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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

VOLCANO-TECTONIC HISTORY OF CRATER FLAT, SOUTHWESTERN NEVADA, AS SUGGESTED BY NEW EVIDENCE FROM DRILL HOLE USW-VH-1 AND VICINITY

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By

W. J. Carr

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VOLCANO-TECTONIC HISTORY OF CRATER FLAT, SOUTHWESTERN NEVADA, AS SUGGESTED BY NEW EVIDENCE FROM DRILL HOLE USW-VH-1 AND VICINITY

By

W. J. Carr

ABSTRACT

New evidence for a possible resurgent dome in the caldera related to eruption of the Bullfrog Member of the Crater Flat Tuff has been provided by recent drilling of a 762-meter (2,501-foot) hole in central Crater Flat. Although no new volcanic units were penetrated by the drill hole (USW-VH-1), the positive aeromagnetic anomaly in the vicinity of the drill hole appears to result in part from the unusually thick, densely welded tuff of the Bullfrog. Major units penetrated include alluvium, basalt of Crater Flat, Tiva Canyon and Topopah Spring Members of the Paintbrush Tuff, and Prow Pass and Bullfrog Members of the Crater Flat Tuff.

In addition, the drill hole provided the first subsurface hydrologic information for the area. The water table in the hole is at about 180 meters (600 feet), and the temperature gradient appears slightly higher than normal for the region.

INTRODUCTION

As a part of the exploration and technical evaluation of the Yucca Mountain area at the Nevada Test Site (fig. 1) for an underground nuclear waste storage repository, a 762.3-m (2,501-ft) hole, designated USW-VH-1, was drilled in central Crater Flat. Drilling began in October and was completed in December 1980. Hydrologic testing was completed in February 1981. The hole was drilled by Reynolds Electrical and Engineering Company for the U.S. Department of Energy, Las Vegas, Nevada. The U.S. Geological Survey (USGS) sited the drill hole and is interpreting results obtained.

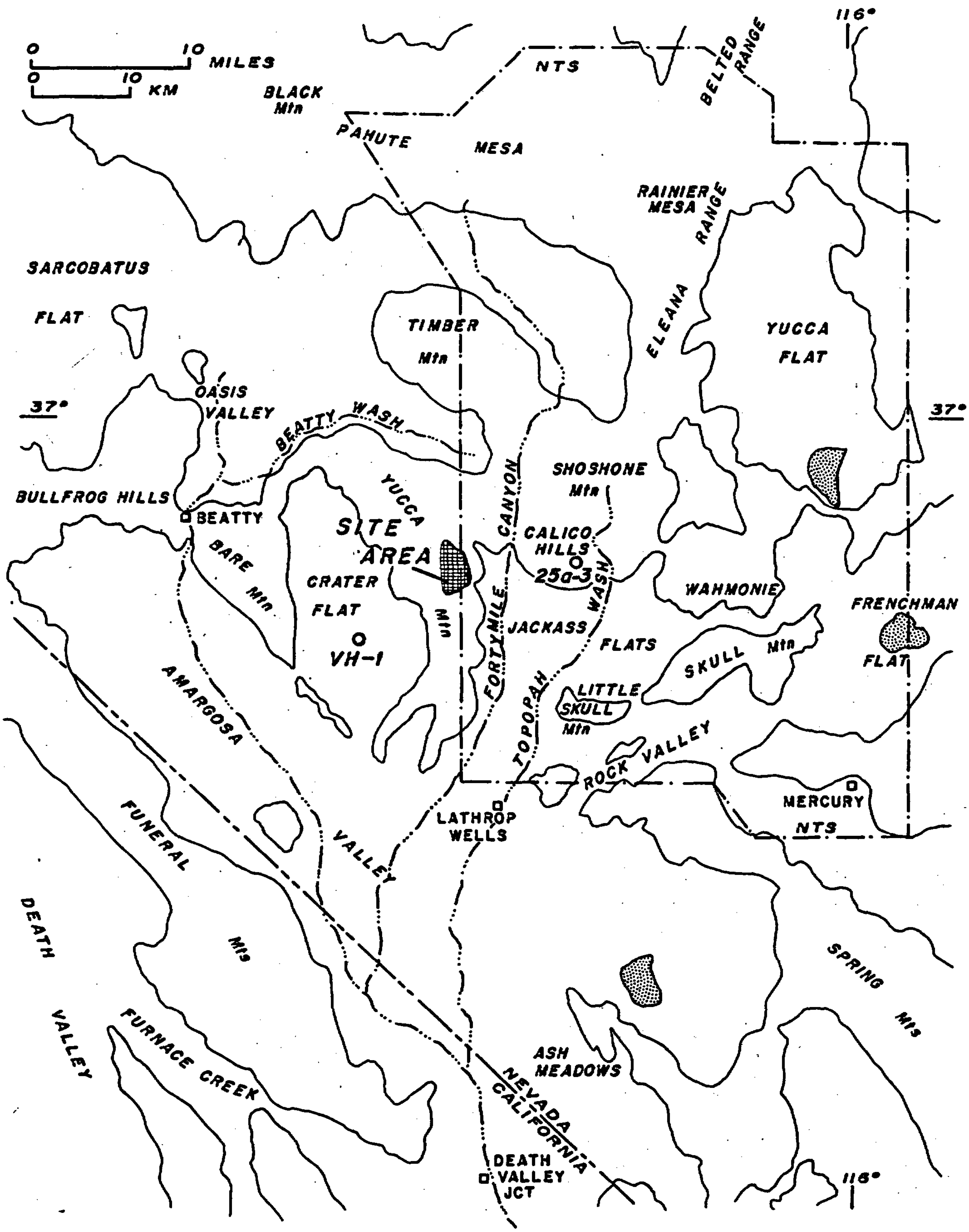


Figure 1.--Index map of Nevada Test Site region, showing location of VH-1 drill hole and Yucca Mountain site area.

The primary objectives of the hole were to aid volcanic hazard assessment in the Crater Flat area, and to provide the first subsurface hydrologic information for that area. The hole was sited to explore a positive aeromagnetic anomaly in south-central Crater Flat. Specifically, the geologic purpose was to determine whether additional basalt flows or other evidence of late Cenozoic volcanism is present in central Crater Flat. Two groups of basalts are recognized at the surface in the area (fig. 2); the older of the two has been dated at about 3.75 m.y., the younger at 1.1 m.y. (R. F. Marvin, U.S. Geological Survey, written commun., 1980).

ACKNOWLEDGMENTS

The author thanks the following geologists from Fenix & Scisson, Inc. (F&S), who helped monitor the drilling: M. P. Chornak, R. W. Orsak, J. B. Warner, L. D. Parrish, G. A. DePaolis, S. Koether, R. G. Lahoud, and S. J. Waddell.

The assistance of F. M. Byers, Jr., and D. C. Muller, USGS, is appreciated for their work on the petrography of drill-hole samples, and overseeing of geophysical logs, respectively. R. B. Scott and F. Maldonado, USGS, made a number of helpful suggestions in their review of the report.

DRILL-HOLE LOCATION AND HISTORY

Drill hole USW-VH-1 is located in central Crater Flat (fig. 1), about 2,400 m (1.5 mi) S. 13° E. from Red Cone, at Nevada coordinates N. 743,356 ft and E. 533,625 ft. The hole is about 10 km (7 mi) southwest of the Yucca Mountain exploration area. Elevation is 954 m (3,131 ft). The location was staked on August 26, 1980, by A. G. Gordon, F&S, and W. J. Carr, USGS.

The following summary of coring, casing history, and hole configuration was prepared from data provided by F&S, Mercury, Nev. Drilling operations began on October 28, 1980. Polymer mud and airfoam were used as drilling fluids. A 31.1-cm (12 1/4-in.) hole was drilled to 14.3 m (47 ft) and 24.4-cm (9 5/8-in.) casing installed. The hole was then drilled at a diameter of 15.9 cm (6 1/4 in.) to 33.5 m (110 ft), and 11.4-cm (4 1/2-in.) casing set. The hole was cored with a 10-cm (3.94-in.) diameter bit from 33.5 to 90 m (110 to 295 ft). The 11.4-cm (4 1/2-in.) casing was pulled and the hole reamed to 15.9 cm (6 1/4 in) to a depth of 197 m (645 ft). After setting 11.4-cm (4 1/2-in.) casing to 197 m (645 ft), the hole was continuously cored at a diameter of 10 cm (3.94 in.) from 197 m (645 ft) to total depth (T.D.) at 762.3 m (2,501 ft). The 11.4-cm (4 1/2-in) casing was pulled and the hole reamed to 15.9 cm (6 1/4 in.) to a depth of 438 m (1,437 ft). The hole was later reamed to 22.2 cm (8 3/4 in.) to a depth of 278 m (912 ft), and 19.4-cm (7 5/8-in.) casing installed. A 5.1-cm (2-in.) pipe was installed to a depth of 656.5 m (2,154 ft). The hole was bridged at 666.3 m (2,186 ft) on Feb. 13, 1981. The drill rig was moved out on Feb. 18, 1981.

A directional survey showed the hole deviated from the vertical about 37 m (120 ft) in a S. 45° E. direction. This deviation was essentially uniform in amount and direction below about 60 m (200 ft).

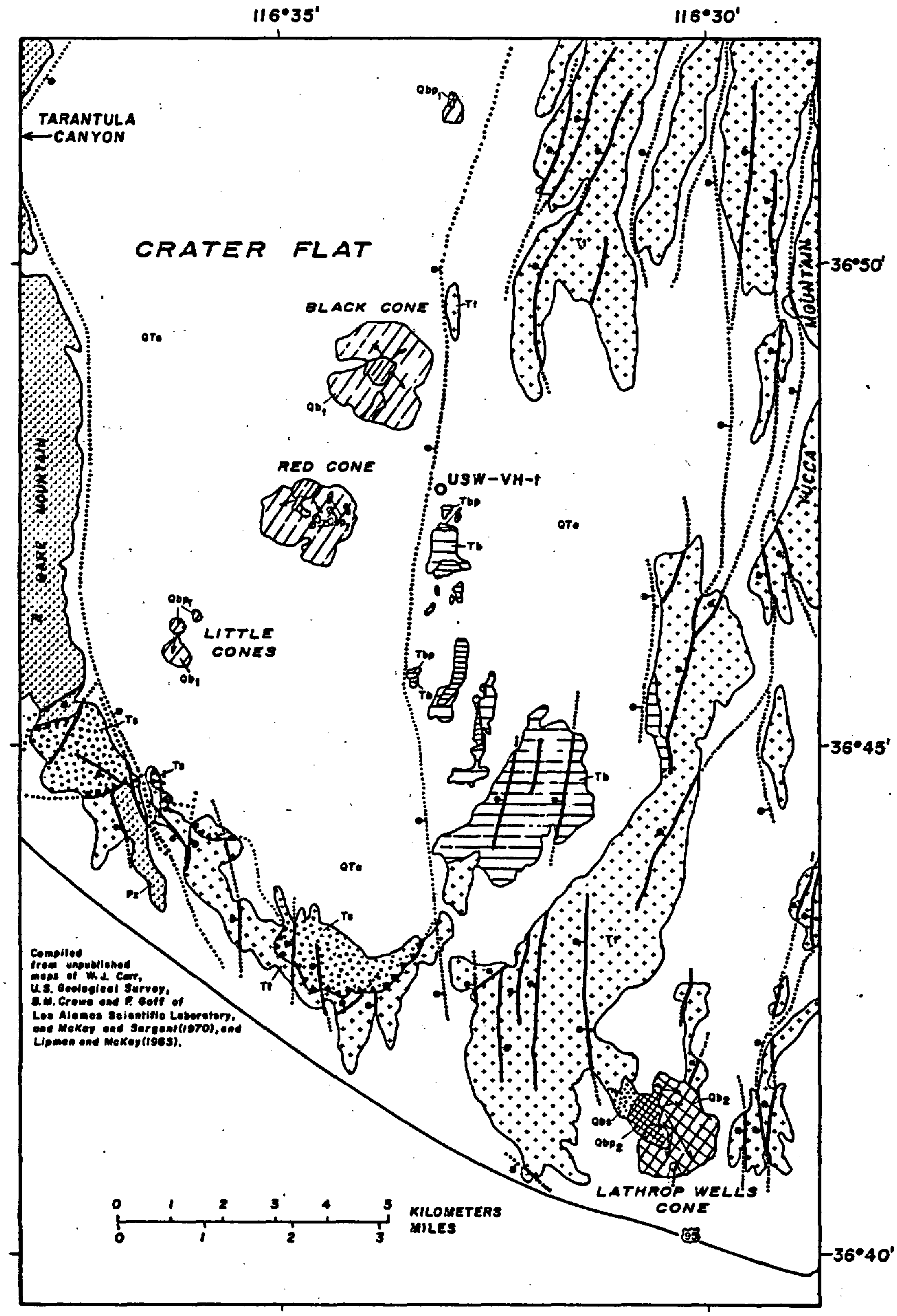


Figure 2.--Generalized geologic map of the southern Crater Flat area.

EXPLANATION

CORRELATION OF MAP UNITS

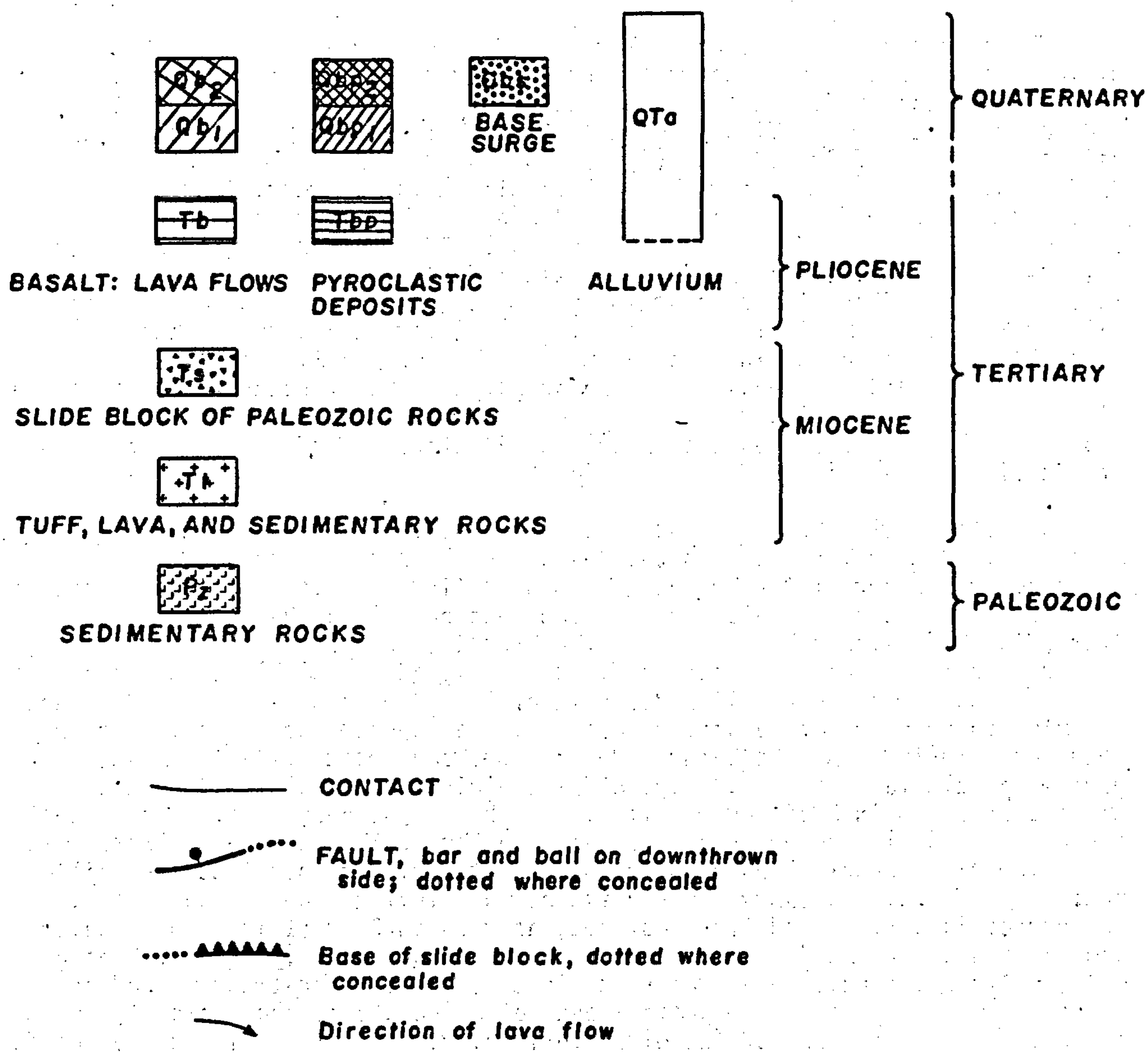


Figure 2.--Continued

GEOLOGIC FRAMEWORK OF CRATER FLAT

Crater Flat is a sloping basin lying between Yucca Mountain on the east and Bare Mountain on the west (fig. 1). Minimum elevation at the south end is about 820 m (2,700 ft), and at the north end reaches about 1,200 m (4,000 ft). Though separated from the Amargosa Valley by a low ridge (figs. 1 and 2), Crater Flat drains southward through this ridge. Bare Mountain, on the west side of Crater Flat, is made up of a thick sequence of carbonate and clastic rocks ranging in age from Precambrian to Mississippian. Elsewhere, the flat is rimmed by highly faulted volcanic rocks of Miocene age.

These volcanic rocks consist largely of welded ash-flow tuffs that are divided into three main formations, from oldest to youngest: Crater Flat Tuff, Paintbrush Tuff, and Timber Mountain Tuff. The latter two formations had their source in the Timber Mountain-Oasis Valley caldera complex a few kilometers north of Crater Flat (Byers and others, 1976). The Crater Flat Tuff consists of three main members, from oldest to youngest: Tram unit, Bullfrog Member, and Prow Pass Member; these ash flows may have originated from Crater Flat itself (see section on Crater Flat volcano-tectonics). In the VH-1 area, the Paintbrush Tuff consists of the Topopah Spring and the Tiva Canyon Members. The Timber Mountain Tuff also consists of two members, the Rainier Mesa and Ammonia Tanks Members. The latter welded tuff units are generally thin to absent in much of the southern Crater Flat and Yucca Mountain area, and are deposited unconformably across structural blocks in the older volcanic rocks, indicating that considerable structural uplift and topography had developed on the underlying Paintbrush Tuff prior to eruption of the Timber Mountain Tuff.

Basalts of two ages are exposed in the basin: 3.75 and 1.1 m.y. old (R. F. Marvin, USGS, written commun., 1980). The older group crops out in southeastern Crater Flat; the younger forms a linear, slightly arcuate zone of four eruptive centers stretching from southwestern to north-central Crater Flat (fig. 2). Although essentially synchronous, they represent separate centers consisting of small basalt flows, dikes, and partially eroded scoria mounds. Except for thin eolian deposits of late Pleistocene age and Holocene alluvium in or near active stream channels, the exposed basalts are younger than the alluvium. At the Lathrop Wells cone, southeast of Crater Flat, a younger basalt lava about 0.3 m.y. old is overlain by basaltic cinders that are incorporated in Pleistocene alluvium. The only exposures of beds directly beneath the basalts occur in a small area on the southeast edge of Crater Flat where the older basalt laps onto the Miocene tuffs. At that locality, silicic pumice was found in a sandy, poorly indurated alluvium beneath the basalt. The pumice is silicic and light colored, as much as 3 cm (1 in.) in diameter, and is somewhat rounded by transport. An age of 6.3±0.8 m.y. (C. W. Naeser, USGS, written commun., 1979) was determined by the fission-track method on zircon from the pumice. The pumice does not correlate petrographically or chronologically with any of the older tuff units. Therefore, it is reasonable to conclude that the source of the pumice is buried somewhere within Crater Flat. One of the purposes of drilling in Crater Flat was to try to locate and verify the age of such an eruptive center, as well as document the presence or absence of additional basalt eruptions prior to 1.1 m.y. ago. The source of the pumice was not found in VH-1, and no additional basalt lavas were penetrated.

Although details of structure within Crater Flat are poorly known, geologic mapping is available for the bordering bedrock areas (Cornwall and Kleinhampl, 1961· Lipman and McKay, 1965; McKay and Sargent, 1970; Crowe and Carr, 1980). Additional mapping is in progress. The generalized geologic map of southern and central Crater Flat area, shown on figure 2, is modified slightly from Crowe and Carr (1980).

The eastern half of the area, including the southern part of Yucca Mountain, is characterized by a series of northerly trending Basin and Range-type faults that consistently repeat and rotate long blocks of the tuffs about 10°-20° in an easterly direction. These faults are nearly all downdropped on the west, but outcrops of the tuffs occur in Crater Flat considerably west of the eastern basin margin, indicating that the eastern margin as defined by alluvium is not controlled by large-scale youthful faulting. Even though it is likely that the 3.75-m.y.-old basalts vented from this fault system, only minor structural disturbance of these flows has been noted. The abrupt westward termination of the 3.75-m.y.-old basalt and tuff outcrops a little east of the center of Crater Flat suggests, however, that an important fault or fault zone may lie nearly along the north-south axis of the basin, just west of drill hole VH-1. The west side of Crater Flat is marked by a zone of major north-trending normal faults at the base of Bare Mountain. This east-dipping fault zone probably has considerable vertical displacement that drops the Paleozoic rocks, possible volcanic units, and alluvium several thousand feet below the surface of the flat. The slightly arcuate alignment of four 1.1 m.y. old basalt centers (Little Cones, Red Cone, Black Cone, and an unnamed small center to the north, fig. 2) outlines a vent or rift zone that seems to be fault controlled even though it trends about 20° to the east of both the major fault at the east side of Bare Mountain and the series of west-dipping faults on the west side of Yucca Mountain. Gravity studies (Snyder and Carr, USGS, written commun., 1981) indicate a trough of volcanics and alluvium at least 2,500 m (8,200 ft) deep in central Crater Flat.

Quaternary faults cut the alluvium on both east and west sides of the basin. Those on the east side of Crater Flat, as suggested above, probably have small Quaternary displacement. The major fault along the east base of Bare Mountain is covered for most of its length; however, evidence of Quaternary uplift and faulting is displayed by steep fans at the foot of the mountain and by scarps at the mouth of Tarantula Canyon (fig. 2) that displace Pleistocene alluvium. Evidence currently being gathered suggests the age of the youngest significant movement on the faults on the east side of Crater Flat is greater than 100,000 years and some is probably the same age as the 1.1-m.y.-old basalt eruptions. Youngest activity on the fault zone at the foot of Bare Mountain is probably early Holocene (±10,000 years), based on the age of alluvium involved in the faulting.

AEROMAGNETIC ANOMALIES

One of the chief reasons for suspecting the presence of additional upper Miocene, Pliocene or even early Pleistocene volcanic rocks buried beneath Crater Flat is the occurrence of several distinct aeromagnetic anomalies (fig. 3). These are not interpretable on the basis of exposed volcanic rocks; for example, all basalts at the surface in Crater Flat have been determined to be reversed magnetically, yet a rather large positive anomaly occurs in the southern part of Crater Flat in the same area as the reversed basalts

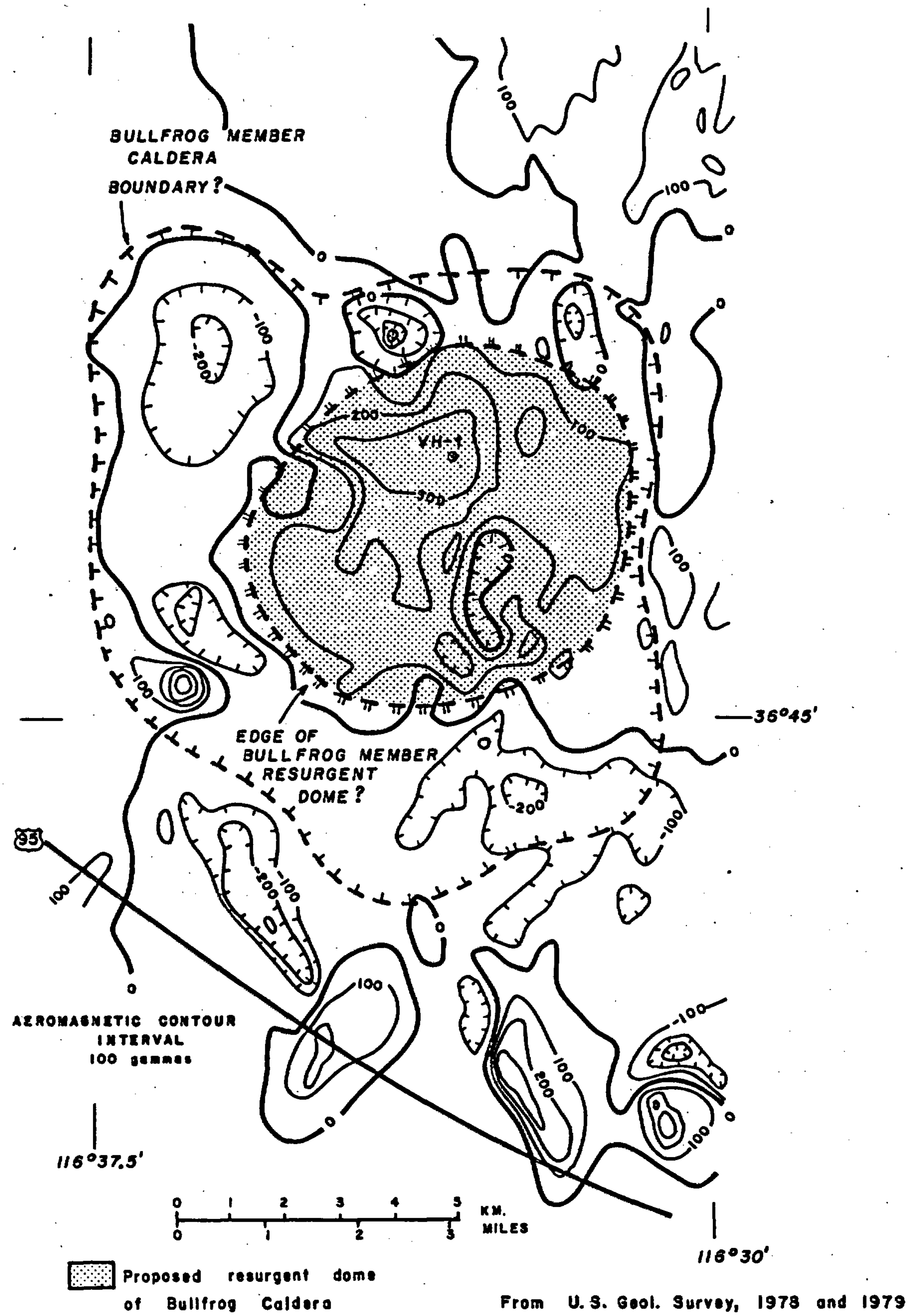


Figure 3.--Aeromagnetic map of southern Crater Flat area, showing caldera boundaries and resurgent dome.

(fig. 3). Evidence from drill hole VH-1 strongly suggests, however, that this anomaly is due largely to the presence of a thick, normally magnetized Miocene welded tuff, the Bullfrog Member of the Crater Flat Tuff. The normally magnetized Topopah Spring Member cannot produce the anomaly because the 290 m (950 ft) measured is not abnormal in thickness or welding for the region. Although only 141 m (464 ft) of the Bullfrog Member were drilled, the unit is densely welded in VH-1, and there is no evidence that the base of the unit was approached.

A negative aeromagnetic anomaly of interest occurs west of Black Cone. The size, shape, and gradients of the anomaly suggest a body of rhyolite lava or thick welded tuff. According to Gordon Bath (USGS, oral commun., 1981) the depth to the anomaly-causing body is on the order of 450-600 m (1,500-2,000 ft). It is possible that this body is related to a rhyolite lava center that supplied the 6.3-m.y.-old pumice mentioned earlier.

Other smaller positive anomalies related to rocks beneath alluvium are present west and south of Little Cones (fig. 2). These are most likely small areas of basalt lava, possibly related to a 10-m.y.-old basalt that occurs along the bedrock ridge between Crater Flat and U.S. Highway 95, or they may be basalt emplaced during the Gauss normal polarity magnetic epoch between about 3.4 and 2.5 m.y. ago.

VOLCANO-TECTONIC HISTORY OF CRATER FLAT

Drill hole VH-1 has added to evidence that suggests that Crater Flat is the source area for some or all of the members of the Crater Flat Tuff. The area is a distinct compound gravity low (D. B. Snyder and W. J. Carr, USGS, written commun., 1981), although this in itself does not indicate a buried caldera. Figure 4 shows hypothetical caldera collapse areas for the normally magnetized Prow Pass and Bullfrog Members and for the reversely magnetized Tram unit. The shape of the combined postulated Crater Flat collapse areas suggests a sector graben type of feature, which could owe its tectonic development to a partial collapse of the flanks of the Crater Flat Tuff source area. However, portions of the exposed bedrock display arcuate boundaries, such as the north edge of the ridge around the south edge of Crater Flat (fig. 2). Within the Paleozoic bedrock of Bare Mountain is a zone of 13.9-m.y.-old altered rhyolite to rhyodacite dikes, the same age as lava flows underlying the Tram unit. These dikes form an arcuate pattern gently concave toward Crater Flat. If these dikes are related to the Tram they could represent outer ring dikes beyond the west wall of the Crater Flat collapse.

Drill hole VH-1 penetrated 141 m (464 ft) of the Bullfrog Member, and all but the uppermost 30 m (100 ft) are densely welded. Because the partially granophyric, crystalline groundmass suggests the unit cooled slowly, the member is probably considerably thicker than the 141 m (464 ft) penetrated. As mentioned, aeromagnetic evidence supports this conclusion. It is therefore suggested that the roughly circular positive aeromagnetic anomaly in southern Crater Flat, including the area at VH-1, coincides with a resurgent dome, approximately 6 km (4 mi) across, that coincided with the position of the thick intracaldera Bullfrog Member (fig. 3). The overlying Prow Pass Member, which is only 50 m (165 ft) thick in VH-1, may have thinned on this dome. The volume of the Prow Pass is apparently much less than the Bullfrog and may not have been sufficient to produce a large collapse.

The caldera associated with the Tram unit is postulated to be in the northern part of Crater Flat, although part of southern Crater Flat could also have been involved in collapse. Briefly, the evidence for locating the Tram caldera in the northern Crater Flat-Beatty Wash area is as follows:

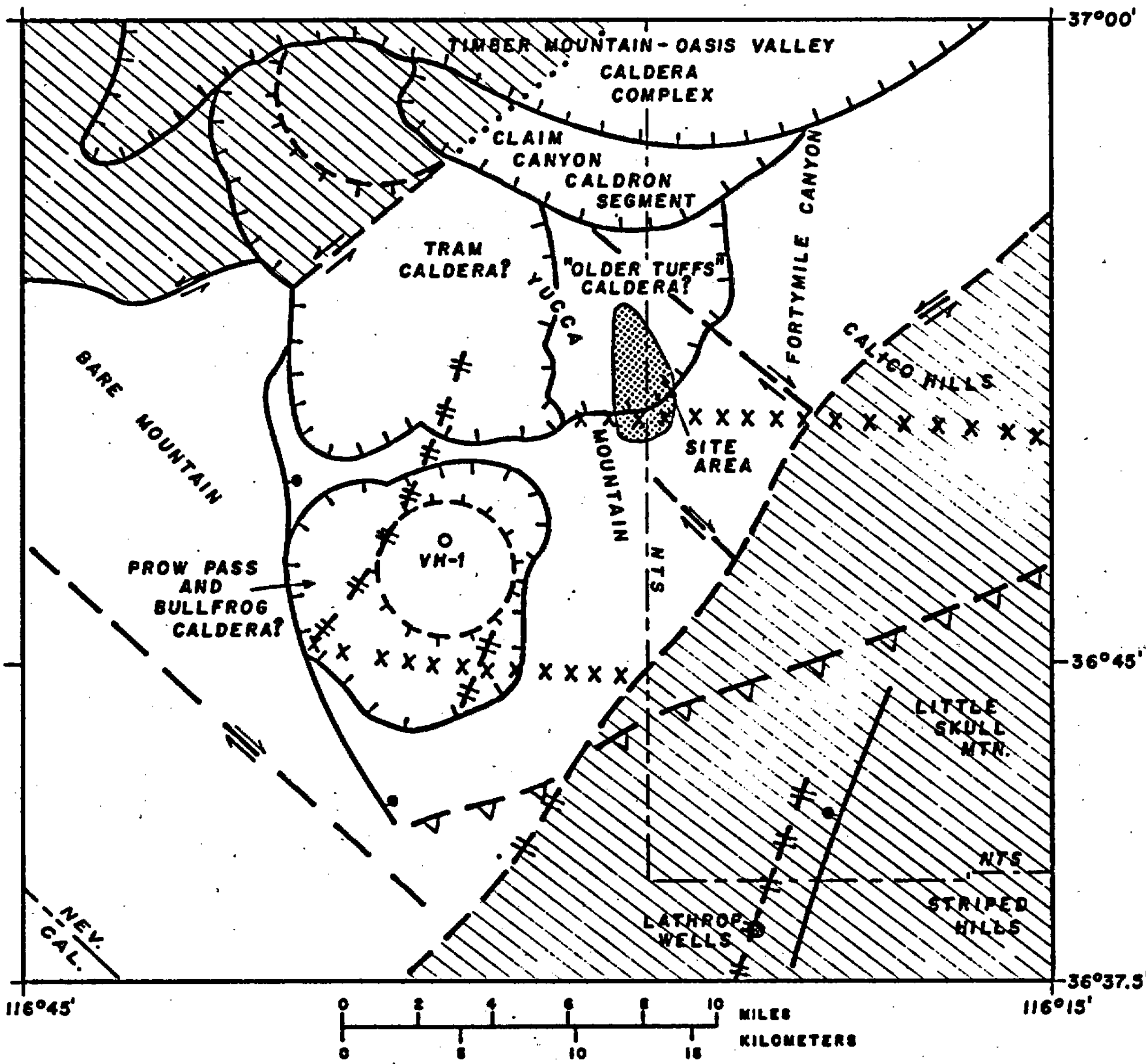
(1) Arcuate dikes on Bare Mountain (concave toward Crater Flat) are the same age and general composition as a lava flow underlying the Tram unit in Beatty Wash.

(2) As silicic lava flows associated with ash flows are commonly in or close to ring fractures of calderas they accompany, it is likely that the lava beneath the Tram in Beatty Wash represents early eruptions from the same magma chamber; if so, they may be near the northwest edge of the subsequent collapse area, and their exposure could be due in part to resurgence of part of the Tram collapse area.

(3) The thickest exposed Tram is present in the Beatty Wash-Northern Crater Flat area, where it is at least 457 m (1,500 ft) thick.

(4) In northwestern Crater Flat thick altered Tram is abruptly terminated along a north-south structure that may be a caldera wall.

None of the units of the Crater Flat Tuff are believed to have originated from the repository site area on Yucca Mountain because all three units are not unusually thick in drill holes in that area.



Area dominated by northeast-trending faults

Major high-angle fault zone, bar and ball on downthrown side

Important strike-slip shear zone or boundary of zone, as shown by hatching; arrows indicate direction of lateral displacement in pre-Pliocene time

Possible "rift" zone with associated basaltic volcanism

Area being explored for a possible waste disposal site

Approximate buried trace of CP thrust system; teeth on upper plate of predominantly carbonate rocks; Eleana Formation (Mississippian and Devonian age) predominant in lower plate to northwest

Caldera wall

Possible resurgent dome

XXXX Aeromagnetic lineament marking southern edge of possible east-west trending granitic bodies

Figure 4.--Tectonic diagram of Crater Flat region, showing structural setting of proposed calderas, major-thrust and strike-slip fault zones, and basalt "rift" zones.

LITHOLOGY OF DRILL HOLE

The following tables present the lithology and major contacts penetrated in drill hole VH-1.

Table 1.--Summary of major contacts and lithologic units in drill hole VH-1

Thickness meters (feet)	Unit	Interval meters (feet)
29 (94.0)	Alluvium	0-29 (0-94)
24. (78.5)	Basalt	29-52.5 (94-172.5)
0.5 (1.5)	Basalt cinders	52.5-53 (172.5-174)
102 (336.0)	Alluvium	53-155 (174-510)
106 (348.0)	Tiva Canyon Member[1/]	155-262 (510-858)
3 (9.0)	Ash-fall tuff	262-264 (858-867)
294 (966.0)	Topopah Spring Member	264-559 (867-1,833)
8 (27.0)	Ash-fall tuff	559-567 (1,833-1,860)
50 (165.0)	Prow Pass Member	567-617 (1,860-2,025)
4 (12.0)	Ash-fall tuff	617-621 (2,025-2,037)
141 (464.0)	Bullfrog Member	621-762 (2,037-2,501)

[1/]Top of the Tiva Canyon determined largely on the basis of caliper and electric logs.

Table 2.--Detailed lithologic log and stratigraphic description of drill hole USW-VH-1

[No samples 0-16 m (0-54 ft); cuttings only 16-34 m (54-110 ft) and 90-194 m (295-635 ft)]

Stratigraphy and rock description	Depth meters (feet)	Thickness of interval, meters (feet)
Alluvium, light-brown, abundant fragments of Paintbrush Tuff	0- 23 (0- 74)	23 (74)
Alluvium, same as 0-23 m (0-74 ft), but also containing reddish-brown basalt scoria	23- 29 (74- 94)	6 (20)
Basalt, dark-gray, massive, about 5 percent 1-2 mm olivine phenocrysts, partly altered to iddingsite, and a few 1 mm or less plagioclase laths in a fine crystalline groundmass. Occasional vugs and fractures contain calcite, tiny quartz and phlogopite crystals. Magnetic polarity is reversed. Highly fractured, especially from about 34 m (112 ft) to 51 m (168 ft). Most of fractures are low angle (0°-45°) and many are irregular	29- 51 (94-167.5)	22 (73.5)
Basalt, dark-purplish-gray, vesicular--about 20 percent unfilled small voids--contains olivine altered to iddingsite; minor calcite, some clay. A few prominent openings coated with botryoidal-appearing calcite	51- 52.5 (167.5-172.5)	1.5 (5.0)
Basalt cinders, brownish-orange to dark-reddish-brown, moderately indurated, stratified in fine and coarse grained layers, mostly lapilli-size; some calcite cement	52.5- 53 (172.5-174.0)	.5 (1.5)

Table 2.--Detailed lithologic log and stratigraphic description of drill hole USW-VH-1--Continued

Stratigraphy and rock description	Depth meters (feet)	Thickness of interval, meters (feet)
Alluvium, light-yellowish-brown to light-orange-pink, moderately indurated, tuffaceous, clayey, abundant calcite cement, containing 10-30 percent angular fragments of tuff and silicic lava as much as 10 cm across, but mostly 1/2- 2 cm. Some fragments are gray silicic lava (probably the rhyolite lava of Windy Wash (Byers and others, 1976)) with abundant large corroded resorbed quartz, and plagioclase, biotite, and minor sphene and hornblende	53- 56 (174.0-183.0)	3.0 (9.0)
Alluvium, similar to 53-56 m (174.0-183.0 ft), but fragments are much coarser, and include gray silicic lava as much as 0.3 m in diameter, and dark-gray dolomite	56-72.5 (183.0-238.0)	16.5 (55.0)
Alluvium, light-yellowish-gray, poorly indurated, containing much clay and calcite, clasts are sand to pebble-size, nearly all tuff and rhyolite, and most are subround instead of angular, some are well rounded	72.5-90 (238.0-295.0)	17.5 (57.0)
Alluvium, some cavings; many fragments are Paleozoic rocks, mostly dolomite; these decrease in abundance below this unit. Abundant quartz grains; calcareous cement	90-135.5 (295.0-445.0)	45.5 (150.0)
No cuttings obtained	135.5-141.5 (445.0-465.0)	6.0 (20.0)
Alluvium, similar to 90-135.5 m (295-445 ft). A few fragments of a possible silicic ash bed at about 155.5 m (510 ft)	141.5-155.5 (465.0-510.0)	14.0 (45.0)
Paintbrush Tuff		
Tiva Canyon Member[1]		
Tuff, ash-flow, purplish-gray; some cavings in cuttings	155.5-193.5 (510.0-635.0)	38.0 (125.0)

Table 2.--Detailed lithologic log and stratigraphic description of drill hole USW-VH-1--Continued

Stratigraphy and rock description	Depth meters (feet)	Thickness of interval, meters (feet)
Paintbrush Tuff--Continued		
Tiva Canyon Member--Continued		
Tuff, ash-flow, purplish-gray, densely welded, devitrified, small rare pumice. Tight fracture about every 0.2 m (0.5 ft), coated with thin calcite or silica. Maximum dip of pumice is about 10°. A few fracture surfaces show slight movement, i.e., polishing of surface. Less than 1 percent plagioclase phenocrysts; sphene noted. Unit is magnetically reversed. Unit is moderately fractured, especially between 206-217 m (675-711 ft), where fractures occur about every 0.3-1.5 m (1-5 ft)	193.5-228.5 (635.0-750.0)	35.0 (115.0)
Tuff, ash-flow, purplish-gray, densely welded, devitrified, mottled with gray nonflattened pumice. Fractures in this interval have distinct bleaching along some of them, particularly notable at 233 m (764 ft). Highly fractured between about 235.5 and 246 m (772 and 808 ft), 248-248.5 m (814-816 ft), and 250-251 m (821-824 ft)	228.5-251.0 (750.0-824.0)	22.5 (74.0)
Tuff, ash-flow, dark-gray, moderately welded, vitric, mottled and streaked with pinkish-orange zones of devitrification and clay alteration	251.0-255.5 (824.0-838.0)	4.5 (14.0)
Tuff, ash-flow, pinkish-orange, moderately welded, devitrified, with white clayey pumice, and black vitric pumice 1-3 cm long. Matrix ash is mostly altered to clay. Becomes light-pink at base of zone. Highly fractured below 258 m (846 ft)	255.5-261.5 (838.0-858.0)	6.0 (20.0)

Table 2.--Detailed lithologic log and stratigraphic description of drill hole USW-VH-1--Continued

Stratigraphy and rock description	Depth meters (feet)	Thickness of interval, meters (feet)
Bedded tuff		
Tuff, bedded, brown to white, almost entirely altered to clay; biotite noticeable	261.5-264 (858.0-867.0)	2.5 (9.0)
Paintbruch Tuff--Continued		
Topopah Spring Member		
Tuff, ash-flow, light-gray, nonwelded vapor phase. Caprock phase, biotite noticeable; phenocrysts ±5 percent	264-268 (867.0-879.0)	4.0 (12.0)
Tuff, ash-flow, purplish-brown, moderately to densely welded in lower part, streaky black glass and scattered pink pumice as much as 5 cm long; bleaching and alteration along fractures. Becomes mostly caprock vitrophyre at base of zone. Core box contains much cored clayey cavings. Fractures approximately every 0.5 m	268-270.5 (879.0-887.0)	2.5 (8.0)
Tuff, ash-flow, orange, clayey, base of caprock vitrophyre	270.5-271 (887.0-889.0)	.5 (2.0)
Tuff, ash-flow, light-purplish-gray, densely welded, mostly devitrified, caprock phase, occasional large (2-7 cm) pumice, some orange-brown in color. Highly fractured zone 272.5-273 m (895-896 ft), 274.5 m (901 ft). Biotite in pumice. Dip of foliation 10° or less. Polished fracture surface at 277.5 m (911 ft)	271-278 (889.0-912.0)	7.0 (23.0)
Tuff, similar to 271-278 m (889-912 ft), except abundant large (>3 cm) purplish-brown to orange pumice	278-279.5 (912.0-917.0)	1.5 (5.0)

Table 2.--Detailed lithologic log and stratigraphic description of drill hole USW-VH-1--Continued

Stratigraphy and rock description	Depth meters (feet)	Thickness of interval, meters (feet)
Paintbrush Tuff--Continued		
Topopah Spring Member--Continued		
Tuff, similar to 271-278 m (889-912 ft), except pumice is smaller and less abundant; highly fractured 284.5-285 m (934-936 ft) and 286-287 m (938-941 ft)	279.5-287.5 (917.0-943.0)	8.0 (26.0)
Tuff, ash-flow, purplish-brown, densely welded, devitrified, common lithophysae, some as much as 10 cm across; some are lined with quartz, tridymite, and specular hematite. Core is highly broken, but mostly by drilling, particularly 287.5-321 m (943-1,053 ft) and 329.5-354 m (1,081-1,162 ft). Ground-up pinkish-brown tuff of Topopah Spring Member in core run from 330-333 m (1,082-1,092 ft); otherwise, no core recovered	287.5-353 (943.0-1,159.0)	65.5 (216.0)
Basalt, dike, grayish-brown, altered to dark-brown and yellowish-green montmorillonite clay, olivine altered to iddingsite	2/353-353.5 (1,159.0-1,160.0)	.5 (1.0)
Tuff, ash-flow, same as 287.5-353.5 m (943-1,160 ft), except lithophysae less abundant. Core still highly highly broken, especially 354-387 m (1,162-1,269 ft)	353.5-393 (1,160.0-1,290.0)	39.5 (130.0)

Table 2.--Detailed lithologic log and stratigraphic description of drill hole USW-VH-1--Continued

Stratigraphy and rock description	Depth meters (feet)	Thickness of interval, meters (feet)
Paintbrush Tuff--Continued		
Topopah Spring Member--Continued		
Tuff, ash-flow, light-purplish-gray; densely welded, devitrified, less broken than above, but a few tight fractures evident. Probable fault at about 423-424.5 m (1,388-1,393 ft); some brecciation; also faulted and much broken at 425.5-438.5 m (1,396-1,438 ft). Core loss in the intervals 434.5-435 m (1,425-1,426 ft) and 437-438 m (1,433-1,437 ft). Dip of foliation still about 10°. Some prominent fractures from 447.5-448.5 m (1,469-1,472 ft). Relatively unfractured intervals occur between 466.5-469.5, 472.5-483.5 and 490.5-492 m (1,531-1,541, 1,550-1,587,1,609-1,615 ft). Contacts are gradational over several meters	393-498 (1,290.0-1,633.0)	105 (343.0)
Tuff, ash-flow, yellowish-brown, densely welded, much clay alteration, indicating originally glassy character. Fine shardy matrix. Highly fractured and broken	498-500 (1,633.0-1,640.0)	2.0 (7.0)
Tuff, ash-flow, light-gray, densely to moderately welded, vitrophyric, with pinkish-orange pumice, grading downward to dark-gray and gray-brown with black glassy pumice; minor clayey alteration, local brecciation. Partially open but largely filled prominent fractures and breccia between 511-521 m (1,677-1,709 ft). Distinctly fewer fractures below this point. Fractures and between-breccia fragments are filled with clay and opaline silica--no calcite. Contacts very gradational	500-526 (1,640.0-1,725.0)	26.0 (85.0)
Tuff, ash-flow, grayish-brown with light-pink pumice and black shards, moderately to slightly welded at base; purple lithics as much as 5 cm in diameter; mostly vitric, very little fracturing	526-538.5 (1,725.0-1,766.5)	12.5 (41.5)

Table 2.--Detailed lithologic log and stratigraphic description of drill hole USW-VH-1--Continued

Stratigraphy and rock description	Depth meters (feet)	Thickness of interval, meters (feet)
Paintbrush Tuff--Continued		
Topopah Spring Member--Continued		
Tuff, ash-flow, light-pinkish-brown to nearly white, nonwelded, yellow 2 cm pumice; zeolitized and clayey, abundant purple tuff and lava lithics. Sharp irregular contact at base	538.5-558.5 (1,766.5-1,833.0)	20 (66.5)
Bedded tuff		
Tuff, ash-fall, very light pinkish to orange-brown, rather massive, contains small white pumice (1 cm or less) and about 10 percent 1-2 mm dark lithics. Tight fault dipping about 75° at 560.5 m (1,839 ft). Slickensides indicate right-lateral oblique slip. Few phenocrysts at top, but increase downward to about 10 percent quartz, feldspar, and biotite; none of unit is obviously stratified. Basal contact indistinct	558.5-567 (1.833.0-1,860.0)	8.5 (27.0)
Crater Flat Tuff		
Prow Pass Member		
Tuff, ash-flow, very light pinkish gray, nonwelded, vapor phase, zeolitic and clayey, <10 percent biotite, quartz, and feldspar, 1-2 cm lithics, including red and black siltstone(?). Contains scattered large pumice 5 cm long with black manganese staining; smaller pumice is light gray, fine textured. Less than 5 percent small phenocrysts of feldspar, biotite and quartz. Some fracturing and minor faults at 576-577 and 583.5-584.5 m (1,890-1,894 and 1,915-1,918 ft)	567-591.5 (1,860.0-1,940.0)	24.5 (80.0)

Table 2.--Detailed lithologic log and stratigraphic description of drill hole USW-VH-1--Continued

Stratigraphy and rock description	Depth meters (feet)	Thickness of interval, meters (feet)
Crater Flat Tuff--Continued		
Prow Pass Member--Continued		
Tuff, ash-flow, same as 567-591.5 m (1,860-1,940 ft), but slightly welded. A few irregular fractures at about 596.5-598 m (1,957-1,962 ft); these are coated with dried polymer drilling mud. Lithic content increases slightly	591.5-603.5 (1,940.0-1,980.0)	12.0 (40.0)
Tuff, ash-flow, similar to above except pumice is smaller and porosity less. A few minor fractures, one at about 613 m (2,011 ft). Nonwelded in lower part. Unit is magnetically normal	603.5-617.0 (1,980.0-2,025.0)	13.5 (45.0)
Bedded tuff		
Tuff, ash-fall, pink, reworked, nonstratified to crudely bedded, fine-grained, with pumice fragments <1 cm, becoming coarser towards base	617.0-621.0 (2,025.0-2,037.0)	4.0 (12.0)
Crater Flat Tuff--Continued		
Bullfrog Member		
Tuff, ash-flow, light-gray, vapor-phase, nonwelded, pumice 1-2 cm, 5-10 percent phenocrysts, quartz, feldspar, biotite, and hornblende; slightly welded toward base	621.0-626.0 (2,037.0-2,053.0)	5.0 (16.0)

Table 2.--Detailed lithologic log and stratigraphic description of drill hole USW-VH-1--Continued

Stratigraphy and rock description	Depth meters (feet)	Thickness of interval, meters (feet)
Crater Flat Tuff--Continued		
Bullfrog Member--Continued		
Tuff, ash-flow, light-purplish-gray, moderately welded, small pumice, mostly 1-2 cm; white to purplish-gray, vapor phase in pumice; phenocrysts as in unit 621.0-626.0 m (2,037-2,053 ft). Much core breakage 631.0-635.5 m (2,070-2,085 ft), a few fractures 644.5-645.5, 647.5, and 648.5 m (2,115-2,118, 2,125, and 2,127 ft). Unit is magnetically normal	626.0-649.0 (2,053.0-2,130.0)	23.0 (77.0)
Tuff, ash-flow, light-purplish-gray to purplish-brown, densely welded, pumice flattening ratio 10 to 1 or more. Phenocrysts increase to about 15 percent in middle, 20 percent toward base. Contains conspicuous embayed quartz phenocrysts. Foliation dip less than 10°. Occasional fine-grained siltstone(?) lithic fragments, ½ - 2 cm. High-angle fracturing common, especially in lower part of unit below 671.0 m (2,202 ft). Calcite in mostly low-angle fractures at 720.5 m (2,364 ft), 740.5 m (2,430 ft), 744.5 m (2,442 ft), 745 m (2,444 ft), and 760.5 m (2,495 ft)	649.0-762.0 (2,130.0-2,501.0)	113.0 (371.0)
	Total depth	762.0 m (2,501.0 ft)

1/Top of the Tiva Canyon determined largely on the basis of caliper and electric logs.

2/Unit, as marked in core box is at about 351.5 m (1,153 ft), but electric log suggests actual depth is about 353 m (1,159-1,160 ft).

STRUCTURAL PROPERTIES OF THE CORE

A detailed analysis of the fracturing and faulting in the drill core was not attempted. The lithologic log (table 2) mentions most important fault and fracture zones; no faults with large displacement were recognized. The welded portions of the Topopah Spring and Tiva Canyon Members are the most fractured of the lithologic units, which is typical for the region. Fracturing is also common in the basalt from about 30 to 50 m (100 to 170 ft); many of these fractures occur at low angles and contain calcite coatings. Below about 500 m (1,700 ft), fracturing becomes less common, although the welded Bullfrog Member contains numerous small fractures at a frequency of one about every 1.5-3 m (5-10 ft) of core. Calcite occurs in these openings to the total depth of the hole.

HYDROLOGIC AND GEOPHYSICAL SUMMARY

No attempt is made here to report or interpret hydrologic or geophysical information in detail. A few salient features are of particular interest, however.

The static water level in VH-1 is reported by G. C. Doty (USGS, oral commun., 1981) to be at a depth of about 185 m (605 ft), within the welded tuff of the Tiva Canyon Member. Pumping tests indicate the hole is a good water producer. Comparison of the water table altitude with data given by Winograd and Thordarson (1975) for the region indicates a gradient of about 7.5 m/km (40 ft/mi) between central Crater Flat and the edge of the Amargosa Valley.

Geophysical logs run in VH-1 include vibroseis, caliper, induction, gamma-ray neutron, density, temperature, electric, 3-D velocity, epithermal neutron, and neutron.

A log run in mid-January 1981, shortly after hole completion, measured a temperature of about 35°C (95°F) at a depth of 518 m (1,700 ft), and about 43°C (109°F) at 750 m (2,459 ft). These temperatures are a few degrees higher than those measured in holes at Yucca Mountain itself, but lower than those measured in drill hole UE25a-3 (Sass and others, 1980) in the Calico Hills east of Yucca Mountain. However, temperatures may not have completely stabilized in the drill holes by the time the logs were run.

Density logs of the alluvium below the basalt flow (52.5-167.5 m; 172-550 ft) show the alluvium consistently averages about 2.0 g/cm^3, except for a zone between about 125 and 140 m (410 and 460 ft), which is a little denser, probably because of a higher content of Paleozoic carbonate rock fragments.

The compensated neutron porosity log shows the welded Topopah Spring Member has a porosity of about 20 percent, and the welded Bullfrog Member about 15 percent.

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