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UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGY OF DRILL HOLE USW VH-2, AND STRUCTURE OF CRATER FLAT, SOUTHWESTERN NEVADA

by

W. J. Carr and L. D. Parrish

Open-File Report 85-475

Prepared in cooperation with the
Nevada Operations Office
U.S. Department of Energy
(Interagency Agreement DE-AI08-78ET44802)

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ABSTRACT

A 1,219 meter (4,000 ft) drill hole in Crater Flat shows the absence of buried Pliocene or Quaternary volcanic rocks, and penetrates a section of Timber Mountain, Paintbrush, and the upper part of the Crater Flat Tuffs, similar to that exposed adjacent to Crater Flat. A prominent negative aeromagnetic anomaly between the drill hole and Bare Mountain is attributed to a westward thickening section of a reversely magnetized Miocene basalt. The relatively shallow depth of this basalt in the west-central part of Crater Flat indicates that no large amount of tectonic movement has occurred in approximately the last 10 m.y. Massive brecciated wedges of Paleozoic rocks are penetrated in two stratigraphic intervals in the drill hole; the older one, between the Tiva Canyon Member of the Paintbrush Tuff and the Rainier Mesa Member of the Timber Mountain Tuff, correlates with the time of maximum faulting east of Crater Flat in the Yucca Mountain area. The younger slide masses are correlated with a large slide block of probable late Miocene age exposed along the southwestern rim of Crater Flat.

The structural pattern and style buried beneath central and western Crater Flat is deduced to be similar to that exposed at Yucca Mountain, but less developed. The major fault system controlling the steep east face of Bare Mountain, though probably still active, is believed to have developed mainly as a result of caldera collapse between 13 and 14 m.y. ago. Relations between faulting and four episodes of basalt eruption in the Crater Flat area strongly suggest contemporaneity of the two processes.

INTRODUCTION

Drill hole USW VH-2 was cored to a depth of 1,219 m (4,000 ft) in central Crater Flat, a valley between Yucca Mountain and Bare Mountain in Nye County, southwestern Nevada (fig. 1). Drilling was done in 1983 by Reynolds Electrical and Engineering Company for the U.S. Department of Energy, Las Vegas, Nevada, in 1983. The U.S. Geological Survey sited the hole and interpreted the results.

The hole was drilled to obtain more information on the volcano-tectonic history of Crater Flat adjacent to Yucca Mountain, an area being explored for a nuclear waste repository under the Department of Energy Nevada Nuclear Waste Storage Investigations Project. Specifically, the objectives were (1) to determine whether evidence of additional basalt or rhyolite eruptions is buried beneath Crater Flat, an area where four different ages of basalt were known from surface exposures (Vaniman and others, 1982, and this report); (2) to help test the validity of a proposed caldera complex beneath Crater Flat (Carr, 1982; Carr and others, 1984); (3) to determine the cause of a prominent aeromagnetic gradient between a high at drill hole USW VH-1 (Carr, 1982, fig. 3) and a large magnetic low on the west side of Crater Flat (fig. 1), and (4) to provide stratigraphic data to help define the late Cenozoic structural history of Crater Flat.

ACKNOWLEDGMENTS

Particular thanks are due to Fenix & Scisson, Inc., geologists who ably monitored the drilling, kept logs, and sampled the core: M. P. Chornack, L. D. Parrish, J. B. Warner, B. W. Cork, E. Larsen, K. Johnson, and H. Huckins. W C Swadley, F. Maldonado, and W. J. Carr of the U.S. Geological Survey supervised geologic operations and collection of geologic data.

DRILL-HOLE LOCATION AND HISTORY

Drill hole USW VH-2 is located in central Crater Flat (fig. 1) between Red Cone and Black Cone at Nevada State coordinates N. 748,320 ft and E. 526,264 ft. Surface elevation is 974.5 m (3,197 ft). The hole is located approximately 2.7 km (1.7 mi) northwest of drill hole USW VH-1 (Carr, 1982), slightly west of the northeast alignment of Quaternary basalt cinder cones.

Fenix & Scisson, Inc., records show that drilling began February 15, 1983, and operations were completed on April 28, 1983. The hole was continuously cored (HCQ - 3.937 in. diameter) from the bottom of surface casing at 7 m (23 ft) to 1,219 m (4,000 ft) T.D. Polymer mud was used as a drilling fluid. Core recovery was excellent, 100 percent in most intervals, except in alluvium from the surface to a depth of about 100 m (330 ft). Even in that interval, sidewall core, conventional core below about 61 m (200 ft), cuttings and geophysical logs were sufficient to insure that no volcanic units remained undetected. Casing (5 1/2 in.) was installed to 220 m (720 ft) and 1.9-in. pipe was set to a depth of 1,215 m (3,986 ft). A directional survey shows that the hole deviated westward about 15 m (50 ft) from the vertical to a depth of about 640 m (2,100 ft), and thence southeastward, so that the bottom of the hole is about 12 m (40 ft) southwest of the surface location.

No hydrologic testing was done in USW VH-2 because polymer mud was used in the drilling.

STRATIGRAPHY AND LITHOLOGY OF DRILL HOLE USW VH-2

The two following tables report the major contacts and lithology penetrated in drill hole USW VH-2.

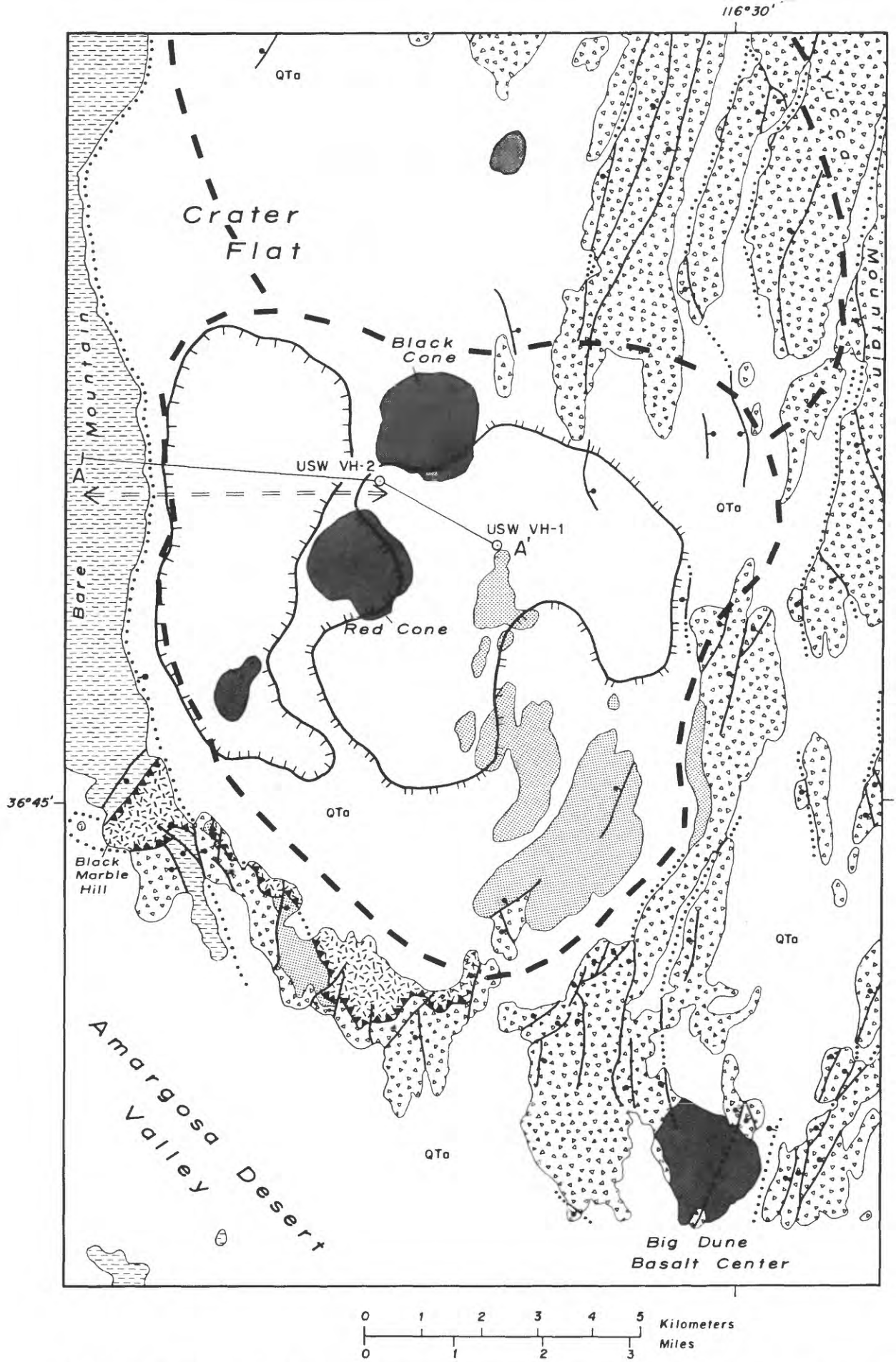

Figure 1.--Generalized geologic and index map of the southern Crater Flat area, showing location of USW VH-1 and USW VH-2 drill holes with respect to geophysical anomalies and basalts.

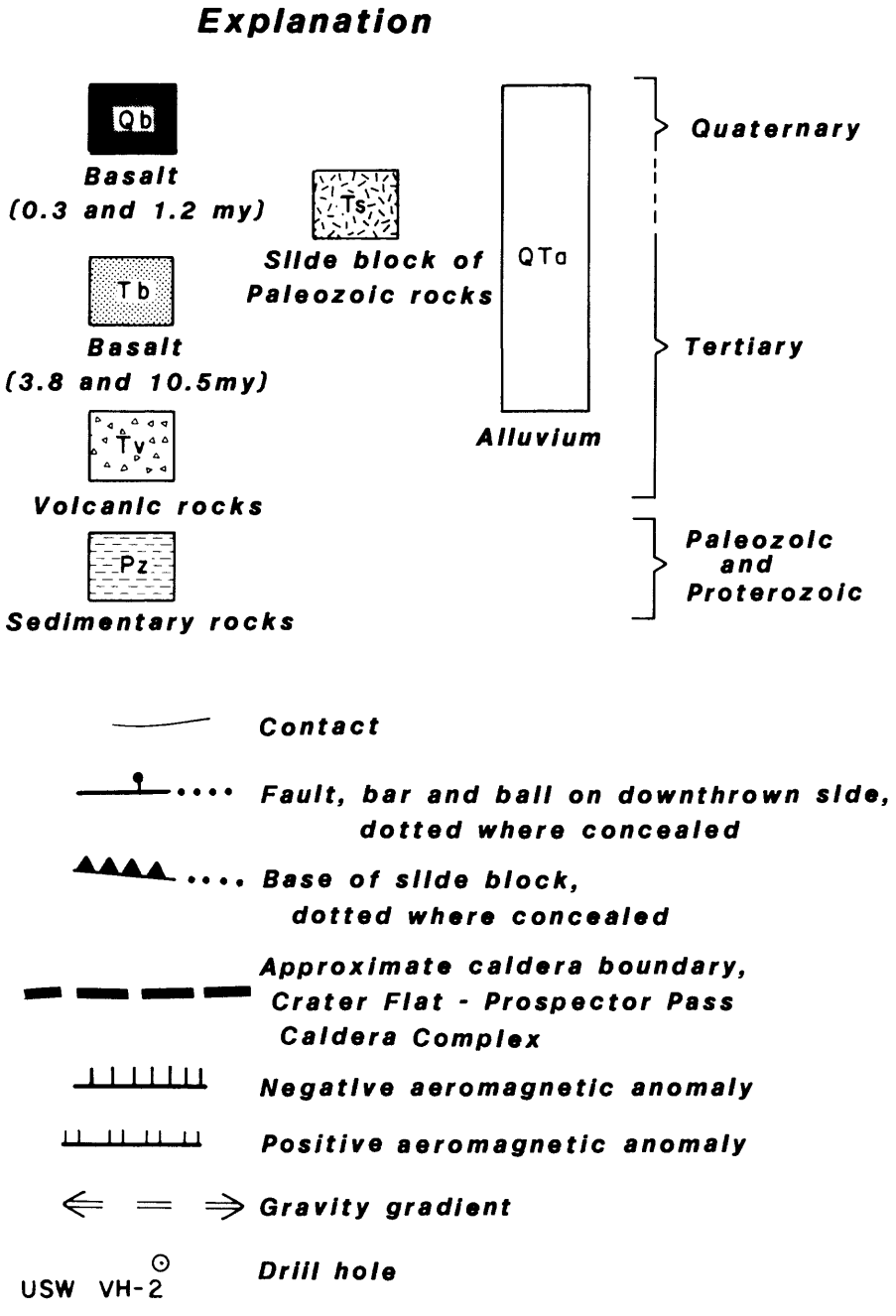

Figure 1.--Continued

Table 1.--Summary of major contacts and lithologic units in drill hole USW VH-2

Unit	Thickness, meters (feet)	Interval, meters (feet)
Alluvium and very large blocks of Paleozoic rocks	360 (1,180)	0-360 (0-1,180)
(Static water level ±163 m or 535 ft)		
Basalt and minor scoria, basalt breccia and sandstone	30 (99)	360-390 (1,180-1,279)
Timber Mountain Tuff Ammonia Tanks Member	54 (178)	390-444 (1,279-1,457)
Ash-fall tuff	0.5 (2)	444-444.5 (1,457-1,459)
Timber Mountain Tuff Rainier Mesa Member	87.5 (287)	444.5-532.5 (1,459-1,746)
Ash-fall and bedded tuff and breccia	2.5 (8)	532.5-534.5 (1,746-1,754)
Very large blocks of Paleozoic carbonate rocks, and minor alluvium	61 (200)	534.5-595.5 (1,754-1,954)
Paintbrush Tuff Tiva Canyon Member	164.5 (540)	595.5-760 (1,954-2,494)
Ash-fall, bedded tuff and thin ash-flow tuffs	17 (56)	760-777 (2,494-2,550)
Paintbrush Tuff Topopah Spring Member	[1]357.5 (1,173)	777-1,134.5 (2,550-3,723)
Bedded tuff	4 (12)	1,134.5-1,138.5 (3,723-3,735.5)
Crater Flat Tuff Prow Pass Member	74 (243)	1,138.5-1,213 (3,735.5-3,978.5)
Ash-fall and bedded tuff	1.5 (6.5)	1,213-1,214.5 (3,978.5-3,985)
Crater Flat Tuff Bullfrog Member	4.5 (15+)	1,214.5-1,219 (3,985-4,000)
		Total depth

[1]Minimum, because faults between about 983 and 1,036 m (3,224 and 3,400 ft) cut out an unknown, but probably small amount, based on appearance of core and general absence of large lithologic differences across structures in the core.

Table 2.--Lithologic log and stratigraphic description of drill hole USW VH-2

[Depths and thicknesses rounded to nearest foot or 0.5 meter for most units]

Stratigraphic and rock description[1]	Depth meters (feet)	Thickness of interval, meters (feet)
Alluvium, pale-yellowish-gray and brown to grayish-orange, unconsolidated to poorly consolidated, poorly sorted. Clasts pebble- to boulder-size, weakly cemented by caliche and clay, are 20-40 percent Paleozoic limestone, dolomite, quartzite, and siltstone, 60-80 percent volcanic rocks (no basalt); matrix is mostly silt- and sand-size grains of volcanic rocks	0-107 (0-350)	107 (350)
Alluvium, pale-yellowish-brown to gray, poorly consolidated, poorly sorted, weakly cemented by caliche; clasts are subround to subangular and consist of about 90 percent limestone, dolomite, quartzite and siltstone, and 10 percent volcanic rocks	107-131 (350-430)	24 (80)
Alluvium, pale-yellowish-brown to gray moderately to well consolidated, poorly sorted. Texture suggests debris flows. Clasts are about 80 percent quartzite and siltstone, 20 percent limestone and dolomite, probably from the Stirling Quartzite and Wood Canyon Formation. Matrix is light tan clay and fine volcanic debris; no volcanic clasts	131-207 (430-680)	76 (250)
Alluvium, pale yellowish-brown to grayish-orange, poorly to moderately consolidated, weakly cemented by caliche; clasts similar to above. Consists mainly of poorly sorted subangular debris with minor interbedded gravels	207-273 (680-895)	66 (215)

Table 2.--Lithologic log and stratigraphic description of drill hole USW VH-2--continued

Stratigraphic and rock description[1]	Depth meters (feet)	Thickness of interval, meters (feet)
Alluvium, pale-yellowish-orange to light-bluish- and yellowish-gray, poorly consolidated, poorly sorted; clasts of Paleozoic siltstone, quartzite, and minor dolomite; matrix is largely silt of volcanic rock origin	273-283 (895-928)	10 (33)
Alluvium, very light gray to yellowish-gray, poorly to well consolidated, poorly sorted. Clasts mainly dolomite and limestone; matrix is calcareous clay and silt with intercalated zones of pale-yellowish-gray silt and clay, partly of volcanic rock origin	283-309 (928-1,013)	26 (85)
Debris, mainly brecciated blocks of Paleozoic carbonate rocks and calcareous siltstone, brownish-gray to medium-light-gray; boulder-sized blocks in lower part. Abundant narrow fractures and vugs filled with manganese oxide, quartz, and calcite. Small[2] fault dipping at about 45° with slickensides suggesting a component of left-lateral slip[3] is present at 316 m (1,036 ft). Zone about 0.6 m (2 ft) thick of crudely stratified 1-2 cm (1/4-1/2-in.) fragments at base	309-360 (1,013-1,180)	51 (167)
Basaltic breccia, dark-yellowish-brown, mostly subround fragments as much as 8 cm (2 1/2 in.) across in dark-yellowish-orange matrix	360-361 (1,180-1,183)	1 (3)

Table 2.--Lithologic log and stratigraphic description of drill hole USW VH-2--continued

Stratigraphic and rock description[1]	Depth meters (feet)	Thickness of interval, meters (feet)
Basalt lava flow and scoria, dark-yellowish-brown and blackish-red, olivine-bearing; irregular calcite-filled fractures	361-363 (1,183-1,191)	2 (8)
Basalt lava flow, dark-gray to brownish-black, vesicular; vesicles mostly filled with calcite and green clay	363-368 (1,191-1,207)	5 (16)
Basalt lava flow, blackish-red to dark-yellowish-brown, locally brecciated; irregular calcite-filled fractures	368-370 (1,207-1,213)	2 (6)
Basalt scoria, dark-reddish-brown; fault slickenside at 370.5 m (1,214 ft)	370-370.5 (1,213-1,214)	0.5 (1)
Basalt lava flow, blackish-red to brownish-gray, vesicular; calcite in vugs and fractures; olivine altered to iddingsite; small fault[2] at 375 m (1,231 ft) with calcite filling	370.5-378.5 (1,214-1,241)	8 (27)
Basalt scoria and breccia, grayish- to blackish-red; calcite in vugs and fractures	378.5-382.5 (1,241-1,255)	4 (14)
Basalt lava, blackish-red to greenish-black, vesicular; green clay in vesicles; small fault[2] with slickensides at 383 m (1,256 ft)	382.5-386 (1,255-1,267)	3.5 (12)
Basalt, scoriaceous, dark-reddish-brown; calcite in vesicles	386-386.5 (1,267-1,268)	0.5 (1)

Table 2.--Lithologic log and stratigraphic description of drill hole USW VH-2--continued

Stratigraphic and rock description[1]	Depth meters (feet)	Thickness of interval, meters (feet)
Basalt lava, blackish -and grayish-red; abundant calcite, some botryoidal, filling vesicles and fractures; zone of small faults[2] 389-389.2 m (1,276-1,277 ft)	386.5-389.5 (1,268-1,278)	3 (10)
Sandstone, basaltic, tuffaceous, dark-reddish-brown, fine-grained, moderately consolidated, poorly sorted	389.5-389.8 (1,278-1,279)	0.3 (1)
Timber Mountain Tuff Ammonia Tanks Member Tuff, ash-flow, dark-reddish-brown, nonwelded; white argillized friable pumice. Phenocrysts, 15 percent, consisting of sanidine, quartz, and biotite; a few pale-red volcanic lithic fragments	389.8-390.4 (1,279-1,281)	0.6 (2)
Tuff, ash-flow, grayish-red to brownish-gray, moderately to densely welded, partially vitric; pumice, white and pale-yellowish-brown, variably flattened, as much as 7 cm (2.7 in.) in diameter, and a few larger purplish-brown phenocryst-rich pumice more than 10 cm (4 in.) across; vapor-phase crystallization. Phenocrysts, 20 percent, consisting of quartz, sanidine, plagioclase, and biotite. A few small (1-2 cm) dark-gray volcanic lithic fragments	390.4-394.7 (1,281-1,295)	4.3 (14)

Table 2.--Lithologic log and stratigraphic description of drill hole USW VH-2--continued

Stratigraphic and rock description[1]	Depth meters (feet)	Thickness of interval, meters (feet)
Timber Mountain Tuff--Continued		
Ammonia Tanks Member--Continued		
Tuff, ash-flow, light-gray to brownish-gray, densely welded, devitrified; pumice, pale-yellowish-gray to white, partly argillized, commonly less than 3 cm long; phenocrysts 20 percent, similar to unit above; sparse small (1-2 cm) volcanic lithic fragments. Small fault[2] at 439.2 m (1,441 ft)	394.7-439.2 (1,295-1,441)	44.5 (146)
Tuff, ash-flow, grayish-red to moderate-reddish-brown, moderately welded to nonwelded at base, devitrified; pumice, very light gray. Phenocrysts same as in unit above, but including sparse sphene, and constituting 10 percent of the rock; rare volcanic lithic fragments. Low-angle (less than 45°) faults with slickensides and manganese oxide and clay coating at 441 m (1,445 ft) and 444 m (1,456 ft)	439.2-444 (1,441-1,457)	4.8 (16)
Bedded tuff		
Tuff, crudely bedded and reworked, light-brownish-gray, devitrified. Dip 20°	444-444.7 (1,457-1,459)	0.7 (2)
Timber Mountain Tuff		
Rainier Mesa Member		
Tuff, ash-flow, pale- to moderate-reddish-brown, nonwelded to slightly welded; 20 percent pumice, pale-red and light-brownish-gray. Phenocrysts, 10 percent, consisting of quartz, sanidine, plagioclase, biotite; 5 percent varicolored volcanic lithic fragments,		

Table 2.--Lithologic log and stratigraphic description of drill hole USW VH-2--continued

Stratigraphic and rock description[1]	Depth meters (feet)	Thickness of interval, meters (feet)
Timber Mountain Tuff--Continued		
Rainier Mesa Member--Continued		
mostly 0.5 to 1 cm, but as much as 5 cm across	444.7-456.6 (1,459-1,498)	11.9 (39)
Tuff, ash-flow, pale-red, partly to moderately welded, devitrified and friable; pumice as in unit above. Phenocrysts, same as in unit above, but constituting 15 percent,of rock. Sparse volcanic lithic fragments. Several small faults[2] at about 457 m (1,500 ft)	456.6-457.5 (1,498-1,501)	0.9 (3)
Tuff, ash-flow, grayish-pink to very light gray, nonwelded to slightly welded, devitrified, vapor-phase crystallization. Pumice, 15 percent of rock, mostly less than 1 cm across. Phenocrysts as above. Several small[2] low-angle (less than 45°) faults between 473 m (1,552 ft) and 473.7 m (1,554 ft)	457.5-473.7 (1,501-1,554	16.2 (53)
Tuff, ash-flow, light-gray, slightly to moderately welded, devitrified, some vapor-phase crystallization in pumice. Phenocrysts 10 percent, same as in overlying unit; rare small (0.5-1.5 cm) volcanic lithic fragments. Small[2] faults or fractures, mostly high-angle (more than 45°), at 477.3-478.5 m (1,566-1,570 ft), 491.3 m (1,612 ft), 492 m (1,614 ft), 496 m (1,627 ft), 499 m (1,637 ft) and 500 m (1,640 ft), dipping from 50 to 90°; one at 505 m (1,657 ft) dips 70° and has nearly horizontal slickensides	473.7-509.3 (1,554-1,671)	35.6 (117)

Table 2.--Lithologic log and stratigraphic description of drill hole USW VH-2--continued

Stratigraphic and rock description[1]	Depth meters (feet)	Thickness of interval, meters (feet)
Timber Mountain Tuff-Continued Rainier Mesa Member--Continued Tuff, ash-flow, light-brownish-gray, slightly welded, devitrified; sparse small (0.5-2 cm) pumice. Phenocrysts, 10 percent, same as overlying unit	509.3-512 (1,671-1,680)	2.7 (9)
Tuff, ash-flow, grayish-red, slightly welded, highly argillized; sparse pumice and phenocrysts. Several faults are present; one at 513 m (1,684 ft) dips 80°; some have manganese oxide coatings and nearly horizontal slickensides	512-514 1,680-1,687	2 (7)
Tuff, ash-flow, pale-red to moderate-reddish-orange, non-welded, partly vitric; small (0.5-2 cm) pale-yellowish-brown to white pumice, partly vitric. Phenocrysts, 2 percent, consisting mostly of sanidine, quartz, and biotite	514-532 (1,687-1,746)	18 (59)
Tuff, bedded, ash-fall and reworked, grayish-orange-pink, massive to crudely bedded, slightly argillized. Phenocrysts 10 to 15 percent and sparse, small (0.5-2.0 cm) volcanic lithic fragments. Abrupt lower contact	532-534.5 (1,746-1,754)	2.5 (8)
Breccia, limestone and dolomite, medium-light- to dark-gray, poorly consolidated. Fragments angular to subangular, as much as 6 cm across, but mostly 1 cm or less, in grayish-orange to yellowish-gray silty calcareous matrix. Disseminated limonite. Pale-reddish-brown clay zone 0.15 m (0.5 ft) thick at top; crudely sorted zones in lower part of unit	534.5-561.5 (1,754-1,843)	27 (89)

Table 2.--Lithologic log and stratigraphic description of drill hole USW VH-2--continued

Stratigraphic and rock description[1]	Depth meters (feet)	Thickness of interval, meters (feet)
Alluvium and breccia, light-brown to moderate-reddish-brown, moderately consolidated; fragments mostly gray limestone and dolomite, subround to subangular, as much as 10 cm across. A few fractures and vugs lined with calcite. Bed of gravel at 567 m (1,861 ft) dips 40°	561.5-568.5 (1,843-1,866)	7 (23)
Breccia, limestone, monolithologic, probable slide block, light- to medium-gray; irregular fractures coated with dark-reddish-brown clay and scattered vugs lined with calcite	568.5-583 (1,866-1,913)	14.5 (47)
Breccia, similar to unit above, but also contains pale reddish-brown and greenish-gray silty limestone, and is more highly fractured. Fragments resemble Antelope Valley Limestone	583-595 (1,913-1,952)	12 (39)
Alluvium, light- to medium-gray and dark-reddish-brown, poorly consolidated, mixed with carbonate rock and tuff fragments, subangular to subround, as much as 8 cm (3.2 in) across	595-595.5 (1,952-1,954)	0.5 (2)
Paintbrush Tuff Tiva Canyon Member Tuff, ash-flow, dark-reddish-brown, nonwelded to slightly welded, partly vitric; pumice, white and reddish-orange, partly vitric, 1-3 cm long. Phenocrysts 10 percent of rock, consist of plagioclase, sanidine, biotite, and minor quartz and clinopyroxene; sparse small (0.5-2 cm) blackish-red to grayish-red volcanic lithic fragments	595.5-596 (1,954-1,956	0.5 (2)

Table 2.--Lithologic log and stratigraphic description of drill hole USW VH-2--continued

Stratigraphic and rock description[1]	Depth meters (feet)	Thickness of interval, meters (feet)
Paintbrush Tuff-Continued		
Tiva Canyon Member--Continued		
Tuff, ash-flow, moderate-reddish-brown to dark-reddish-brown, moderately to densely welded; pumice, similar to unit from 595.5 to 596 m (1,954-1,956 ft), increasing in abundance downward. Phenocrysts and lithic fragments similar to unit above. Several small faults[2] and fractures between 598 and 599 m (1,962-1,966 ft); one at 599 m (1,966 ft) has slickensides and dips 15°	596-599 (1,956-1,966)	3 (10)
Tuff, ash-flow, vitrophyre, densely welded, black, vitric; pumice, very light gray to light-brownish-gray, reddish-brown and grayish-pink, partly vitric, flattened, as much as 2 cm long. Phenocrysts, 15 percent of rock including plagioclase, sanidine, biotite, and minor quartz and clinopyroxene; sparse small (0.5-1 cm volcanic lithic fragments. Clay-coated fracture at 601.5 m (1,973 ft) dips 80°	599-601.5 (1,966-1,974)	2.5 (8)
Tuff, ash-flow, moderate- to dark-reddish-brown, densely welded, devitrified; pumice, brownish- gray to very light gray, partly vitric. Phenocrysts, 10 percent, similar to unit above	601.5-608 (1,974-1,995)	6.5 (21)

Table 2.--Lithologic log and stratigraphic description of drill hole USW VH-2--continued

Stratigraphic and rock description[1]	Depth meters (feet)	Thickness of interval, meters (feet)
Paintbrush Tuff-Continued		
Tiva Canyon Member--Continued		
Tuff, ash-flow, light-gray to light-brownish-gray, moderately to densely welded, devitrified; pumice, light-brownish-gray to white as much as 3 cm long. Phenocrysts, 5 percent, same as units above. Foliation dips about 15°. Fault at 613.5 m (2,013 ft) dips 60° and has oblique slickensides that suggest component of right-slip	608-620 (1,995-2,035)	12 (40)
Tuff, ash-flow, light-gray to pale-reddish-brown, locally mottled, moderately welded, devitrified, locally friable and altered, accompanied by abundant small faults[2] and fractures; pumice, gray, mostly 0.5-1.0 cm but as long as 10 cm (4 in.); lithophysae 15-20 percent, increasing in abundance downward, 2-5 cm average diameter, mostly filled. Phenocrysts, mostly sanidine, 5 percent, more abundant in pumice	620-632 (2,035-2,073)	12 (38)
Tuff, ash-flow, pale-grayish-red, densely welded, devitrified, sparse lithophysae near top; pumice, brownish-gray to white, length 1 to 3 cm. Phenocrysts rare, mostly sanidine. Alteration or disequilibrium rings around some pumice. Fault zone 633.5-636.5 (2,079-2,088 ft) containing clayey gouge with slickensides, which suggest component of lateral displacement; one fault at 634 m (2,080 ft) dips about 85°. Most of interval broken by fractures	632-643.5 (2,073-2,111)	11.5 (39)

Table 2.--Lithologic log and stratigraphic description of drill hole USW VH-2--continued

Stratigraphic and rock description[1]	Depth meters (feet)	Thickness of interval, meters (feet)
Paintbrush Tuff-Continued		
Tiva Canyon Member--Continued		
Tuff, ash-flow, light-gray to light-brownish- and purplish-gray, densely welded, devitrified; pumice, light-grayish-pink, as much as 6 cm long; vapor-phase alteration of pumice. Phenocrysts rare (<2 percent, mostly sanidine and minor biotite). Prominent fracture, dipping about 80° at 650-650.5 (2,132-2,134 ft)	643.5-652 (2,111-2,139)	8.5 (28)
Tuff, ash-flow, pale-brown to light-grayish-red, densely welded, devitrified, locally mottled; pumice, as much as 6 cm (2.4 in.) long, contain prominent vapor-phase crystallization, especially in lower part of unit. Phenocrysts very rare. Several high-angle fractures 654-656 m (2,145-2,153 ft) and several small faults[2] with some slickensides; one dips 80° others dip 10°-30°	652-667 (2,139-2,188)	15 (49)
Tuff, ash-flow, grayish-red-purple to brownish-gray, densely welded, devitrified, mottled; pumice, light-brownish-gray, as much as 6 cm (2.4 in.) long. Phenocrysts very rare. Pumice foliation dips about 15°. Fractures common	667-669 (2,188-2,195)	2 (7)

Table 2.--Lithologic log and stratigraphic description of drill hole USW VH-2--continued

Stratigraphic and rock description[1]	Depth meters (feet)	Thickness of interval, meters (feet)
Paintbrush Tuff-Continued		
Tiva Canyon Member--Continued		
Tuff, ash-flow, grayish-red, densely welded, devitrified, slightly mottled; pumice varicolored, as much as 4 cm (1.6 in.) long. Phenocrysts, about 4 percent, mostly sanidine and rare biotite. Numerous high- and low-angle fractures, locally accompanied by bleaching and thin coatings of manganese oxide and clay, mostly in upper part of unit	669-700 (2,195-2,296)	31 (101)
Tuff, ash-flow, similar to unit above, but mottled, and contains sparse lithophysal cavities, 1-3 cm in diameter; pumice slightly more common than in overlying unit, with some vapor-phase crystallization. Phenocrysts similar to those in unit above	700-706 (2,296-2,316)	6 (20)
Tuff, ash-flow, grayish-red to moderate-reddish-brown, densely welded, devitrified; pumice, mostly small (<2.0 cm), varicolored, some larger (as much as 7 cm or 2.7 in. long) toward base of unit. Phenocrysts, 3 percent, mostly sanidine and rare biotite. Minor faults between 713.5-715.7 m (2,341-2,348 ft), dip 80°-90°, filled with clay, and breccia zones as much as 3 cm wide	706-726.5 (2,316-2,383)	20.5 (67)

Table 2.--Lithologic log and stratigraphic description of drill hole USW VH-2--continued

Stratigraphic and rock description[1]	Depth meters (feet)	Thickness of interval, meters (feet)
Paintbrush Tuff-Continued		
Tiva Canyon Member--Continued		
Tuff, ash-flow, grayish-brown to brownish-gray, densely welded, devitrified; pumice, grayish- to dark-reddish-brown, as much as 6 cm long, but mostly 2-3 cm. Very sparse phenocrysts of sanidine and rare biotite	726.5-733.5 (2,383-2,406)	7 (23)
Tuff, ash-flow, brownish-gray, moderately to densely welded, devitrified; pumice, sparse and generally small (<1 cm). Phenocrysts, very sparse, mostly sanidine. A few volcanic lithic fragments	733.5-740.5 (2,406-2,429.5)	7 (24)
Tuff, ash-flow, gray to grayish-brown, densely welded, mostly vitric; pumice, dark-gray to black, vitric; brown alteration bordering fractures and locally between fractures. Low-angle (<45°) fault contacts at argillized zone from 740.5-740.6 m (2,429.5-2,430). Small fault[2] at 745 m (2,445 ft) dips 75° and has slickensides indicating component of lateral displacement. Irregular fractures filled with opal from about 742.8-745 m (2,437 to 2,444 ft)	740.5-748.5 (2,429.5-2,456)	8 (26.5)
Tuff, ash-flow, moderate-brown, moderately to slightly welded. Partly argillized; pumice, moderate-reddish-brown, somewhat altered, 1-3 cm across. Sparse phenocrysts of sanidine and biotite	748.5-750.7 (2,456-2,463)	2.2 (7)
Tuff, ash-flow, similar to unit above, but only slightly welded	750.7-757 (2,463-2,484)	6.3 (21)

Table 2.--Lithologic log and stratigraphic description of drill hole USW VH-2--continued

Stratigraphic and rock description[1]	Depth meters (feet)	Thickness of interval, meters (feet)
Paintbrush Tuff-Continued Tiva Canyon Member--Continued Tuff, ash-flow, pale-yellowish-brown, well compacted but essentially nonwelded, devitrified; pumice brownish to yellowish-gray, as much as 4 cm (1.6 in.) across, but mostly <0.5 cm. Phenocrysts, 3 percent, mainly sanidine and biotite. Basal contact is irregular scoured surface	757-760 (2,484-2,494)	3 (10)
Bedded tuff Tuff, mostly massive, pale-reddish-brown to yellowish-gray and moderate-orange-pink, well indurated; small (<2 cm) pumice, sparse dark-reddish-brown volcanic lithic fragments, mostly <4 mm across. Maximum dip of weak stratification near top is 30°. Small high-angle faults[2] at 760.5 m (2,495 ft) have offset of less than 3 cm. Contact at base dips 35°	760-774 (2,494-2,540)	14 (46)
Tuff, massive to reworked, crudely bedded in places, pale-reddish-brown, small (<2 cm) grayish-brown pumice; partly silicified	774-775 (2,540-2,543.5)	1 (3.5)
Bedded Tuff Tuff, ash-flow(?), massive, nonwelded, yellowish-gray, zeolitic; pumice, grayish-yellow to olive-gray, altered. Phenocrysts, 3-5 percent, quartz, sanidine, and biotite. Numerous dark-reddish-brown volcanic lithic fragments 0.5-3 cm in diameter	775-777 (2,543.5-2,549.5)	2 (6)
Tuff, bedded, reworked, reddish-brown to dark-yellowish-brown. Phenocrysts 8 percent, biotite and sanidine. Dip 20°. Basal contact is fault dipping 10°	777-777.2 (2,549.5-2,550)	0.2 (0.5)

Table 2.--Lithologic log and stratigraphic description of drill hole USW VH-2--continued

Stratigraphic and rock description[1]	Depth meters (feet)	Thickness of interval, meters (feet)
Paintbrush Tuff		
Topopah Spring Member		
Tuff, ash-flow, grayish-red, moderately welded, devitrified; pumice, yellowish-gray, as much as 3 cm long. Phenocrysts, 5 percent, mostly feldspar and biotite	777.2-777.8 (2,550-2,552)	0.6 (2)
Tuff, ash-flow, grayish-red to dark-reddish-brown, moderately to densely welded in lower part, devitrified; pumice, very light gray and moderate-red-brown, as much as 3 cm (1.2 in.) long. Phenocrysts, 10-15 percent, are sanidine and plagioclase with rare biotite, quartz, and clinopyroxene	777.8-782 (2,552-2,565.5)	4.2 (13.5)
Tuff, ash-flow, grayish-red-purple to light-brownish-gray, densely welded, devitrified; pumice, as much as 4 cm (1.6 in.) long. Phenocrysts, 5 percent, similar to those in overlying unit. Numerous small faults[2] and fractures 791-793 m 2,595-2,061 ft) containing clay and breccia	782-793 (2,565.5-2,601)	11 (35.5)
Tuff, ash-flow, similar to unit above, but locally mottled and containing very pale to dark-yellowish-orange pumice, mostly 2-4 cm (0.8-1.6 in.) long; partly vitric in places	793-801.5 (2,601-2,630)	8.5 (29)

Table 2.--Lithologic log and stratigraphic description of drill hole USW VH-2--continued

Stratigraphic and rock description[1]	Depth meters (feet)	Thickness of interval, meters (feet)
Paintbrush Tuff--Continued		
Topopah Spring Member--Continued		
Tuff, ash-flow, mottled moderate-reddish-brown, grayish-red, gray and dark-yellowish-orange, densely welded, devitrified; pumice, as much as 6 cm (2.3 in.) long. Lithophysae, increasing downward in size and abundance, mostly 2-6 cm (0.8-2.3 in.) across, coated with vapor-phase minerals, and bordered by bleached alteration rims. Phenocrysts, 5 percent, mainly sanidine and plagioclase with rare biotite	801.5-836.5 (2,630-2,745)	35 (115)
Tuff, ash-flow, similar to unit above, but with addition of brownish-gray pumice, and more fractures, some containing coarse calcite crystals	836.5-857.5 (2,745-2,814)	21 (69)
Tuff, ash-flow, light- to moderate- brown, mottled, densely welded, devitrified; pumice, 1-2 cm long, brownish-gray. Rare collapsed lithophysae in upper part have alteration halos and vapor-phase crystallization. Phenocrysts, 2 percent, consist mainly of biotite, sanidine, plagioclase. Some fractures have calcite filling	857.5-868.5 (2,814-2,850)	11 (36)

Table 2.--Lithologic log and stratigraphic description of drill hole USW VH-2--continued

Stratigraphic and rock description[1]	Depth meters (feet)	Thickness of interval, meters (feet)
Paintbrush Tuff-Continued		
Topopah Spring Member--Continued		
Tuff, ash-flow, light- to moderate-brown and pale-yellowish-orange, locally mottled, moderately to densely welded, devitrified; pumice, rare and small (<2 cm). Lithophysae, 1-6 cm (0.4-2.4 in.) across, largely collapsed, are as much as 40 percent of rock, and contain vapor-phase minerals. Very sparse phenocrysts, similar to those in unit above, and rare light-gray and blackish-red volcanic lithic fragments. Numerous fractures. Lower contact very gradational	868.5-905 (2,850-2,969)	36.5 (119)
Tuff, ash-flow, pale- to moderate- yellowish-brown, slightly mottled, densely welded, devitrified; pumice, gray, 1-2 cm long in upper part, as much as 6 cm (2.4 in.) long in lower part, with common alteration halos and vapor-phase minerals. Phenocrysts, 1-2 percent, consist largely of sanidine and minor biotite; fractures abundant, many filled with calcite	905-942 (2,969-3,090)	37 (121)
Tuff, ash-flow, pale-brown to yellowish-brown, densely welded, devitrified; pumice, as much as 6 cm (2.4 in.) long, light-brownish-gray and grayish-red, with pale-yellowish-orange alteration halos and minor vapor-phase crystallization. Phenocrysts sparse. Numerous fractures and faults at 942 m (3,091 ft) dip 65°, 982.5-984.5 m (3,223-3,230 ft). Pumice lineations dip about 25°	942-984.5 (3,090-3,230)	42.5 (140)

Table 2.--Lithologic log and stratigraphic description of drill hole USW VH-2--continued

Stratigraphic and rock description[1]	Depth meters (feet)	Thickness of interval, meters (feet)
Paintbrush Tuff-Continued		
Topopah Spring Member--Continued		
Tuff, ash-flow, pale- to moderate- brown, densely welded, devitrified; pumice, 1-3 cm long with alteration halos, increasing in size and abundance to 35 percent in lower part of unit. Phenocrysts, 2-3 percent, mostly sanidine and rare biotite. Abundant high-angle irregular fractures; small faults[2] at 984.5-986 m (3,230-3,235 ft), and 997.5 m (3,272 ft)	984.5-997.5 (3,230-3,273)	13 (43)
Tuff, ash-flow, pale- to moderate- brown, densely welded, devitrified; pumice, 30 percent, as much as 6 cm (2.4 in.) long, grayish-red to dark-reddish-brown and gray, common light-colored alteration halos. Phenocrysts very sparse. Faults in zone at 1,017-1,018 m (3,336-3,340 ft) dip 50°-80°; fault zones also at 1,032.5-1,033.5 m (3,387-3,391 ft) and 1,036.5-1037 m (3,401-3,403 ft); locally highly fractured and brecciated, especially at 1,047-1,047.5 m (3,435-3,437 ft). Calcite and manganese oxide in many fractures	997.5-1,048 (3,273-3,438)	50.5 (165)

Table 2.--Lithologic log and stratigraphic description of drill hole USW VH-2--continued

Stratigraphic and rock description[1]	Depth meters (feet)	Thickness of interval, meters (feet)
Paintbrush Tuff-Continued		
Topopah Spring Member--Continued		
Tuff, ash-flow, light-brown to black, vitrophyre, densely welded; pumice, moderate-reddish-orange and orange-pink to black, mostly vitric, as much as 6 cm (2.4 in.) long, smaller near base of unit; some alteration halos; 5 percent volcanic lithic fragments, a few as large as 6 cm (2.4 in.), increase in abundance downward; local oxidation and argillization, especially along fractures; a few high-angle fractures, commonly with opal coatings. Fault at 1,053 m (3,456 ft) with slickensides that suggest lateral component of movement. Phenocrysts very sparse	1,048-1,095 (3,438-3,593)	47 (155)
Tuff, ash-flow, light-brown to moderate-brown, moderately to slightly welded, decreasing downward, partly vitric; pumice, brown, as much as 4 cm (1.6 in.) across, partly silicified; matrix is grayish-orange glass shards. Sparse phenocrysts are mainly sanidine and rare biotite. Volcanic lithic fragments about 15 percent, as much as 4 cm (1.6 in.) across. Irregular calcite and silica-coated fractures, mostly between 1,095-1,096.5 m (3,593-3,598 ft). Small faults[2] at 1,098.5 m (3,604 ft) and 1,104 m (3,622 ft)	1,095-1,104 (3,593-3,622.5)	9 (29.5)

Table 2.--Lithologic log and stratigraphic description of drill hole USW VH-2--continued

Stratigraphic and rock description[1]	Depth meters (feet)	Thickness of interval, meters (feet)
Paintbrush Tuff--Continued		
Topopah Spring Member--Continued		
Tuff, ash-flow, grayish-orange-pink to light-brown, nonwelded but well indurated; pumice, varicolored, argillized and zeolitized. Small (1-2 cm) volcanic lithic fragments about 10 percent. Phenocrysts very sparse, mainly feldspar. Small fault[2] at 1,129-1,129.5 m (3,704.5-3,706 ft) dips 75°, and has slickensides plunging 60°, suggesting component of right-lateral movement	1,104-1,134.5 (3,622.5-3,723)	30.5 (100.5)
Bedded tuff		
Tuff, bedded, reworked, moderate to pale reddish-brown; a few small (<2 cm) volcanic lithic fragments. Beds at 1,135.5 m (3,725 ft) dip 15°; at 1,137 m (3,731 ft) dip 20°	1,134.5-1,138.5 (3,723-3,735.5)	4 (12.5)
Crater Flat Tuff		
Prow Pass Member		
Tuff, ash-flow, moderate-reddish-brown, nonwelded to slightly welded, devitrified; pumice, small, about 1 cm across. Phenocrysts, 15 percent, quartz, sanidine, plagioclase, rare biotite; a few volcanic lithic fragments, mostly less than 1 cm across, and sparse reddish-brown mudstone lithic fragments, 2-4 mm across	1,138.5-1,139.5 3,735.5-3,738.5	1 (3)
Tuff, ash-flow, light-brown to grayish-orange, slightly to moderately welded; welding increases abruptly downward; pumice, argillized, as much as 4 cm (1.6 in.) across. Phenocryst and lithic content same as in unit above	1,139.5-1,145.5 (3,738.5-3,757.5)	6 (19)

Table 2.--Lithologic log and stratigraphic description of drill hole USW VH-2--continued

Stratigraphic and rock description[1]	Depth meters (feet)	Thickness of interval, meters (feet)
Crater Flat Tuff--Continued		
Prow Pass Member--Continued		
Tuff, ash-flow, pale-red to grayish-red, densely welded, devitrified and zeolitized; pumice small (2-4 mm), with vapor-phase minerals. Phenocrysts, 20 percent, same as in overlying units; lithic fragments as in above units	1,145.5-1,146.5 (3,757.5-3,761)	1 (3.5)
Tuff, ash-flow, light grayish-red and purple to very light brownish-gray, moderately to densely welded, devitrified; pumice, white and brown, mostly 1-3 cm long. Phenocrysts, 8-10 percent, quartz, sanidine, plagioclase, rare hornblende and biotite, sparse lithic fragments like those in overlying units	1,146.5-1,156.5 (3,761-3,794.5)	10 (33.5)
Tuff, ash-fall, medium-light-gray, fine-grained, crudely stratified. Phenocrysts and lithic fragments similar to those in unit above. Dip 20°	1,156.5-1,156.7 (3,794.5-3,795)	0.2 (0.5)
Tuff, ash-flow, similar to 1,146-1,156 m (3,761-3,794.5 ft). Pumice and lithic fragments increase slightly in size and abundance downward	1,156.7-1,194.3 (3,795-3,918.5)	37.6 (123.5)
Tuff, ash-flow, pale-yellowish- to reddish-brown, moderately to densely welded, devitrified; pumice, small, light-gray. Phenocrysts 8-10 percent, mainly quartz, sanidine, and plagioclase, lithic fragments mostly 2-4 mm, mudstone and volcanic. Foliation dips 25°	1,194.3-1,196.5 (3,918.5-3,925)	2.2 (6.5)

Table 2.--Lithologic log and stratigraphic description of drill hole USW VH-2--continued

Stratigraphic and rock description[1]	Depth meters (feet)	Thickness of interval, meters (feet)
Crater Flat Tuff-Continued		
Prow Pass Member--Continued		
Tuff, ash-flow, pale-yellowish-brown, moderately to densely welded, devitrified; pumice, zeolitized, grayish-orange to yellowish-gray. Phenocrysts and lithic fragments same as in unit above	1,196.5-1,208 (3,925-3,963)	11.5 (38)
Tuff, ash-flow, greenish-gray, pale grayish-yellow-green, zeolitic, moderately welded or compacted, devitrified; pumice, small (1-2 cm). Phenocrysts, 5 percent, mostly feldspar; lithic fragments, mainly 2-4 mm across, are volcanic rock and dark-red mudstone	1,208-1,212.7 (3,963-3,978.5)	4.7 (15.5)
Bedded Tuff		
Tuff, ash-fall, pale-pink and grayish-yellow-green, zeolitized, well-sorted; bedding dips 15°	1,212.7-1,212.8 (3,978.5-3,979)	0.1 (0.5)
Tuff, crudely bedded, reworked, moderate-reddish-brown	1,212.8-1,214.6 (3,979-3,985)	1.8 (6)
Crater Flat Tuff		
Bullfrog Member		
Tuff, ash-flow, grayish-red to pale-reddish-brown, moderately to densely welded, devitrified; pumice, brownish-gray to red-purple, argillized, 1-6 cm (0.4-2.4 in.) long. Sparse grayish-red volcanic lithic fragments. Phenocrysts 10-15 percent, sanidine, plagioclase, quartz, biotite, and hornblende	1,214.6-1,218.6 (3,985-3,998)	4 (13)

Table 2.--Lithologic log and stratigraphic description of drill hole USW VH-2--continued

Stratigraphic and rock description[1]	Depth meters (feet)	Thickness of interval, meters (feet)
Crater Flat Tuff--Continued		
Bullfrog Member--Continued		
Tuff, ash-flow, pale-yellowish-brown, densely welded, devitrified; pumice, small, mostly less than 1 cm across across, pale-brown. Phenocrysts as in unit above	1,218.6-1,219.2 (3,998-4,000) Total depth	0.6 (2)

[1]Percentages of constituents, including phenocrysts, are visual estimates made with the binocular microscope.

[2]A small fault is defined as one with a gouge or breccia zone less than about 5 cm (2 in.) in width, and (or) displacement that does not juxtapose significantly different lithologies.

[3]Sense of lateral slip direction assumes a normal fault.

BASALT PENETRATED BY THE DRILL HOLE

One of the main purposes of drill hole USW VH-2 was to establish whether subsurface basalts, or other young volcanic rocks, are present near the surface basalt flows of central Crater Flat. The hole was sited a short distance (about 0.6 km or 0.35 mi) west of the alignment of four Quaternary basalt centers in Crater Flat (fig. 1), in order to intersect any earlier basalts vented from the alignment in the vicinity of Red or Black Cones. The only basalt found in the drill hole was at a depth of 360 m (1,180 ft) to 390 m (1,278 ft) (tables 1 and 2). It consists of several thin flows, breccia and scoriaceous intervals with no extraneous alluvial material. The basalt is holocrystalline with a seriate texture, a plagioclase-clinopyroxene groundmass and about 5 percent olivine crystals and a few clots of clinopyroxene. Measurements with a portable fluxgate magnetometer indicate the basalt has strong reverse magnetic polarity. The flows lie directly on the Ammonia Tanks Member of the Timber Mountain Tuff, which has a normal polarity (Byers and others, 1976, p. 47), and a K-Ar age of 11.4 m.y. (corrected for new constants; Kistler, 1968; Dalrymple, 1979). A sample of the basalt from a depth of 366 m (1,200 ft) gave an age of 11.3 $\pm$ 0.4 m.y. (R. F. Marvin, written commun., 1983). This date may be a little too old, for the following reasons: (1) Petrographically similar basalt exposed at the southern edge of Crater Flat in the same stratigraphic position is also magnetically reversed and gave an age of 10.5 $\pm$ 0.1 m.y. (R. J. Fleck, written commun., 1978); (2) the Ammonia Tanks Member has normal magnetic polarity, and is separated from the overlying basalt at the southern edge of Crater Flat by several meters of crudely bedded alluvium, (3) basalt K-Ar ages in general tend to be too old with respect to stratigraphically controlled K-Ar ages on tuffs, and (4) a basalt dike in a major fault on the west side of Yucca Mountain gave a K-Ar age of 10.0 $\pm$ 0.4 m.y. (R. F. Marvin, written commun., 1979), and it too is magnetically reversed.

In a report on drill hole USW VH-1 (Carr, 1982, p. 9 and fig. 3) it was suggested that the prominent large negative anomaly just west of USW VH-2 might be caused by a reversely magnetized rhyolite lava. The evidence from USW VH-2 now suggests that this anomaly is due to a westward thickening of the magnetically reversed basalt penetrated by the drill hole (fig. 2). The basalt is close enough to the surface and appears strongly enough magnetized to account for the anomaly. It would thus occupy the typical position of a younger basalt within the moat area of an older caldera. The magnetic anomaly associated with the body extends westward very close to the topographic scarp on the east face of Bare Mountain (fig. 1). This interpretation leaves in doubt the source of a 6.3 m.y.-old rhyolitic pumice found at the southeast edge of Crater Flat (Carr, 1982, p. 6), but the absence of any silicic pyroclastic layers in the alluvium of the drill hole indicates the source is probably not near USW VH-2.

PALEOZOIC ROCK DEBRIS PENETRATED BY THE DRILL HOLE

One of the most interesting and structurally significant aspects of the section penetrated by drill hole USW VH-2 are the large masses or debris of Paleozoic rocks that occur both above and within the volcanic rock units. This material occurs in two intervals (table 2)--from a depth of 309 m (1,013 ft) to the top of the Miocene basalt at 360 m (1,180 ft), and between the Rainier Mesa Member of the Timber Mountain Tuff and the Tiva Canyon Member

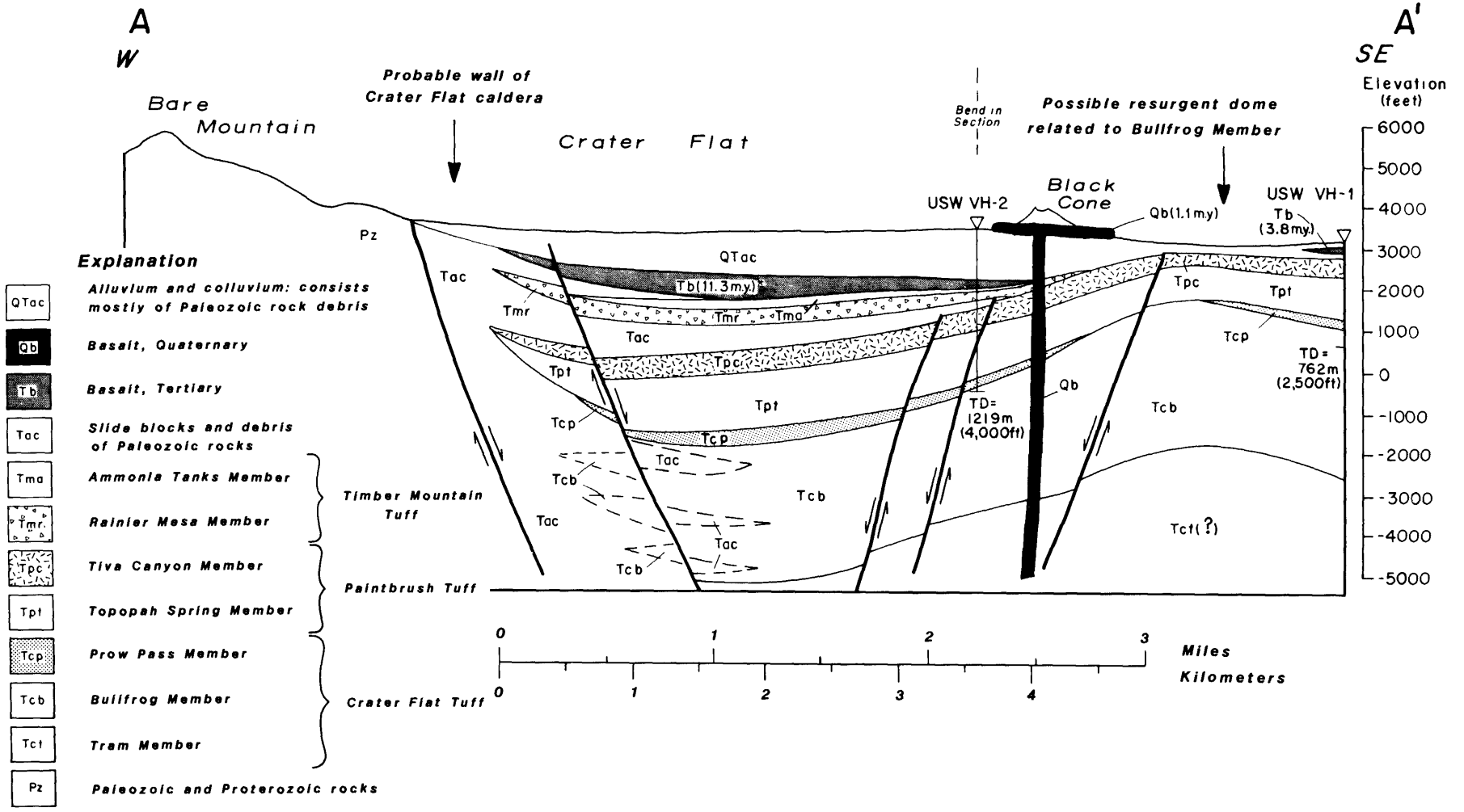

Figure 2.--Cross-section of west central Crater Flat between Bare Mountain and drill hole USW VH-1.

of the Paintbrush Tuff (535 to 596 m; 1,754-1,954 ft). These two intervals are characterized by a complete absence of volcanic matrix or rock fragments and subordinance of features suggesting sorting or bedding. Fragments are mostly angular to subangular and closely packed; larger blocks are a meter or more across and most are brecciated or crackled. Many of the large blocks are monolithologic, mainly limestone or dolomite. Lithologies suggestive of the Bonanza King Formation and Pogonip Group are common.

The general character of this material, in particular the large, brecciated but coherent monolithologic blocks, indicates a slide block origin for parts of both stratigraphic intervals. Moreover, the upper zone, above the basalt, correlates in stratigraphic position with an extensive (at least 7 km or 5 mi across) slide block of lower Paleozoic rocks exposed along the south rim of Crater Flat (fig. 1). This remarkably continuous mass of rock, largely the Bonanza King Formation of Cambrian age, rests on basalt dated at 10.5 m.y. (R. J. Fleck, written commun., 1978) that is very similar to that in the USW VH-2 drill hole. The breakaway zone of the slide would have been the relatively weak thin-bedded limestones and clastic rocks of the Carrara Formation, which underlies the Bonanza King on Bare Mountain. It is evident that this slide, or contemporary slides, also occurred at least as far northeast as the USW VH-2 drill hole, suggesting an aerial distribution approaching 100 km^2. Precipitous terrain would seem to have been required, as well as air-cushion transport, perhaps as a result of ground shock from major earthquakes.

STRUCTURE PENETRATED BY THE HOLE

No obvious thinning of units, or wide disturbed zones were seen in the core, indicating that no large faults of hundreds of meters displacement were encountered in the hole, a situation similar to that at USW VH-1 (Carr, 1982). As is usual in the area, the thick, brittle welded tuff units, such as the Tiva Canyon and Topopah Spring Members, are locally highly fractured and contain many small faults with displacements mostly less than a meter. Below the base of the Topopah Spring Member (1,134.5 m; 3,723 ft) no faults and few fractures were seen in the core (table 2). Also, only one fault was seen in the alluvium, although a few could be present but undetected as a result of poor core recovery in a few intervals. The first fault encountered was at 316 m (1,036 ft) in probable slide block debris, 44 m (144 ft) above the top of the Miocene basalt.

Faults in the drill hole are summarized in table 3.

Thirteen attitudes of beds, contacts, and lineations measured in the core range from 15° to 40°; the average is about 23°, or 21° if the anomalous 40° dip is excluded. The latter attitude is from a bed of gravel within the alluvium and breccia unit that occurs between the Tiva Canyon and Rainier Mesa Members, and probably represents a local, partly depositional dip. Many of the fault surfaces display slickensides, most of which suggest a component of right-lateral slip. Stress field orientation for the region (Carr, 1974) suggests that the faults showing evidence of right-slip strike between about N. 15° E. and northwest.

Table 3.--Faults and fault zones noted in the core of USW VH-2

Depth[1] m	Depth[1] ft	Unit	Dip	Remarks
316	1,036	Slide block	45°	Slickensides suggest left-lateral slip component
370	1,214	Basalt	--	Slickensides
375	1,231	Basalt	--	Calcite filled
383	1,256	Basalt	--	Slickensides
389	1,277	Basalt	--	--
439.5	1,441	Ammonia Tanks Member	--	--
441-444	1,445-1,456	Ammonia Tanks Member	Less than 45°	Slickensides, MnO and clay coatings
457	1,500	Rainier Mesa Member	--	--
473-474	1,552-1,554	Rainier Mesa Member	Low-angle	--
478-500	1,566-1,640	Rainier Mesa Member	50°-90°	Series of small faults
505	1,657	Rainier Mesa Member	70°	Nearly horizontal slickensides
513	1,684	Rainier Mesa Member	High-angle	Several faults; one dips 80° and has horizontal slickensides
598-599	1,962-1,966	Tiva Canyon Member	Low-angle	Several faults; one at 599 m (1,966 ft) has slickensides and dips 15°
613.5	2,013	Tiva Canyon Member	60°	Oblique slickensides suggest component of right-lateral displacement
620-632	2,035-2,073	Tiva Canyon Member	--	Numerous small faults

Table 3.--Faults and fault zones noted in the core of USW VH-2--continued

Depth[1] m	Depth[1] ft	Unit	Dip	Remarks
635.5-636.5	2,079-2,088	Tiva Canyon Member	High-angle	Fault zone containing clayey gouge and slickensides; one fault at 634 m (2,080 ft) dips 85°
654-656	2,145-2,153	Tiva Canyon Member	10°-30°, 80°	Several faults, some with slickensides
713.5-716	2,341-2,348	Tiva Canyon Member	80°-90°	Clay and breccia, as much as 2 cm wide
740-741	2,429-2,430	Tiva Canyon Member	Low-angle	Argillized zone
745	2,445	Tiva Canyon Member	75°	Slickensides suggest some lateral displacement
760.5	2,495	Bedded tuff	High-angle	Several faults with total offset less than 3 cm
777	2,550	Bedded tuff/ Topopah Spring Member	10°	At contact
791-793	2,595-2,601	Topopah Spring Member	Mostly high-angle	Clay and breccia; several faults
942	3,091	Topopah Spring Member	65°	--
982.5-986	3,223-3,235	Topopah Spring Member	--	Numerous fractures also
997	3,272	Topopah Spring Member	High-angle	Altered and crumbly rock
1,017-1,018	3,336-3,340	Topopah Spring Member	50°-80°	Fault zone
1032.5-1033.5	3,387-3,391	Topopah Spring Member	High-angle	Highly fractured; calcite and MnO coated; some breccia
1036.5-1037	3,401-3,403	Topopah Spring Member	--	Highly fractured; calcite and MnO coated; some breccia

Table 3.--Faults and fault zones noted in the core of USW VH-2--continued

Depth[1] m	Depth[1] ft	Unit	Dip	Remarks
1,047-1,047.5	3,436-3,437	Topopah Spring Member	--	Highly fractured and brecciated; calcite and MnO coated
1,053	3,456	Topopah Spring Member	High-angle	Slickensides suggest lateral slip component
1,098.5	3,604	Topopah Spring Member	--	--
1,104	3,622	Topopah Spring Member	--	--
1,129	3,705	Topopah Spring Member	75°	Slickensides plunge 60° and suggest right-lateral slip component

[1]Measurements are to nearest foot or 0.5 meter.

GEOPHYSICAL LOGS AND HYDROLOGIC DATA

A suite of geophysical logs was obtained in drill hole USW VH-2, including caliper, neutron porosity, induction electric, 3-D velocity, radioactivity spectralog, density, and magnetometer. No analysis of these logs is attempted here, but in general they help define and agree well with the lithology as described in table 2. The density logs deserve special mention as they illustrate the unusually high density of the lower part of the alluvium and the brecciated Paleozoic rock masses between the Rainier Mesa and Tiva Canyon Members. Between about 244.5 m (700 ft) and the bottom of the basalt at about 390 m (1,280 ft), density of the section is mostly over 2.5 g/cm^3, and averages about 2.6 g/cm^3. The same is true of the interval from 534.5 m to 595 m (1,754 ft to 1,954 ft). Thus, nearly 244 m (800 ft) of the section averages about 2.6 g/cm^3.

The continuity of the blocks of Paleozoic rocks shows as uniform 3-D velocity (6-ft spacing) intervals between 306 m (1,005 ft) and near the top of the basalt at about 357 m (1,170 ft), and in the interval between about 570 and 594 m (1,870 and 1,950 ft). The compensated neutron log suggests that porosity in these same zones is quite low, generally less than 15 percent, despite the obvious brecciated character of the rocks.

The importance of the above observations will be discussed later.

No hydrologic tests were conducted in this drill hole, because of the coring program and use of polymer drilling mud, which is considered to alter rock permeability and render most hydrologic tests invalid. The static water table is estimated to be at a depth of about 163 m (535 ft) (elevation 811 m or 2,662 ft), which is about 41.5 m (136 ft) higher than in USW VH-1, 2.7 km (1.7 mi) to the southeast. This is about twice the gradient estimated (Carr, 1982) between USW VH-1 and the Amargosa Desert Valley, but not enough control is available on the water table in the Crater Flat area to interpret the available data. The depth to the static water table in USW VH-2 is based on a fluid level of 162 m (530 ft) indicated by an induction log, and 164 m (538 ft) as indicated by downhole video camera.

As mentioned, geophysical logs confirm the relatively low porosity and high density of the section from near the water table to the top of the Tiva Canyon Member at about 597.5 m (1,960 ft). The only zones likely to have significant fracture permeability in the upper part of the saturated zone are the basalt at 360-390 m (1,180-1,279 ft), and perhaps parts of the Ammonia Tanks and Rainier Mesa Members.

STRUCTURAL AND VOLCANO-TECTONIC SIGNIFICANCE OF DRILL HOLE USW VH-2

Relation to Gravity

The drill hole was sited at the foot of the tremendous gravity gradient of about 30 mGal between Bare Mountain and central Crater Flat (Snyder and Carr, 1982; 1984). Snyder and Carr (1982, p. 26; 1984, p. 10,202) attributed the eastward extension of high density rocks beneath western Crater Flat to a shelf in the Paleozoic rocks controlled by buried major faults several kilometers east of the mountain front. The presence of about 244 m (800 ft)

of high-density rocks in the post-tuff section at USW VH-2, together with the absence of major faults to a depth of at least 1,220 m (4,000 ft) in the drill hole, and the apparent lack of linear trends in the large negative aeromagnetic anomaly between USW VH-2 and Bare Mountain, suggest that the main structural boundary between Crater Flat and Bare Mountain probably lies close to the present steep mountain front. The gravity profile can be explained by westward thickening wedges of Paleozoic debris and slide blocks (fig. 2). Additional such masses are likely at depth within the Crater Flat Tuff, if the caldera model is valid (Carr and others, 1984).

Structure of Crater Flat

Drill hole USW VH-2 has provided valuable information about the structure of central and western Crater Flat. It is significant that no major faults with hundreds of meters displacement were encountered in the hole, and the volcanic section appears to be a normal one for the area, at least to the depths drilled. The drill hole failed to cross any major structure (fig. 2) that might have controlled the curvilinear arrangement of the 1.2 m.y.-old basalts. Also, the hole is located so that if other Pliocene or Quaternary basalts had been extruded from the same zone as those at Red and Black Cones, they would have been intersected.

Probably the most significant structural feature of the drill hole is the presence of large wedges of Paleozoic rock debris in two stratigraphic intervals, one between the Tiva Canyon and Rainier Mesa Members, the other above the basalt that is probably about 10.5 m.y. old. Much of both intervals, though highly brecciated, has the continuity of slide block material. The masses of Paleozoic rock between the Tiva Canyon and Rainier Mesa Members were deposited in a time interval when major faulting took place in much of the area south and east of Crater Flat, including Yucca Mountain. These faults on Yucca Mountain displace the Tiva Canyon Member and older rocks hundreds of meters, but have much less effect on younger rocks (Lipman and McKay, 1965; Scott and Bonk, 1984). The presence of large slide blocks of probable tectonic origin is compatible with major structural movement between Tiva Canyon and Rainier Mesa time, and suggests a continuity or continuation of structural style from Yucca Mountain westward beneath Crater Flat. However, neither gravity (Snyder and Carr, 1982) nor aeromagnetic (Kane and Bracken, 1983) maps suggest a pattern of prominent faulting like that exposed on Yucca Mountain. The Paleozoic debris above the basalt in the drill hole is somewhat more heterogeneous than that between the Rainier Mesa and Tiva Canyon Members, and it contains some deposits of obvious alluvial origin, but is otherwise similar to the older interval. Of particular interest is the stratigraphic equivalence of the slide blocks penetrated by the drill hole with a very large slide block that occurs along the southwestern edge of Crater Flat from Black Marble hill southeastward about 7 km (5 mi) to the southernmost part of Crater Flat (fig. 1). Where the slide is exposed along the southwestern flank of Crater Flat, it is remarkably intact and is cut by only a few small faults. At the southeast corner of Black Marble hill, where the large frontal fault zone on the east side of Bare Mountain crosses into the Amargosa Desert Valley (fig. 1), very little vertical movement appears to have occurred after emplacement of the slide. The exact age of the slide is

not known; it is younger than 10.5 m.y. and older than 3.8 m.y.-old basalts in the southeastern part of Crater Flat. From the evidence discussed, it is suggested that emplacement of the slide, or slides, coincides with the episode of the last major movements on the east frontal fault of Bare Mountain.

The rate of burial or tectonic adjustment at USW VH-2 during about the last 11 m.y. has been estimated at 0.03 m/1,000 years (Carr, 1984, table 2). The complete absence of volcanic debris in alluvium or debris below about 122 m (400 ft) in depth in USW VH-2 suggests there was no positive structural tilt to the west prior to that point in the stratigraphic record. Assuming the correct age of the basalt is about 10.5 m.y., at USW VH-2 only about 366 m (1,200 ft) of alluvium and slide material has accumulated in that time, two-thirds of it (244 m or 800 ft) before the influx of volcanic clasts from the east began. Using a simple proportion and assuming a uniform deposition rate yields an age of about 3.5 m.y. ago for the change in deposition from entirely Paleozoic fragments to mainly volcanic fragments. The presence of basalt a little over 1 m.y. old at the surface at nearby Red Cone and Black Cone, suggests a significant slowing of the alluviation process and (or) stabilization of tectonic adjustments in at least the last 1 m.y. or so. If the incorporation of volcanic clasts in the alluvium began roughly 3-4 m.y. ago, the cause could have been gentle westward tilting accompanying renewed displacement on the Bare Mountain frontal fault zone, or conversely, the ending of significant uplift on Bare Mountain could have slowed the accumulation of Paleozoic rock debris fans and allowed encroachment of volcanic clasts from the east. Figure 2 assumes the latter explanation, with only minor structural tilting after the Tertiary basalts were extruded.

Thus, although the east front of Bare Mountain is obviously the focus of persistent young faulting, there is fairly good evidence that no major structural displacement has occurred in central and eastern Crater Flat in the last 10 m.y. or so. There are, however, indications that each basalt eruptive episode in and near Crater Flat has been accompanied by some faulting. The most obvious relationship was found in two trenches across faults in eastern Crater Flat near Yucca Mountain, where basalt ash, probably related to the 1.2 m.y. episode[1], was found at several meters depth within the faults (Swadley and Hoover, 1983). Large-scale landsliding possibly triggered by faulting and earthquakes, appears to be closely associated in time with the 3.8 m.y.- and 10-11 m.y.-old basalt episodes. Some or all of the youngest minor surface faulting in the area may have accompanied the Big Dune basalt (approximately 0.27 m.y.-old eruption; fig. 1). This faulting, of less than 1-m displacement, was estimated by Swadley and Hoover (1983) to have occurred between 260,000 and 40,000 years ago, with the evidence favoring the older part of this range.

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[1]Later studies by D. T. Vaniman at Los Alamos National Laboratory have indicated that the chemistry and petrology of the basalt ash from the 1.2 m.y.-old centers in Crater Flat cannot be confidently distinguished from the ash of the 0.3 m.y.-old Big Dune (formerly called Lathrop Wells) basalt center. A good case can be made (Swadley and others, 1984), however, for the older of the basalt eruptive episodes.

Significance of USW VH-2 Drill Hole with Respect to the Crater Flat Caldera Model

Crater Flat has been described (Carr, 1982; Carr and others, 1984) as the source of the Crater Flat Tuff. This volcano-tectonic feature, named the Crater Flat-Prospector Pass caldera complex, is thought to underlie most of Crater Flat. Evidence supporting the caldera model is given by Snyder and Carr (1982; 1984), Carr (1982), and Carr, Byers, and Orkild (1984), and is not repeated in detail here. In summary, however, the most important evidence for a caldera source of the Crater Flat Tuff beneath Crater Flat is as follows: (1) The proposed caldera complex is fringed by a number of dacitic and rhyodacitic lava flows and dikes whose age and stratigraphic position are compatible with the concept that these bodies represent magmatic precursors of the Crater Flat Tuff eruptions; (2) seismic (Hoffman and Mooney, 1983) and gravity data (Snyder and Carr, 1982; 1984) suggest that 2-5 km (6,500 to 16,000 ft) of volcanic rocks fill the structural low in Crater Flat--a thickness suggesting major volcano-tectonic collapse; (3) the Crater Flat Tuff is distributed in an apparent east-west asymmetric pattern centered on Crater Flat; and (4) drill hole USW VH-1 bottomed in densely welded intracaldera-like Bullfrog Member after penetrating 141 m (464 ft) of the unit.

Drill hole USW VH-2 did not produce much additional data on the caldera, although it does fit well with the proposed concept of a resurgent dome beneath USW VH-1 (Carr, 1982). On figure 2, USW VH-2 is interpreted to lie near the outer edge of a gentle resurgent structure in the caldera related to eruption of the Bullfrog Member of the Crater Flat Tuff. The Prow Pass Member, which is only 50 m (165 ft) thick at USW VH-1, thickens slightly to 74 m (244 ft) at USW VH-2. The Topopah Spring and Tiva Canyon Members in the USW VH-2 drill hole are among the thickest sections of these units in the region, emphasizing the negative tectonic character of Crater Flat during the time of their emplacement.

In summary, the USW VH-2 drill hole produced additional evidence as already described, that Crater Flat is not a Pliocene or Quaternary structural graben, but rather a relatively old (mid-Miocene) volcano-tectonic feature that has not been greatly modified by subsequent tectonic activity. The curvilinear fault trace at the east foot of Bare Mountain is interpreted to be basically an old feature that originated as the main caldera ring fracture that accomodated collapse of the Crater Flat-Prospector Pass caldera complex. This concept is supported by the fact that faults of similar trend within Bare Mountain show very little or no displacement after dikes dated at 13.9 m.y. were emplaced (Carr and others, 1984). One, or several of these faults were subsequently utilized as the main collapse structure accompanying eruption of the Bullfrog and possibly the Tram Members of the Crater Flat Tuff about 13.8-13.5 m.y. ago (Carr and others, 1984). With the information from USW VH-2, I would now place the caldera boundary shown in their fig. 18 (Carr and others, 1984) closer to Bare Mountain.

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