R. W., Muller, D. C, and Livermore, R. B., 1979, Preliminary report on the geology and geophysics of drill hole UE25a-1, Yucca Mountain, Nevada Test Site: U S. Geological Survey Open-File Report 79-1244, 43 p.

Spengler, R. W., and Rosenbaum, J. G., 1980, Preliminary interpretations of geologic results obtained from boreholes UE25a-4, -5, -6, and -7, Yucca Mountain, Nevada Test Site: U.S. Geological Survey Open-File Report 80--929, 33 p.

Stuckless, J. S., Van Trump, George, Jr., 1979, A revised version of graphic normative analysis program (GNAP) with examples of petrologic problem solving: U.S. Geological Survey Open-File Report 79-1237, 112 p.

GPO 833-883

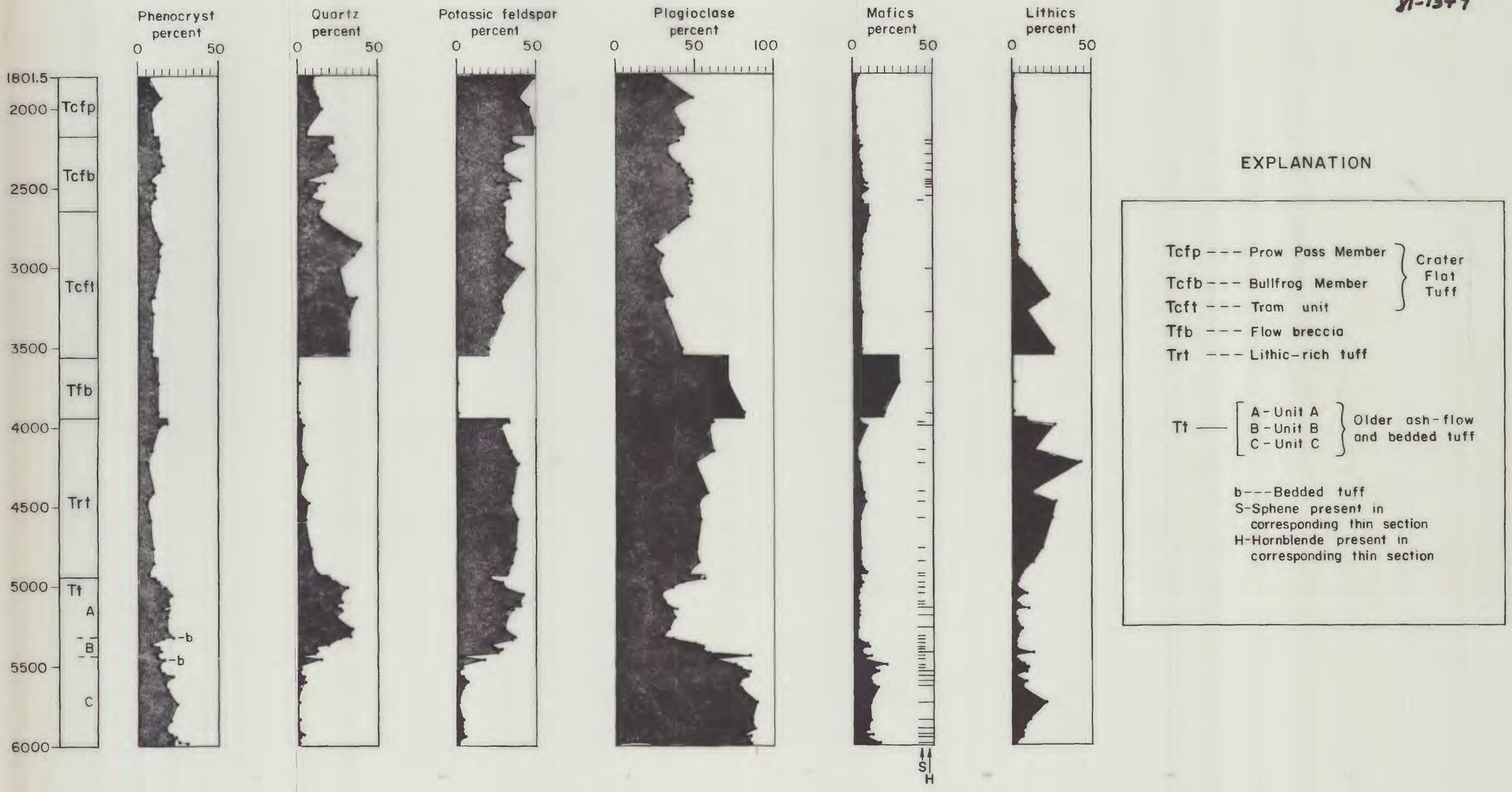
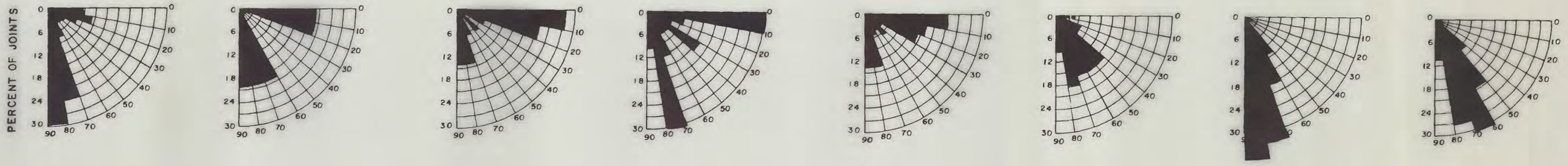
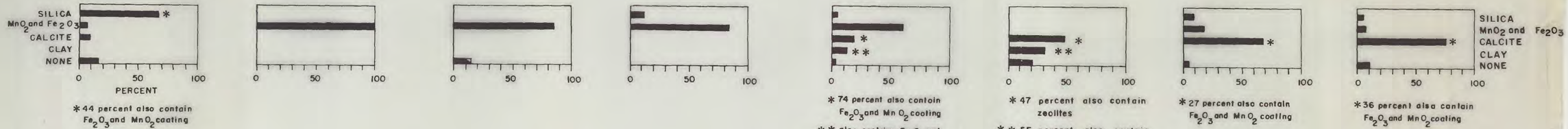


Figure 5.-- Modal phenocryst and lithic contents in stratigraphic units below the tuffaceous beds of Calico Hills

81-1349

STRATIGRAPHIC UNIT	TOPOPAH SPRING MEMBER	TUFFACEOUS BEDS OF CALICO HILLS	PROW PASS MEMBER	BULLFROG MEMBER	TRAM UNIT	FLOW BRECCIA	LITHIC-RICH TUFF	OLDER ASH-FLOW TUFFS
INTERVAL (FEET)	292-1425.5	1425.5-1801.5	1801.5-2173.0	2173.0-2639.4	2639.4-3558.2	3558.2-3945.8	3945.8-4940.2	4940.2-6000.0
PERCENT OF JOINTS PER 10° INCREMENT								
NUMBER OF MEASURED JOINTS	262	5	14	32	117	42	27	29
PERCENT OF TOTAL JOINTS	49.6	1.0	2.6	6.1	22.2	7.9	5.1	5.5
AVERAGE NUMBER OF JOINTS PER 10-FOOT INTERVAL	2.3	0.1	0.4	0.7	1.3	1.2	0.3	0.3

A.--INCLINATIONS OF JOINTS WITHIN STRATIGRAPHIC UNITS

TYPES AND PERCENT OF FRACTURE FILLINGS								
	*44 percent also contain Fe_2O_3 and MnO_2 coating				*74 percent also contain Fe_2O_3 and MnO_2 coating; **also contains Fe_2O_3 and MnO_2 coating	*47 percent also contain zeolites; **55 percent also contain zeolites	*27 percent also contain Fe_2O_3 and MnO_2 coating	*36 percent also contain Fe_2O_3 and MnO_2 coating
NUMBER OF EXAMINED FRACTURES	251	3	14	25	101	63	22	37
PERCENT OF "HEALED" FRACTURES	19.5	100	57.1	80	75.3	30	77.3	46

B.--TYPES AND PERCENT OF FRACTURE FILLINGS WITHIN STRATIGRAPHIC UNITS

FIGURE 9.--INCLINATION OF JOINTS AND TYPES OF FRACTURE FILLINGS WITHIN RESPECTIVE STRATIGRAPHIC UNITS

Table 5.--Chemical analyses and calculations of normative minerals, Barth's cations, Niggli values, and color index for selected samples from the Crater Flat Tuff and flow breccia in USW-G1

[Analyst: J. S. Wahlberg, J. Taggart, J. Baker; computer calculations made by methods reported by Stuckless and Van Trump, 1979; stratigraphic symbols defined on pl. 1; leaders (---) indicate minerals not identified]

Stratigraphic unit	Tcfp	Tcfb	Tcfb	Tcfb	Tcfb	Tcft	Tcfb	Tcfb	Tcft	Tcft	Tcft	Tcft	Tcft	Tfb	Tfb
Depth	1,943.4	2,354.6	2,397.4	2,461.5	2,470.6	2,678.3	2,507.0	2,557.0	2,678.0	2,772.6	2,851.7	2,931.4	3,013.9	3,724.0	3,908.2
SiO_2	74.70	75.00	74.30	75.20	75.20	74.20	74.50	69.80	69.40	73.10	73.80	74.40	74.50	56.30	53.70
Fe_2O_3	1.29	1.21	1.37	1.14	1.36	1.14	1.21	1.18	1.35	1.32	1.70	1.45	1.42	5.80	7.34
MgO	.19	.19	.19	.15	.14	.15	.16	.21	.27	.50	.31	.31	.35	2.15	2.34
CaO	.52	.64	.65	.57	.61	.61	.60	1.34	1.11	1.18	.91	.89	1.17	4.61	4.90
Na_2O	3.51	3.15	3.42	3.52	3.69	3.70	3.67	3.73	3.09	2.38	3.02	3.15	2.66	3.88	3.60
K_2O	5.10	4.94	4.77	4.79	4.87	5.00	4.92	3.15	4.62	4.38	5.17	4.97	4.64	1.36	1.02
TiO_2	.10	.11	.12	.10	.11	.10	.10	.11	.16	.15	.22	.17	.15	.93	.97
P_2O_5	---	---	---	---	---	---	---	---	---	---	.06	---	---	.06	.31
MnO	.02	.08	.07	.08	.08	.08	.09	.04	.03	.05	.08	.04	.04	.04	.05
H_2O	.91	.70	.88	.72	.58	.67	.57	7.34	5.84	3.15	.87	.89	2.28	5.54	6.20
TOTAL(-O)	99.44	98.82	98.97	99.17	99.84	98.95	99.02	99.40	98.57	99.11	99.14	99.07	99.61	99.22	99.03
ADJUSTED OXIDES - H_2O FREE															
SiO_2	75.81	76.44	75.75	76.38	75.76	75.50	75.67	75.82	74.84	76.18	75.10	75.78	76.54	60.10	57.85
Al_2O_3	13.30	13.05	13.46	13.10	13.30	13.53	13.41	13.58	13.70	13.44	13.23	13.04	12.74	19.53	20.04
Fe_2O_3	1.31	1.23	1.40	1.16	1.37	1.16	1.23	1.28	1.46	1.38	1.73	1.48	1.46	6.19	7.91
MgO	.19	.19	.19	.15	.14	.15	.16	.23	.29	.52	.32	.32	.36	2.30	2.52
CaO	.53	.65	.66	.58	.61	.62	.61	1.46	1.20	1.23	.93	.91	1.20	4.92	5.28
Na_2O	3.56	3.21	3.49	3.58	3.72	3.76	3.73	4.05	3.33	2.48	3.07	3.21	2.73	4.14	3.88
K_2O	5.18	5.03	4.86	4.87	4.91	5.09	5.00	3.42	4.98	4.56	5.26	5.06	4.77	1.45	1.10
TiO_2	.10	.11	.12	.10	.11	.10	.10	.12	.17	.16	.22	.17	.15	.99	1.04
P_2O_5	---	---	---	---	---	---	---	---	---	---	.06	---	---	.33	.33
MnO	.02	.08	.07	.08	.08	.08	.09	.04	.03	.05	.08	.04	.04	.04	.05
NORMATIVE MINERALS - H_2O FREE															
Q	33.867	36.810	35.148	35.500	33.834	32.573	33.317	35.699	33.393	40.872	34.808	35.332	39.291	17.419	16.960
C	.873	1.129	1.253	.902	.755	.704	.758	.563	.645	2.187	.941	.632	.899	2.995	3.670
Or	30.587	29.751	28.736	28.751	28.993	30.063	29.531	20.220	29.441	26.972	31.089	29.914	28.171	8.579	6.493
Ab	30.144	27.165	29.503	30.254	31.457	31.856	31.543	34.284	28.197	20.987	26.004	27.149	23.126	35.046	32.815
An	2.618	3.236	3.287	2.872	3.049	3.079	3.023	7.221	5.938	6.100	4.195	4.497	5.964	22.251	24.005
En	.480	.482	.482	.379	.351	.380	.405	.568	.725	1.298	.786	.786	.896	5.716	6.278
Mt	---	---	---	---	---	---	.004	---	---	---	---	---	---	---	---
Hm	1.309	1.233	1.397	1.158	1.370	1.160	1.226	1.282	1.456	1.376	1.730	1.477	1.495	6.191	7.907
Il	.043	.174	.153	.174	.172	.174	.193	.093	.069	.111	.174	.087	.088	.091	.115
Ru	.079	.020	.042	.010	.020	.010	---	.071	.136	.098	.132	.127	.108	.945	.984
Ap	---	---	---	---	---	---	---	---	---	---	.145	---	---	.784	.791
TOTAL	100.000	100.001	100.001	100.001	100.001	100.001	100.001	100.001	100.000	100.001	100.004	100.001	100.001	100.018	100.018
SALIC	98.089	98.091	97.927	98.280	98.087	98.277	98.173	97.987	97.614	97.118	97.038	97.523	97.450	86.291	83.943
FEMIC	1.912	1.910	2.074	1.721	1.914	1.724	1.828	2.013	2.386	2.882	2.967	2.478	2.550	13.727	16.075
BARTH'S CATIONS															
Si	70.90	71.75	70.94	71.50	70.84	70.46	70.69	70.84	70.10	71.90	70.57	71.13	72.20	55.95	54.13
Al	14.65	14.43	14.85	14.46	14.65	14.89	14.76	14.95	15.12	14.95	14.65	14.42	14.16	21.43	22.10
Fe+3	.92	.87	.98	.82	.96	.81	.86	.90	1.03	.98	1.22	1.04	1.04	4.34	5.57
Mg	.27	.27	.27	.21	.20	.21	.23	.32	.41	.73	.44	.44	.51	3.18	3.52
Ca	.53	.66	.66	.58	.62	.62	.61	1.46	1.20	1.24	.93	.91	1.21	4.91	5.29
Na	6.46	5.84	6.33	6.49	6.74	6.81	6.75	7.34	6.05	4.54	5.60	5.84	5.00	7.48	7.04
K	6.18	6.03	5.81	5.81	5.85	6.06	5.96	4.08	5.95	5.50	6.31	6.06	5.74	1.72	1.31
Ti	.07	.08	.09	.07	.08	.07	.07	.08	.12	.11	.16	.12	.11	.69	.74
P	---	---	---	---	---	---	---	---	---	---	.05	---	---	.26	.26
Mn	.02	.06	.06	.06	.06	.06	.07	.03	.03	.04	.06	.03	.03	.03	.04
NIGGLI VALUES															
Al	47.64	48.06	48.00	48.02	47.39	47.74	47.60	47.03	46.60	48.27	45.96	46.25	46.47	38.58	37.28
Fm	7.84	8.04	8.47	7.26	7.92	7.00	7.50	7.88	8.99	11.31	10.85	9.73	10.53	27.20	30.79
C	3.44	4.37	4.30	3.86	3.98	3.98	3.93	9.17	7.41	8.03	5.85	5.85	7.97	17.67	17.85
Alk	41.08	39.53	39.23	40.86	40.71	41.28	40.97	35.92	37.00	32.39	37.34	38.17	35.22	16.56	14.08
Si	461.02	477.87	458.46	475.07	458.10	451.99	455.86	445.67	432.15	464.19	442.71	456.24	435.22	201.39	182.62
Ri	.46	.53	.56	.48	.50	.46	.46	.53	.75	.72	.99	.78	.72	2.50	2.48
P	---	---	---	---	---	---	---	---	---	---	.15	---	---	.47	.45
K	.49	.51	.48	.47	.46	.47	.47	.36	.50	.55	.53	.51	.53	.19	.16
Mg	.22	.22	.21	.19	.16	.19	.19	.25	.28	.42	.26	.29	.32	.42	.39
Si'	264.30	258.13	256.92	263.43	262.86	265.10	263.89	243.66	248.01	229.56	249.37	252.66	240.89	166.23	156.32
Qz	196.71	219.74	201.54	211.63	195.25	186.88	191.97	202.00	184.14	234.62	193.33	203.58	232.93	35.16	26.30
Al_2O_3/SiO_2	.175	.171	.178	.172	.176	.179	.177	.179	.183	.176	.176	.172	.166	.325	.346
FeO/Fe_2O_3															
USER DEFINED VARIABLES															
C.I.	1.833	1.890	2.032	1.711	1.894	1.714	1.828	1.943	2.250	2.785	2.690	2.350	2.442	11.998	14.300