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QUATERNARY GEOLOGY OF THE BLACK ROCK DESERT, MILLARD COUNTY, UTAH

by
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UTAH GEOLOGICAL AND MINERAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES

C.G. Oviatt QUATERNARY GEOLOGY OF THE BLACK ROCK DESERT, MILLARD COUNTY, UTAH UGMS Special Studies 73

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ABSTRACT

Surficial deposits in the Black Rock Desert of west-central Utah, in an area encompassing 12 7.5-minute topographic quadrangles, were mapped at a scale of 1:100,000. The Black Rock Desert is the southern extension of the Sevier Desert between the Cricket Mountains and the Pavant Range, and lies mostly between altitudes of 4650 feet (1420 m) and 6000 feet (1800 m). Surficial deposits in the map area consist of fine-grained lacustrine deposits of late Tertiary to Quaternary age (including deposits of Lake Bonneville), deltaic and alluvial deposits of the Beaver River, and coarser-grained lacustrine and alluvial deposits in piedmont areas. Thin deposits of eolian sand are present throughout the map area, but are concentrated in dunes in favorable localities. The map area also contains Tertiary and Quaternary basalt lava flows, rhyolite lava domes, and volcanic vents. Quaternary faults cut deposits of all ages.

Radiocarbon ages of samples collected in the Black Rock Desert indicate that Lake Bonneville first began to overflow its threshold near Red Rock Pass, Idaho, after about 15,000 years ago, and that Pavant Butte, a basaltic tuff cone in the Sevier Desert, erupted about 15,500 years ago when the lake was within 50 feet (15 m) of its highest level (the Bonneville shoreline). The Tabernacle Hill tuff ring and basalt flow were erupted into Lake Bonneville at or near the Provo level, as shown by geomorphic relationships and a radiocarbon age of about 14,300 yr B.P. on lacustrine tufa collected from the margin of the flow. The youngest basalt flows in the Black Rock Desert, which are associated with the Ice Springs craters, are about 600 years old.

Quaternary faults cut both surficial deposits and volcanic rocks. The Cove Creek dome, a doubly plunging, north-trending, anticline on the southern boundary of the map area, was uplifted beginning in the late Tertiary. Upward deflection of the Bonneville shoreline and diversion of Cove Creek suggest that uplift may have continued into the late Pleistocene and Holocene.

INTRODUCTION

The purpose of this report is to describe the Quaternary geology and Quaternary history of the Black Rock Desert in southeastern Millard County, Utah. The geologic work reported on here was undertaken as a Cooperative Geologic Mapping (COGEOMAP) project, funded by the U.S. Geological Survey and the Utah Geological and Mineral Survey. Field work for the project was completed in six weeks during June and July, 1987, and the map and report were prepared during the fall and winter of 1987 and 1988. Part of the Sevier Desert north of the Black Rock Desert was mapped for COGEOMAP in 1986 (Oviatt, 1989).

The map area (plate 1) encompasses 12 7.5-minute topographic quadrangles, or approximately 660 mi^2 (1700 km^2), and includes the towns of Meadow and Kanosh, Utah (figure 1). Altitudes in the area range from about 4650 feet (1420 m) along the Beaver River to over 6000 feet (1800 m) in the Cricket Mountains and the Pavant Range. Most of the map area on the floor of the Black Rock Desert has little relief except where resistant volcanic rocks stand higher than the surrounding less-resistant surficial deposits. The Black Rock Desert, which is the southern extension of the Sevier Desert, is bounded on the east by the Pavant Range, on the west by the Cricket Mountains, and on the south by the Mineral Mountains and the northern extension of the Escalante Desert (figure 1).

The climate on the floor of the Black Rock Desert is arid and warm, with mean annual temperatures at Deseret, Utah, of 49 °F (9.4 °C) and mean annual precipitation of 7.06 inches (17.9 cm) during the period 1951-1974 (NOAA, 1980). Precipitation is concentrated in the spring and late autumn to early winter months. The vegetation in the map area is dominated by greasewood *(Sarcobatus vermiculatus)* at low altitudes, shadscale *(Atriplex confertifolia)* and other xerophytes on piedmont slopes and uplands, and pinyon-juniper woodland in the mountains.

Previous work on the surficial deposits and geomorphology of the Black Rock Desert area includes the efforts of Gilbert (1890), Maxey (1946), and Isgreen (1986). The bedrock geology in the Black Rock Desert has been mapped by Steven and Morris (1983), Hintze (1984), and George (1985). The structural geology of the Black Rock Desert region has been studied by Anderson and Bucknam (1979), Cook and others (1981), Allmendinger and others (1983), Anderson and others (1983), and Crone and Harding

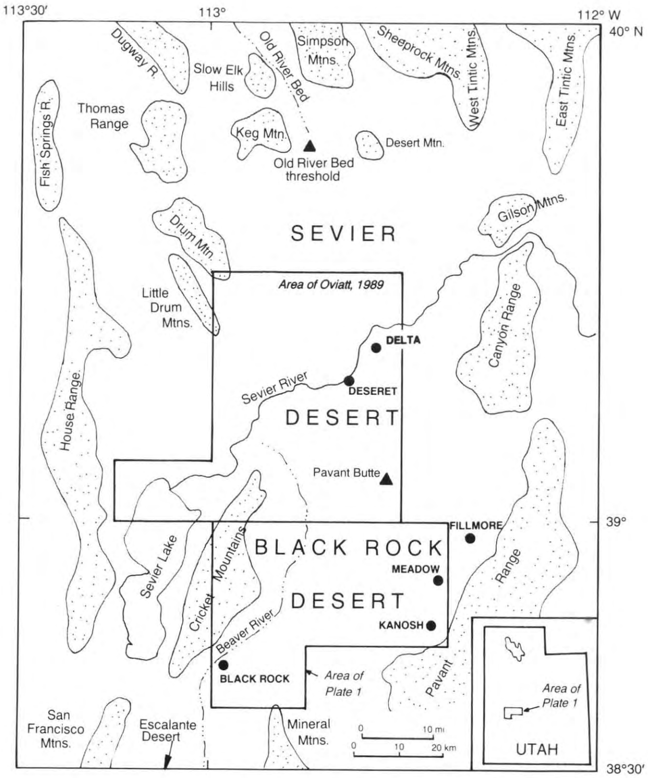


Figure 1. *Location map. The area mapped for COGEOMAP in 1986 (Oviatt, 1989) is also shown.*

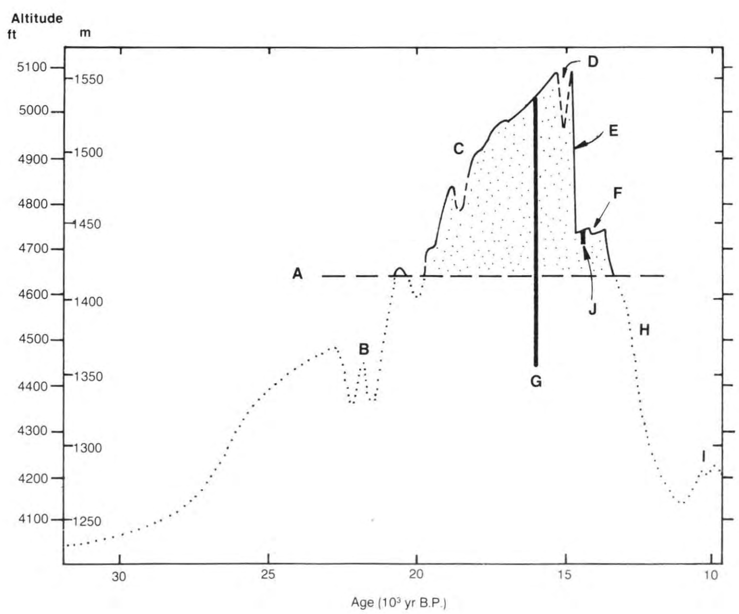


Figure 2. *Lake Bonneville time-altitude diagram, modified from Currey and Oviatt (1985). A = approximate lower altitudinal limit of Lake Bonneville deposits in the Black Rock Desert (The dotted line below A indicates Lake Bonneville history at lower altitudes in the northern part of the Bonneville basin.); B = Stansbury oscillation; C = transgressive phase of Lake Bonneville; D = Keg Mountain oscillation (non-catastrophic drop from the Bonneville shoreline); E = catastrophic drop in lake level during Bonneville flood; F = Provo shoreline; G = Pavant Butte basaltic ash; H = post-Provo regressive phase; I = Gilbert shoreline; J = Tabernacle Hill basaltic ash. The stippled pattern represents the time of deposition of the white marl (Qlm) in the Black Rock Desert.*

(1984). Gilbert (1890), Condie and Barsky (1972), Puskar and Condie (1973), Hoover (1974), Best and others (1980), Evans and others (1980), Carrier and Chapman (1981), Crecraft and others (1981), and Nash (1986) have studied the volcanic rocks. Mower (1965) and Thiros (1988) have studied the hydrogeology of Pavant Valley.

Surficial deposits in the map area consist of fine-grained lacustrine deposits of late Tertiary to Quaternary age, including deposits of Lake Bonneville, deltaic and alluvial deposits of the Beaver River, and coarser-grained lacustrine and alluvial deposits in piedmont areas. Thin deposits of eolian sand are present throughout the map area, but are concentrated in dunes in favorable localities. The map area also contains Tertiary and Quaternary basalt flows and volcanic vents, and Quaternary faults cut deposits of all ages.

DESCRIPTION OF MAP UNITS

For mapping purposes (plate 1) the Quaternary deposits in the Black Rock Desert are classified primarily on the basis of their environments of deposition. The unconsolidated Quaternary sediments were deposited in lacustrine, alluvial, deltaic, playa, spring, and eolian environments as indicated by the first lower-case letter in the map-unit symbols. Other distinguishing characteristics, such as grain size, lithology, or geomorphic expression, are used to subdivide the deposits into mappable units and are indicated by the second lower-case letter in the symbol. Some deposits can be grouped into map units having distinctly different relative ages. In these cases, number subscripts are used, such as in the map units Qal_1 and Qal_2, where the subscript 1 indicates a younger relative age than the subscript 2. Where the surface geologic materials are thin or discontinuous and the shallow subsurface deposits can be determined, map units are stacked so that more than one deposit can be shown. For example, discontinuous or thin eolian deposits that overlie pre-Bonneville basalt, are mapped as Qed/Qvb_2. Stacked units have the color of the lower map unit.

Plate 1 also shows Quaternary volcanic rocks and pyroclastic deposits, which are classified on the basis of lithology and age. Tertiary and Paleozoic rocks are not subdivided to the same degree as the Quaternary deposits.

The ages of the map units discussed below are based on the following criteria: radiocarbon ages obtained for this project (table 1); the ages of volcanic ashes that are interbedded with the deposits (table 2); the radiometric ages of volcanic rocks as obtained from published sources (table 3); and the stratigraphic relationships of the deposits with deposits or landforms of Lake Bonneville, the ages of which are well known (figure 2). In most cases, the Quaternary deposits can be assigned at least an approximate age of early, middle, or late Pleistocene, or Holocene (figure 3), and the ages of late Pleistocene and Holocene deposits can usually be determined with greater accuracy.

The map units are described below under their major genetic categories, but not necessarily in stratigraphic order. Consult the section on geologic history for a discussion of the Quaternary historical development of the Black Rock Desert.

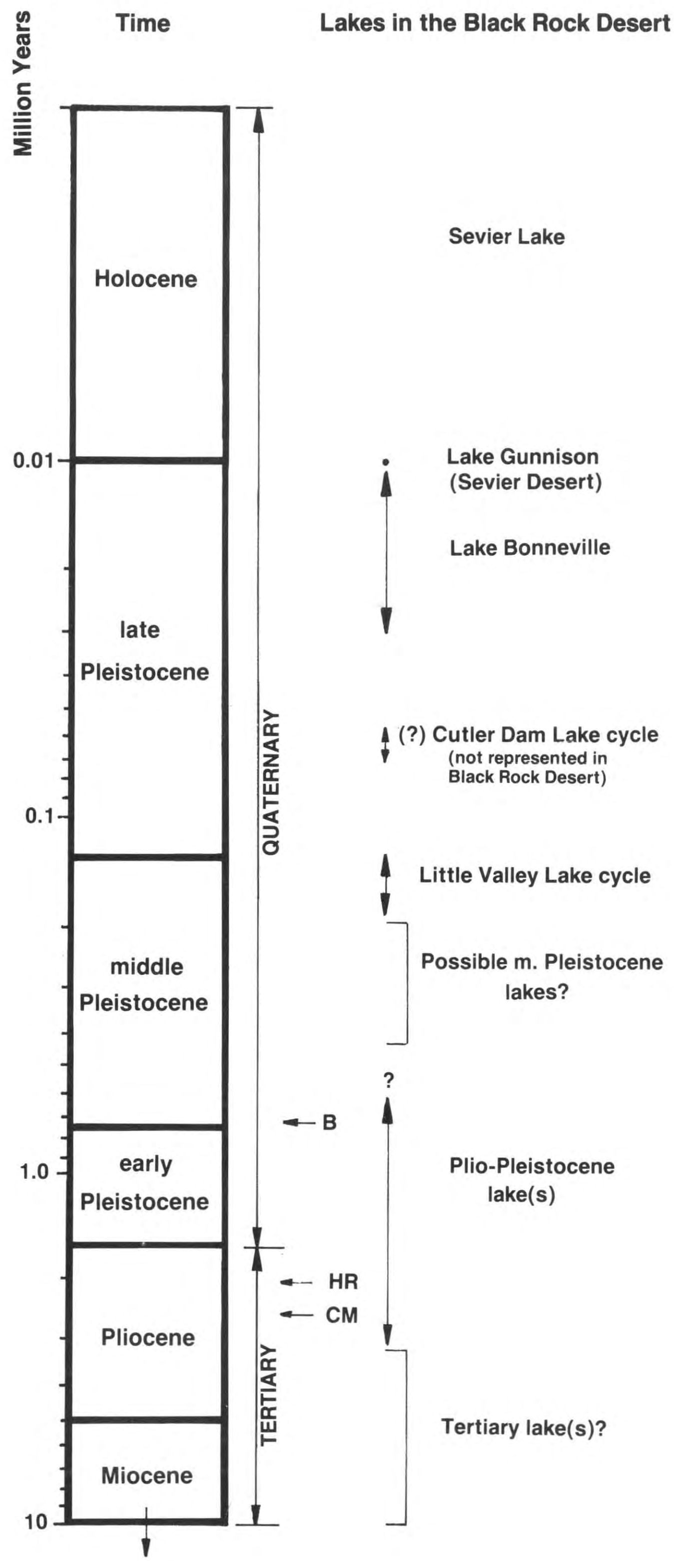


Figure 3. Geologic time scale of the late Cenozoic showing major lake cycles in the Black Rock Desert. B = Bishop ash; HR = Huckleberry Ridge ash; CM = Cudahy Mine ash.

Table 1.
Radiocarbon ages of samples from the Black Rock Desert collected within the boundaries of plate 1.

No.	Significance	Lab Number	Dated Materials	Altitude[a]	Locality[b]	Depositional Setting	^{14}C age[c]	Reference
1	deposition of tufa at or near the Provo shoreline	Beta-23803	tufa	4750 (1448)	F	shorezone at the outer margin of the Tabernacle Hill basalt flow	14,320 ± 90 13,840 ± 90[d]	this report
2	minimum age of pre-Bonneville soil	Beta-25233	charcoal mixed with soil and sediment	5092 (1552)	G	upper part of pre-Bonneville soil and lower part of lagoon fill	14,130 ± 100	this report
3	minimum age of pre-Bonneville soil	Beta-22044	charcoal mixed with soil and sediment	5092 (1552)	G	upper part of pre-Bonneville soil and lower part of lagoon fill	15,900 ± 290	this report
4	minimum age of pre-Bonneville soil	Beta-22043	charcoal mixed with soil and sediment	5105 (1556)	H	upper part of pre-Bonneville soil and lower part of lagoon fill	14,650 ± 190	this report
5	minimum age of pre-Bonneville soil	Beta-23174 ETH-3518	charcoal[e]	5105 (1556)	H	upper part of pre-Bonneville soil	15,250 ± 160	this report
6	minimum age of pre-Bonneville soil	GX-13774	charcoal	5105 (1556)	H	upper part of pre-Bonneville soil	19,840 ± 400	D.R. Currey, personal communication, 1988

[a] *Altitudes in feet and (meters); uncorrected for the effects of isostatic rebound of the basin caused by the water load of Lake Bonneville;*

[b] *Refer to table 4 for locality descriptions*

[c] *Radiocarbon ages in yr B.P., Present = 1950*

[d] *^{13}C-adjusted age; $^{13}C/^{12}C$ = +4.0 per mil (PDB)*

[e] *small piece of charcoal (0.75 g) dated by accelerator mass spectrometry (AMS) at Eidgenossiche Technische Hochschule, Zurich, Switzerland*

Table 2.
Volcanic ashes exposed in or near map area.

Ash	Age[a]	Localities	Reference
Ice Springs basaltic tephra	< 660	E	Valastro and others, 1972
Tabernacle Hill basaltic ash	14,300	see plate 1	this report; Oviatt & Nash, 1989
Pavant Butte basaltic ash	15,500	see plate 1	this report; Oviatt & Nash, 1989
Bishop ash	740,000	C	Izett and others, 1988
Huckleberry Ridge ash	2.02 Ma	A	Izett and Wilcox, 1982
Cudahy Mine ash	2.63-2.22 Ma	B	Nash, 1986 (see table 3, this report)

[a] *Age in years B.P. or million years B.P. (Ma)*

Table 3.
Radiometric ages of volcanic rocks within the area of plate 1

Map Unit	Lava Field	Rock Type	Age (Ma)	Reference
Qvb$_1$	Ice Springs	basalt	< 660 ± 170 yr	5
Qvb$_2$	Tabernacle	basalt	14,320 ± 90 yr	4
———	Pavant Butte	ash	~15,500 yr	4
Qvb$_3$	Pavant	basalt	0.22 ± 0.26	3
Qvb$_3$	Pavant	basalt	0.03 ± 0.03	2
Qvb$_3$	Pavant	basalt	0.18 ± 0.18	10
Qvb$_3$	Pavant	basalt	0.16 ± 0.16	10
Qvb$_4$	Beaver Ridge I	basalt	0.9 ± 0.1	2
Qvb$_4$	Beaver Ridge II	basalt	0.5 ± 0.1	2
Qvb$_4$	Black Rock volcano (Kanosh)	basalt	0.6 ± 0.1	2
Qvb$_4$	Black Rock lava flow	basalt	1.32 ± 0.09	1
Ovb$_4$	Black Rock lava flow	basalt	0.97	3
Qvn	Beaver Ridge	andesite	1.5 ± 0.2	1
Qvr	White Mountain	rhyolite	0.4 ± 0.1	1, 7
Tvb	Cove Creek	basalt	2.53 ± 0.52	1, 6
Tvb	Cove Creek	basalt	2.62 ± 0.35	1, 6
Tvb	Burnt Mountain[b]	basalt	2.11 ± 0.36	1
Tvb	Lava Ridge	basalt	2.22 ± 0.51	1
Tvr	Coyote Hills	rhyodacite	2.74 ± 0.10	1, 8
Tvr	Coyote Hills	rhyodacite	2.67 ± 0.10	1, 8
Tvr	Cudahy Mine	rhyolite	2.63 ± 0.10	1, 8
Tvr	Cudahy Mine	rhyolite	2.54 ± 0.09	1, 8
Tvr	Cudahy Mine	rhyolite	2.48 ± 0.12	1, 8
Tvr	Cudahy Mine	rhyolite	2.38 ± 0.15	7
Tvr	Cudahy Mine	rhyolite	2.22 ± 0.08	9
Tvr	Mid Dome	rhyolite	2.51 ± 0.08	1, 8
Tvr	North Twin Peak	rhyodacite	2.35 ± 0.08	1, 8
Tvr	North Twin Peak	rhyodacite	2.43 ± 0.08	1, 8
Tvr	South Twin Peak	rhyolite	2.43 ± 0.08	1, 8
Tvr	South Twin Peak	rhyolite	2.33 ± 0.12	7
Tvr	South Twin Peak	rhyolite	2.35 ± 0.14	9

[a]*K-Ar ages, except the first three, which are* ^{14}*C*

[b]*not in map area*

References:

1 = Nash, 1986
2 = Hoover, 1974
3 = Condie and Barsky, 1972
4 = this report
5 = Valastro and others, 1972
6 = Crecraft and others, 1981
7 = Lipman and others, 1978
8 = Evans and others, 1980
9 = Leudke and Smith, 1978
10 = Best and others, 1980

Table 4.

List of localities discussed in text and indicated on plate 1

Locality	Description	Significance	Lat.-Long.
A	roadcut along Utah Highway 257	Huckleberry Ridge ash in QTlf	38°45.97′ 112°56.22′
B	gullies and badlands south of Beaver Ridge	Cudahy Mine tephra in QTlf	38° 48.15′ 112° 35.15′
C	shallow depression on surface of Black Rock basalt flow	Bishop ash exposure	38° 42.85′ 112° 57′
D	southwest of South Twin Peak	outcrop of Qal_2 below Black Rock basalt flow	38° 43′ 112° 48.3′
E	cut-bank along Chalk Creek	Ice Springs tephra in barrier-beach lagoon fill	38° 59.54′ 112° 24.9′
F	shallow overhang on east margin of Tabernacle Hill basalt flow	radiocarbon age 1 on lacustrine tufa	38° 53.98′ 112° 30.77′
G	gravel pit near Eight Mile Point	radiocarbon ages 2 and 3 on charcoal mixed with soil and sediment	38° 45.45′ 112° 32.82′
H	gravel pit south of Kanosh at Bonneville shoreline	radiocarbon ages 4, 5, & 6 on charcoal mixed with soil and sediment, and on charcoal (6 m below Bonneville shoreline)	38° 46.88′ 112° 26.38′

Table 5.

Microprobe analyses[a] of the Cudahy Mine tephra and of obsidian from near Twin Peaks, and of Mineral Mountains tephra and pumice

	Ash collected at Locality B	Obsidian from near Twin Peaks	DVP-1	AV-1	Mineral Mtns. pumice
SiO_2	72.6	75.9	74.6	73.2	72.9
TiO_2	0.06	0.11	0.06	0.06	0.08
ZrO_2	0.02	0.01	0.01	0.01	--
Al_2O_3	12.5	12.9	12.6	12.0	12.5
Fe_2O_3	0.77	0.85	0.77	0.48	0.59
Mn0	0.06	0.05	0.06	0.07	0.07
Mg0	0.02	0.07	0.01	0.02	0.17(?)
Ca0	0.70	0.74	0.70	0.37	0.40
Na_20	2.83	3.93	2.55	2.72	3.64
K_20	4.12	4.96	3.88	3.24	4.99
P_20_5	0.02	0.02	0.01	0.01	——
F	0.23	0.20	0.26	0.29	0.26
Cl	0.11	——	0.12	0.12	--
Total	94.04	99.7	95.6	92.6	95.6

[a]analyses by W. P. Nash, 1988

Table 6.
Microprobe analyses[a] of basaltic glass from ash samples collected in the Black Rock Desert[b]

	Pavant Butte				Tabernacle Hill		
	K-5A	B-1A	TH-13A	M-6	TH-6	TH-3A	TH-13B
SiO_2	50.8	50.5	51.4	50.3	50.6	50.6	50.5
TiO_2	1.81	1.60	1.57	1.76	1.88	1.82	1.83
Al_2O_3	16.2	16.1	16.0	15.5	15.6	15.7	15.5
FeO[c]	11.6	11.6	12.0	11.4	11.8	11.7	11.5
MnO	0.18	0.19	0.18	0.17	0.18	0.18	0.18
MgO	5.28	5.09	5.14	5.31	5.45	5.34	5.42
CaO	8.88	8.64	8.52	8.84	9.83	9.63	9.60
Na_2O	3.31	3.33	3.38	3.30	3.01	3.32	3.29
K_2O	1.27	1.27	1.30	1.28	1.23	1.28	1.28
P_2O_5	0.43	0.37	0.38	0.38	0.51	0.49	0.46
Cl	0.02	0.02	0.02	0.02	0.02	0.02	0.02
F	0.05	0.07	0.07	0.07	0.06	0.09	0.10
Total	99.8	98.8	100.0	98.3	100.2	100.2	99.7

[a] all analyses by W. P. Nash (1988, personal communication; see Oviatt and Nash, 1989)
[b] see figures 4 and 6 for collection localities
[c] total iron

Lacustrine Deposits

Plio-Pleistocene lacustrine fines and limestone (QTlf and QTln) — Fine-grained clastic deposits and limestone of a pre-Bonneville lake or lakes are widespread in the Black Rock Desert and are mapped as QTlf and QTln, respectively. QTlf includes brown (7.5 YR 5/4), and light-olive-gray (5 Y 6/2) calcareous silty clay, silt, and minor amounts of sand. QTlf is remarkably uniform in lithology in isolated exposures throughout the Black Rock and Sevier Deserts (Oviatt, 1989). The stratigraphic base of QTlf is exposed outside the map area along the axis of the Cove Creek dome where it overlies alluvium (Crecraft and others, 1981). QTlf probably overlies bedrock surfaces, alluvial-fan deposits, and possibly other upper Tertiary lake beds in other areas.

QTlf contains ostracodes, but other fossils are rare. Gastropods of the genus *Amnicola* (?) have been found at a few localities outside the map area (Oviatt, 1989). Ostracodes collected from equivalent deposits northwest of the map area near Sevier Lake suggest that the Plio-Pleistocene lake water was fresh (Oviatt, 1989).

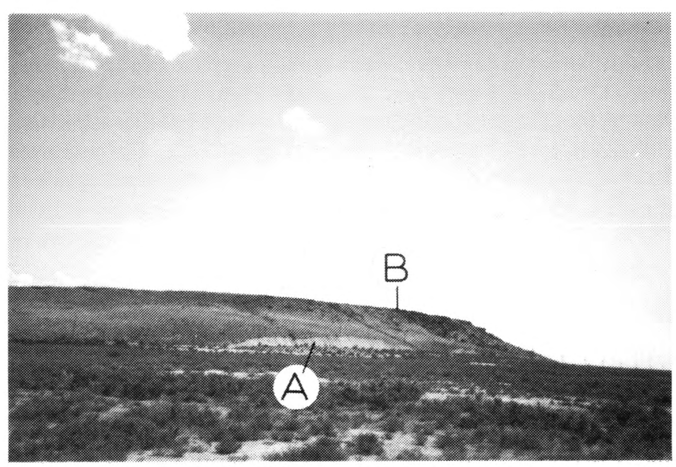


Figure 4. *The Plio-Pleistocene lake beds (QTlf) exposed in a railroad cut (at A) just north of the railroad siding of Black Rock. The lake beds are overlain by the Black Rock basalt flow (B). View is to the east from Utah State Highway 257.*

QTln consists of light-gray to white lacustrine limestone that locally contains gravel, but generally few fossils. The limestone is probably a shallow-water (shorezone) facies of approximately the same age as QTlf, because the two units interfinger in the vicinity of Cove Creek dome. QTlf is mapped in piedmont areas where it is exposed below thin gravel deposits (Qla).

QTlf and QTln are late Tertiary to middle Pleistocene in age, as shown by dated volcanic ashes and lava flows that are interbedded with the fine-grained deposits (figure 4). North of the railroad siding of Black Rock in roadcuts along Utah State Highway 257 (locality A table 4; figure 5), the Huckleberry Ridge ash (Izett and Wilcox, 1982) is interbedded with silty lacustrine deposits mapped as QTlf. The Huckleberry Ridge ash was erupted from the Island Park caldera in eastern Idaho 2.02 Ma (Izett and Wilcox, 1982).

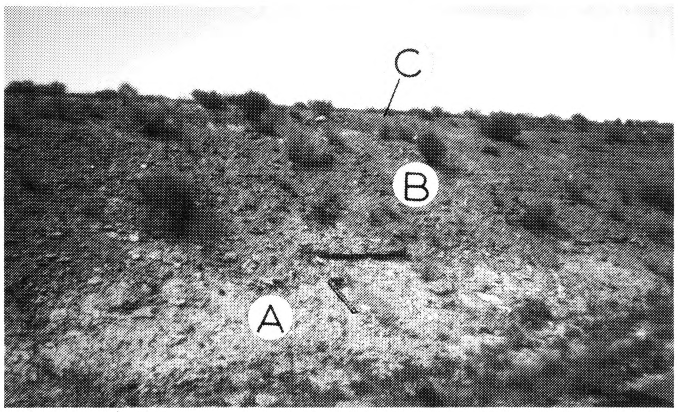


Figure 5. *A roadcut in Plio-Pleistocene lake beds (QTlf) at locality A (table 4) along Utah State Highway 257 along the east piedmont of the Cricket Mountains. A thick volcanic ash (A) identified as the Huckleberry Ridge ash (2.02 Ma; Izett and Wilcox, 1982) is overlain by sandy lake beds (B). Thin alluvial/lacustrine gravel (C) caps an erosion surface cut on the lake beds. Note the shovel lying on the ash exposure for scale (2.5 feet; 0.5 m).*

In exposures south of Beaver Ridge (locality B table 4), a coarse-grained silicic ash, containing pumice lumps and fragments of perlite and obsidian, is interbedded with lacustrine silts mapped as QTlf. This ash is probably correlative with the Cudahy Mine pumice unit, which was erupted between 2.6 and 2.2 Ma from vents about 13 miles (21 km) west of the ash exposures (W. P. Nash, 1988, personal communication; table 2). Cudahy Mine ash is also exposed in a roadcut along Interstate 15 south of the map area (DVP-1, plate 1) where it is interbedded with coarse-grained alluvium. Comparative chemical analyses are given in table 5.

Another locally derived silicic tephra is exposed in a road cut in alluvium south of the map area (AV-1, plate 1). The tephra is chemically similar to Mineral Mountains pumice, which has an age date about 0.5 Ma (W.P. Nash, 1988, personal communication; table 5).

About 0.5 mile (1 km) south of Antelope Spring, limestone mapped as QTln rests on basaltic lava (Qvb_3) of the Black Rock lava flow, which has been dated elsewhere about 1.0 Ma (table 3). In addition, QTlf and QTln are interbedded with, and overlie, basalts dated between 2.6 and 2.11 Ma at the Cove Creek dome and Lava Ridge (Nash, 1986).

The Bishop ash bed has been found in fine-grained deposits, of probable eolian and slope-wash origin, in a shallow depression on top of the Black Rock lava flow near the railroad siding of Black Rock (locality C table 4; Izett and others, 1988). The Bishop ash was erupted from the Long Valley caldera in eastern California approximately 740,000 yr B.P. (Izett and others, 1988). The stratigraphic relationship between the Bishop ash and the QTlf lake beds is unclear at the Black Rock locality because exposures are poor. However, on the western shore of Sevier Lake, the Bishop ash is exposed interbedded with finely bedded calcareous silt mapped as QTlf (Izett and others, 1988; Oviatt, 1989). The Bishop ash has also been found interbedded with lacustrine silts exposed in trenches at the Intermountain Power Plant site north of the town of Delta, Utah (Krusi and Patterson, 1980; Izett and others, 1988; Oviatt, 1989).

Although the deposits at the Black Rock locality cannot be physically traced from Black Rock northward to localities in the Sevier Desert because the exposures are discontinuous (Oviatt, 1989), the same lacustrine stratigraphic unit (QTlf), at least in a broad sense, is probably exposed at each of the localities. The lithology of QTlf is similar at all localities where volcanic ashes have been collected, and it changes very little among the numerous small isolated exposures around all flanks of the Cricket Mountains, eastward to the exposures south of Beaver Ridge, and in the east-sloping piedmont areas west and north of Sevier Lake. Thus QTlf and QTln probably range in age from at least late Pliocene to early middle Pleistocene (figure 3). Unconformities could be present within QTlf that have not yet been discovered.

Gravel of lacustrine and/or alluvial origin (Qla) — In piedmont areas, thin lacustrine gravel deposits overlying either QTlf or pre-Bonneville alluvial-fan deposits are mapped as Qla. The thin lacustrine gravel was derived from coarse-grained alluvium that was reworked by waves during the transgressive and regressive phases of Lake Bonneville. The gravel is moderately well rounded and sorted, and locally contains gastropods. In some areas, the lacustrine-gravel component of Qla is so thin it cannot be easily distinguished from the pre-Bonneville alluvial-fan gravel on which it lies. But Lake Bonneville shorelines, which are visible on aerial photographs, are etched across the pre-Bonneville alluvial fans indicating that waves in Lake Bonneville modified the alluvial-fan surfaces, and that post-Bonneville fluvial activity has been negligible in these areas.

In areas between the Provo and Bonneville shorelines, Qla represents the basal transgressive boulder beach deposits of Lake Bonneville. Below the Provo shoreline, Qla represents both the basal transgressive shorezone deposits and the regressive shorezone deposits of Lake Bonneville. Qlf or Qlm are locally preserved on Qla, but these fine-grained deposits were stripped off in most areas by waves during the regressive phase of Lake Bonneville and by post-Bonneville stream erosion or sheet wash. In some places significant accumulations of lacustrine gravel (Qlg) in spits or barrier beaches are mapped with Qla if they are too small to show at map scale.

Lacustrine gravel (Qlg) — Beach or spit gravel deposited in Lake Bonneville is mapped as Qlg. Only the thickest and most extensive accumulations of lacustrine gravel are shown as Qlg on plate 1. Less extensive accumulations of lacustrine gravel, some of which include well-formed gravel barrier beaches or spits, are lumped with Qla.

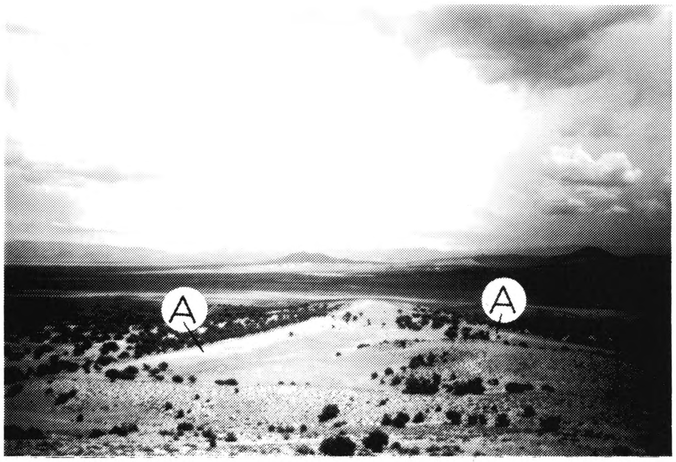


Figure 6. *View east from the Cricket Mountains across the Black Rock Desert showing a V-shaped embankment (A) at the Bonneville shoreline. G.K. Gilbert (1890, Plate VII, number 2) included a map of this embankment in his monograph on Lake Bonneville. Note the small enclosed lagoon between the two arms of the embankment. North and South Twin Peaks and the Pavant Range are visible in the distance.*

The best developed barrier beaches are found at the Bonneville and Provo shorelines (figure 6), but beautifully preserved beaches can be found at almost any level on the piedmont slopes in favorable geomorphic settings.

The ages of barrier beaches and spits that were deposited at the shore of Lake Bonneville at different stages can be inferred from the time-altitude diagram of Lake Bonneville (figure 2). On plate 1 the Bonneville and Provo shorelines are depicted as dashed or dotted lines. Depositional and erosional segments of the shorelines are not distinguished except where gravel embankments are large enough to be mapped as Qlg.

Late Pleistocene fine-grained lacustrine deposits and marl (Qlf and Qlm) — Fine-grained lacustrine sediments deposited in Lake Bonneville are widespread in the Black Rock Desert and are represented in part by the map unit Qlf. These deposits include silt, sand, marl, and calcareous clay. Qlf locally includes the white marl (Qlm), reworked white marl, and other lacustrine sediments that had been eroded and washed basinward during the regressive phase of Lake Bonneville. Qlm (the white marl) is distinguished as a map unit at only a few localities in plate 1.

Locally Qlf includes thin alluvium of post-Lake Bonneville age composed mostly of reworked fine-grained lacustrine deposits, and therefore, in some places it is poorly sorted and mixed with coarser grained debris. In these cases Qlf is difficult to distinguish from Qaf_1 because the alluvial component of the deposit may be significant, or the alluvial component may be gradational with the lacustrine component. In general, however, Qlf is finer grained than Qaf_1. Qlf is Bonneville and post-Bonneville in age.

The open-water or deep-water deposits of Lake Bonneville are shown on plate 1 as Qlm. The map unit Qlm is the same as the stratigraphic unit named the white marl, as defined by Gilbert (1890), and redefined by Oviatt (1987a). Qlm consists of fine-grained white to gray authigenic calcium carbonate, and variable amounts of detrital sediments which were deposited in open-water environments of Lake Bonneville. The white marl is finely bedded to indistinctly laminated and contains abundant ostracodes throughout. Gastropods are locally abundant near the base and top of the stratigraphic unit, and some exposures of Qlm contain abundant diatoms. The thickness ranges from 6 to 30 feet (2 to 10 m), depending on the local depositional setting. Qlm also includes clastic-rich marl at the base and top of the unit.

The map unit Qlm differs from Qlf in that Qlm is mapped in places where the white marl is well preserved and well exposed. Qlm has not been modified significantly by post-Bonneville fluvial activity, whereas Qlf may have a significant alluvial component consisting of reworked Qlm and other fine-grained deposits.

In the Black Rock Desert, Qlm ranges in age from slightly less than 20,000 yr B.P. to slightly greater than 12,000 yr B.P. (figure 2). Therefore, Qlm was deposited for almost 8000 years in the lowest parts of the Black Rock Desert, but marl was deposited during much shorter time periods at higher localities near the Bonneville shoreline (figure 2). The base of the white marl is diachronous. However, at all altitudes between the Bonneville and Provo shorelines the uneroded stratigraphic top of the white marl is essentially isochronous because deposition ceased abruptly due to the sudden lake-level drop caused by the Bonneville flood (Gilbert, 1890; Malde, 1968).

Fine-grained basaltic ash erupted from Pavant Butte (north of the map area) and Tabernacle Hill is interbedded with Qlm or Qlf at many localities in the eastern part of the map area (plate 1). The Pavant Butte ash has been dated about 15,500 yr B.P., and the Tabernacle Hill ash about 14,300 yr B.P. (see discussions below).

Lacustrine pebbly sand (Qls) — At many localities above the Provo shoreline, especially in areas where wave activity in Lake Bonneville was particularly strong, pebbly sand overlies boulder-beach deposits or Qla. The sand is mapped as Qls, and its composition reflects local sources. Qls is well sorted, and it is thin, probably less than 6 feet (2 m) thick in most places. Good exposures of Qls have not been observed, but the bedding appears to be massive.

Qls was deposited in offshore settings in Lake Bonneville as the lake transgressed across alluvial fans or easily eroded bedrock (such as Tertiary rhyolite [Tvr]). Waves in the shorezone eroded the alluvium or soft bedrock, and swept the sand-sized debris offshore to settle out in quieter water. Qls is found associated with large gravel spits and barrier beaches in the southern part of the map area.

Lacustrine lagoon deposits (Qll) — Poorly bedded deposits of silt, sand, and clay filling lagoons behind Lake Bonneville barrier beaches are mapped as Qll. Some of the fine-grained sediment in these settings was probably deposited by waves that washed over the crests of the barrier beaches during storms, and some was deposited in post-Bonneville time as slope-wash from the surrounding hill sides. Qll therefore is Bonneville and post-Bonneville in age. The largest barrier-beach lagoon in the map area is near the railroad siding of Borden and is associated with the Provo shoreline. Other lagoons in the map area (e.g., figure 6) are too small to map at a scale of 1:100,000.

Deltaic Deposits

Deltaic sand and gravel (Qdg) — Sand and gravel deposited near the mouth of the Beaver River during the Bonneville lake cycle is mapped as Qdg on plate 1. Qdg is composed of pebble-sized clasts of igneous and sedimentary rocks mixed with abundant sand. Pebbles of obsidian are common. The gravel was transported to the front of the Beaver River delta by river currents and then was reworked by waves at the Provo shoreline and during the regression of the lake across the front of the delta. Low beach ridges are mapped (in Qlg) on the cuspate delta front at and below the Provo shoreline (dashed lines with arrows in Qlg in plate 1) where waves transported the sediment laterally away from the river mouth.

Qdg covers a large area east of the Beaver River. Abandoned river channels, most of which are partially buried by eolian sand, are mapped across the area of deltaic gravel and sand. The deltaic gravel extends downslope in a wide (4 miles; 6 km) area from just north of the Coyote Hills to the Provo shoreline. It overlies and grades into lacustrine shorezone gravel in barrier-beach ridges at and near the Provo shoreline, and below the Provo shoreline it is confined to a narrow outcrop band (1.5 miles or 2.4 km wide) near the course of the Beaver River (plate 1), where it caps a strath terrace cut into fine-grained deltaic deposits. I interpret this map pattern as indicating a Beaver River delta graded to Lake Bonneville at the Provo shoreline. With regression from the Provo shoreline, the Beaver River entrenched its Provo-age delta and the barrier-beach ridges, and prograded northward. Barrier-beach ridges on the cuspate delta front are not well developed north of, and below, the Provo shoreline, suggesting that the regression from the Provo shoreline was rapid (figure 2).

North of the map area, Qdg both underlies and overlies the white marl, and it therefore was deposited during both the transgressive and regressive phases of the Bonneville cycle (Oviatt, 1989). However, within the area of plate 1, all the exposed sandy gravel mapped as Qdg is Provo and post-Provo in age (i.e., deposited during the regressive phase).

Deltaic fine-grained deposits (Qdf) — Silt and fine sand in the late Pleistocene (Lake Bonneville) fine-grained delta or underflow fan of the Beaver River are mapped as Qdf. An underflow fan is a type of delta composed mostly of fine-grained sediment that is deposited by density currents at the mouth of a major river. Underflow fans have been described from the Lake Agassiz region (Kehew and Clayton, 1983) in north-central North America, and the concept was applied to Lake Bonneville deposits and landforms by Oviatt (1984; 1987a).

The deposits mapped as Qdf on plate 1 were deposited in Lake Bonneville during both the transgressive and regressive phases of the lake. The white marl (Qlm) is exposed at a number of localities along the Beaver River (too small to show in plate 1) where it is found either above, below, or between sections of fine-grained deltaic beds (Qdf). The white marl contains the Pavant Butte basaltic ash in these localities (e.g., B-1A, plate 1) and constitutes a stratigraphic marker indicating the deep-water phase of Lake Bonneville.

Alluvial Deposits

Older alluvial deposits (Qal_2) — Older coarse-grained deposits of Cove Creek and Corn Creek are mapped as Qal_2. Two areas of Qal_2 are mapped along Cove Creek. Alluvium in the larger area along the southern boundary of plate 1 may be Holocene or late Pleistocene in age, although it has not been dated. This alluvium underlies a terrace that stands 6 to 12 feet (2-4 m) above the modern channel of Cove Creek. The alluvium in this area overlies the Black Rock basalt flow (Qvb_3).

Another small area of Qal_2, shown on plate 1, is north of the sharp bend in Cove Creek (locality D table 4). At this locality, the alluvium contains clasts of granitic rocks, typical of sediment in streams draining the Mineral Mountains south of the map area. Cove Creek also transports sediment containing granitic clasts. At locality D, Qal_2 appears to underlie basalt of the Black Rock lava flow, dated about 1 Ma (table 3), suggesting that prior to the eruption of the lava, Cove Creek flowed northward past South Twin Peak into the Black Rock Desert (see further discussion below under Cove Creek dome).

Two small areas of Qal_2 are mapped northeast of Black Rock volcano in the eastern part of the map area. This alluvium consists of sand and gravel deposited by Corn Creek in isolated terrace or fan remnants as much as 20 feet (6 m) above alluvium mapped as Qal_1. The age of Qal_2 at these localities is unknown but is probably late Pleistocene.

Older alluvial-fan deposits (Qaf_2) — Pre-Bonneville alluvial fans are mapped as Qaf_2. These deposits are composed mostly of coarse-grained debris and are mapped in piedmont areas above the Bonneville shoreline. Although most of the material mapped as Qaf_2 was deposited prior to the development of the Bonneville shoreline, Qaf_2 also includes some minor Bonneville-age and post-Bonneville fan deposits in entrenched channels above the Bonneville shoreline that are too small to show at map scale.

Younger alluvial-fan deposits (Qaf_1) — Post-Bonnneville alluvial-fan deposits are mapped as Qaf_1. Qaf_1 consists of poorly sorted, coarse- to fine-grained alluvium of ephemeral washes in channels and in fans on piedmont slopes. In many areas Qaf_1 is composed of fine-grained sediments reworked from lacustrine deposits of Lake Bonneville or from QTlf. Small areas of Qaf_1 are lumped with Qla if they are too small to map at a scale of 1:100,000.

Younger alluvial deposits (Qal_1) — The youngest alluvium along the Beaver River and larger ephemeral streams is mapped as Qal_1. These deposits are mostly silt, clay, and sand found underlying the modern or late Holocene floodplain and underlying low terraces adjacent to the modern channels. Young alluvium is present along many other active ephemeral channels in the Black Rock Desert, but the areas are too small to show at map scale.

Alluvial mud (Qam) — Undifferentiated alluvial mud in Pavant Valley is mapped as Qam. Qam overlies and is gradational with Qlf and locally includes marsh or playa deposits. Qam is Holocene in age based on its relationship to other map units.

Playa Deposits

Playa mud (Qpm) — Playa mud, which consists of poorly sorted clay, silt, and sand, and locally includes gypsum, halite, and other salts, is mapped as Qpm. Qpm is mapped east of the Tabernacle Hill and Ice Springs basalt flows and grades laterally into alluvial mud (Qam). It overlies older lacustrine deposits, such as Qlf. Qpm is Holocene in age.

Eolian Deposits

Eolian deposits (Qed) — Eolian deposits are mapped as Qed in plate 1. The eolian deposits are gradational in composition, texture, and geomorphic expression from well-sorted quartz sand in active barchan dunes to silt and clay in irregular blowout dunes. Where Qed is stacked with other units in plate 1 the map color indicates the underlying unit, which is considered more representative of the surficial geology and tells more about the geologic history of the area than the thin cover of eolian sand.

Barchan, longitudinal, and parabolic dunes are well developed and active in the central part of the map area where the sand is derived from Beaver River deltaic deposits and fine-grained lacustrine deposits. The symbol Qed also refers to eolian dunes composed of clay, silt, and sand. These "clay" dunes form when pellets of mud derived from fine-grained deposits such as Qam, Qpm, or Qlf are deflated by the wind, transported a short distance, and deposited in irregular dunes. Clay dunes form best in places where the ground is intermittently flooded and that later dries out and is exposed to strong winds. The flood water may be derived from either surface runoff or ground-water discharge. Clay dunes are found downwind from playas and small blowout depressions. After the mud pellets are deposited in the dunes, they tend to "melt" when they are rewetted by rain, so that the clay dunes do not have the loose consistency of sand dunes. In the vicinity of White Mountain, Qed includes gypsum dunes on the margins of playas. White Mountain is largely covered with gypsum sand.

All the deposits mapped as Qed are Holocene in age as shown by their stratigraphic relationships with deposits of Holocene and late Pleistocene age.

Spring Deposits

Spring tufa (Qst) — A large area of tufa associated with hot springs is mapped west of Meadow. The tufa or travertine is as much as 90 feet (30 m) thick (figure 7) and has accumulated along a linear fracture system oriented northeast-southwest, parallel to a series of faults just to the west (plate 1; figure 8). In several places the tufa has accumulated along what appear to be secondary fractures that radiate from central points.

At least part of the Meadow-Hatton spring tufa is pre-Bonneville in age, as shown by a small amount of white marl (Qlm) preserved in a one-meter-wide crack in the tufa near the southern margin of the mound. The marl at this locality contains a thin layer of basaltic ash, which is probably the Pavant Butte ash. However, because this is the only place where lacustrine deposits have been found overlying the tufa, some of the spring tufa could be Provo or post-Provo in age. The base of the tufa mound is about 10 feet (3 m) above the altitude of the Provo shoreline. Hatton Hot Springs, at the southern end of the tufa mound, discharges only a small amount of water at present (Mabey and Budding, 1987), but the tufa mound itself must have been produced during a period of much greater discharge. Higher hydraulic heads and ground-water flow rates may have been created during the late Pleistocene when recharge to the aquifers was greater than at present. Nelson and Fuchs (1987), and Fuchs and Nelson (1988) have studied the geology of the Meadow tufa mound in some detail.

Figure 7. A cut face in the spring travertine west of Meadow. Large blocks of travertine were cut using a cable and sand, then shipped by railroad to various parts of the country to be used as ornamental building stone.

Volcanic Rocks

Older Quaternary basalt (Qvb_4) — Older Quaternary basaltic rocks are mapped as Qvb_4. These include, in order of increasing age, the basalts and cinders of the Black Rock volcanoes near Kanosh, the Black Rock basalt flow (near the railroad siding of Black Rock), and the Beaver Ridge basalt flows (see table 3 and the

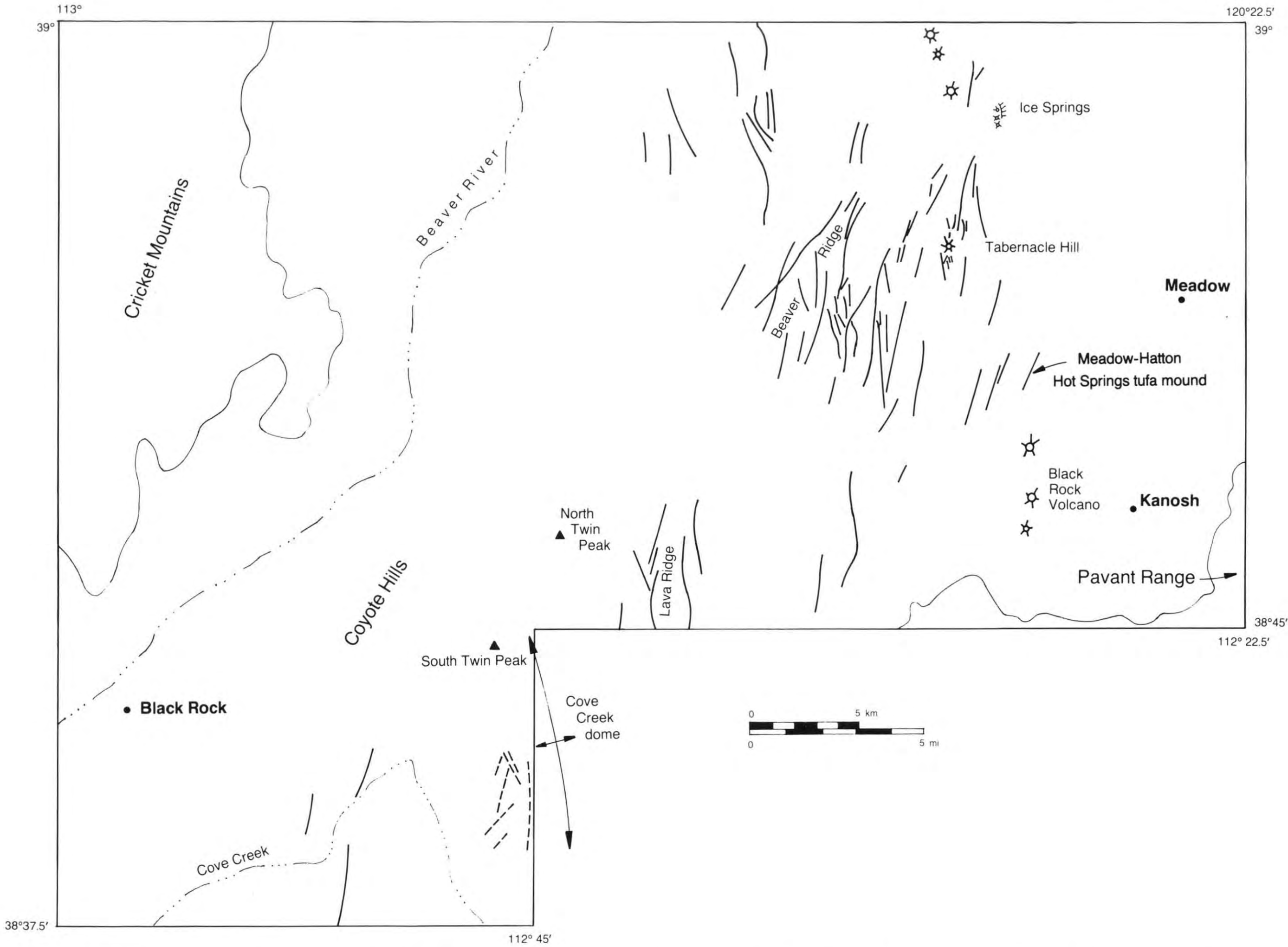


Figure 8. Structural features in the Black Rock Desert. Solid and dashed lines = faults; circles with radiating spikes = volcanic vents.

references listed therein). The topography on these lava flows is relatively subdued, and K-Ar ages confirm their middle or early Pleistocene ages.

Andesite (Qvn) — Andesitic lavas crop out in a small area on Beaver Ridge west of Tabernacle Hill (Hoover, 1974) and are mapped as Qvn. The andesite is early Pleistocene in age (Nash, 1986; table 3).

Rhyolite (Qvr) — A small Quaternary rhyolite dome at White Mountain is mapped as Qvr. This rhyolite, dated at 400,000 yr B.P. (table 3), is the youngest rhyolite in the state of Utah (Lipman and others, 1978; Nash, 1986). The rhyolite dome at White Mountain has been considerably modified by waves in Lake Bonneville and is covered with white gypsum sand.

Basalt of Pavant Ridge (Qvb_3) — Late Pleistocene basaltic rocks are mapped on plate 1 as Qvb_3 (with the exception of the Tabernacle Hill basalt, which is mapped separately as Qvb_2). Qvb_3 includes a series of pre-Bonneville basalt flows that were referred to by Hoover (1974, p. 13-17) as the Pavant lavas. In most places the Pavant lavas are partly covered by either fine-grained Bonneville sediments (Qlf) and/or eolian sand (Qed). Where the basalt is exposed the surface morphology is well preserved, suggesting a relatively young age. Hoover (1974, p. 31-32) reported that the Pavant lavas were erupted between about 30,000 and 128,000 yr B.P. on the basis of K-Ar ages (table 3). Condie and Barsky (1972, p. 338) report a K-Ar age of 220,000 ± 260,000 yr B.P. on a sample of Pavant basalt. Best and others (1980) report two K-Ar ages of samples of Pavant basalt, 180,000 ± 180,000, and 160,000 ± 160,000 yr B.P. Therefore, the Pavant lava flows are probably late middle Pleistocene or late Pleistocene in age.

Basalt of Tabernacle Hill (Qvb_2) — Basaltic rocks in the Tabernacle Hill volcanic field are mapped as Qvb_2. Basaltic tuff comprises the main tuff cone (or ring) and a smaller tuff cone at Tabernacle Hill (figure 9). The tuff at Tabernacle Hill is partially altered to palagonite, which is yellow and slightly indurated but friable. The unaltered tuff is gray to black and also friable. Blocks of basalt, presumably brought up from lava flows underlying the tuff cone during the eruption, and small pieces of baked greenish and reddish fine-grained sediments, are present in the tuff. The fine-grained sediments resemble QTlf and suggest that QTlf underlies Tabernacle Hill at some depth.

Chemical analyses of Tabernacle Hill tephra samples are given in table 6. They indicate that Tabernacle Hill tephra contains more CaO and P_2O_5 than tephra from Pavant Butte (Oviatt and Nash, 1989).

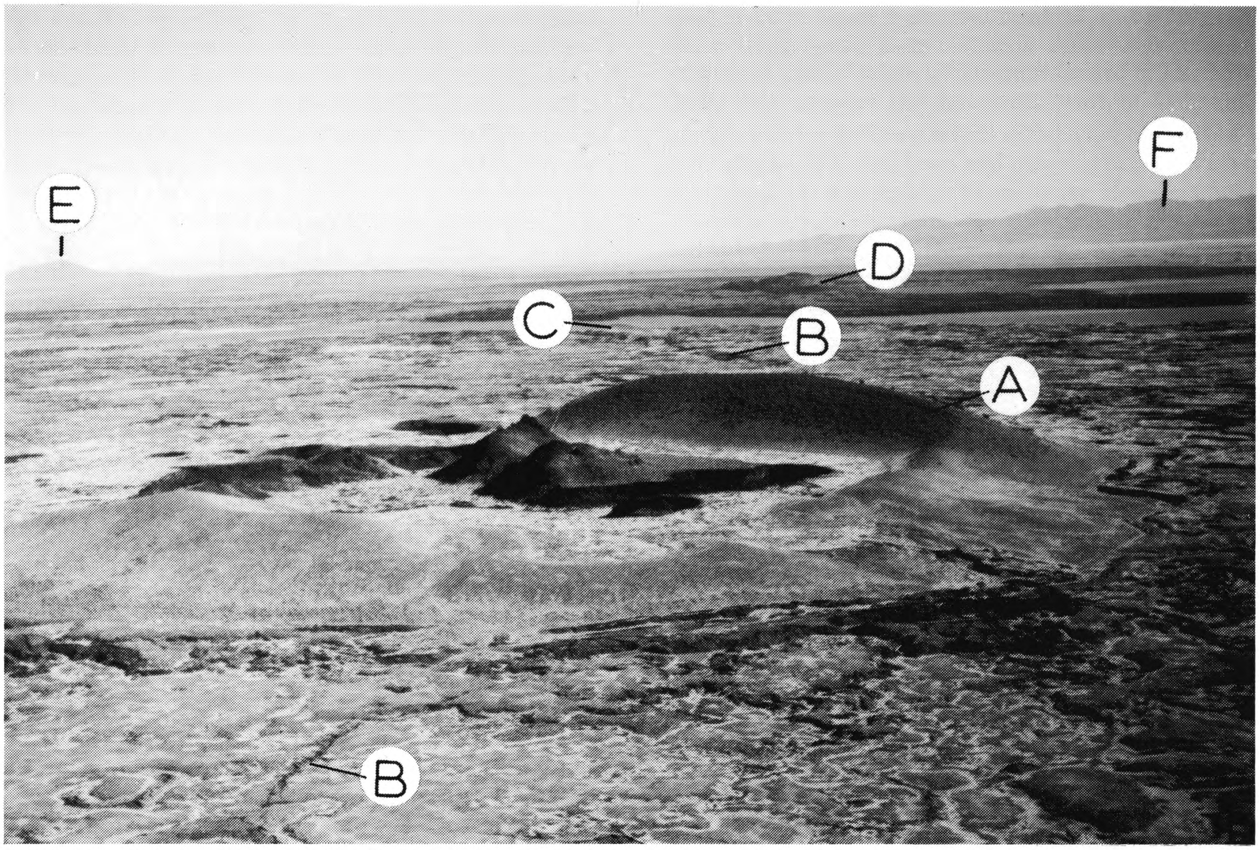


Figure 9. *Oblique aerial view of volcanoes on the floor of the Black Rock Desert. View is to the north of Tabernacle Hill (A), faults cutting the Tabernacle Hill basalt flow (B), and a small tuff cone near the northern margin of the basalt flow (C). The Ice Springs cinder cones (D) and basalt flow are shown in the middle distance, and Pavant Butte (E) and the Canyon Range (F) in the far distance. Photograph courtesy of L.F. Hintze, 1989.*

The Tabernacle Hill basalt flow is also mapped as Qvb_2. It was erupted into Lake Bonneville at or near the level of the Provo shoreline (Gilbert, 1890; Condie and Barsky, 1972; Hoover, 1974; Oviatt and Nash, 1989). Evidence for the age of the Tabernacle Hill basalt flow consists of the following observations: 1) the lava flow is approximately circular in plan form and has a constant altitude of 4740 feet (1445 m) around its margin (figure 10); 2) lava pillows are present on the outer margin of the flow (figure 11); 3) tufa, radiocarbon-dated at 14,320 ± 90 yr B.P. (Beta-23803; locality F; figure 10), is encrusted on the outer margin of the lava flow; 4) basaltic ash derived from the Tabernacle Hill tuff cone is interbedded with the white marl at altitudes below the Provo shoreline and is stratigraphically above the Pavant Butte ash (Oviatt and Nash, 1989; see discussion below).

Basalt of Ice Springs (Qvb_1) — The Ice Springs basalt flow (Qvb_1) was first studied by Gilbert (1890, p. 320-325). The flow is post-Bonneville in age and has a fresh surface morphology, except where it is locally covered by eolian sand. Hoover (1974, p. 20-26) suggested that the Ice Springs basalt flow was erupted about 1000 to 4000 years ago, and Valastro and others (1972, p. 470) have reported a minimum limiting radiocarbon age of 660 ± 170 yr B.P. (Tx-1166) on root fragments from the soil beneath the lava flow.

Basaltic cinders from a set of volcanic events in the Ice Springs volcanic field were not distinguished from Qvb_1 on plate 1 but are located at the volcanic vent symbols near the eastern margin of the Ice Springs flow. The cinder in these cones is being excavated for gravel, and the cones no longer retain the pristine morphology described by Gilbert (1890). Lynch (1980) has studied the geochemical variations within the Ice Springs cinder cones and the associated basalt flows.

Coarse-grained (lapilli-sized) tephra erupted from the Ice Springs vents forms a thin discontinuous mantle mixed with eolian sand over a large area north of the craters. The tephra fragments are angular and ropy, and they are denser and coarser than the Pavant Butte tephra found in the same area. The Ice Springs tephra is interbedded with barrier-beach lagoon fill exposed along Chalk Creek (locality E). The lagoon fill is late Holocene in age.

Pre-Quaternary Rocks

Pre-Quaternary rocks and sediments are shown on plate 1, but not in the detail that the Quaternary deposits are shown. They are broadly grouped into Paleozoic and Tertiary deposits, and the Tertiary units are further subdivided into sedimentary and volcanic categories. The reader should consult other sources for more

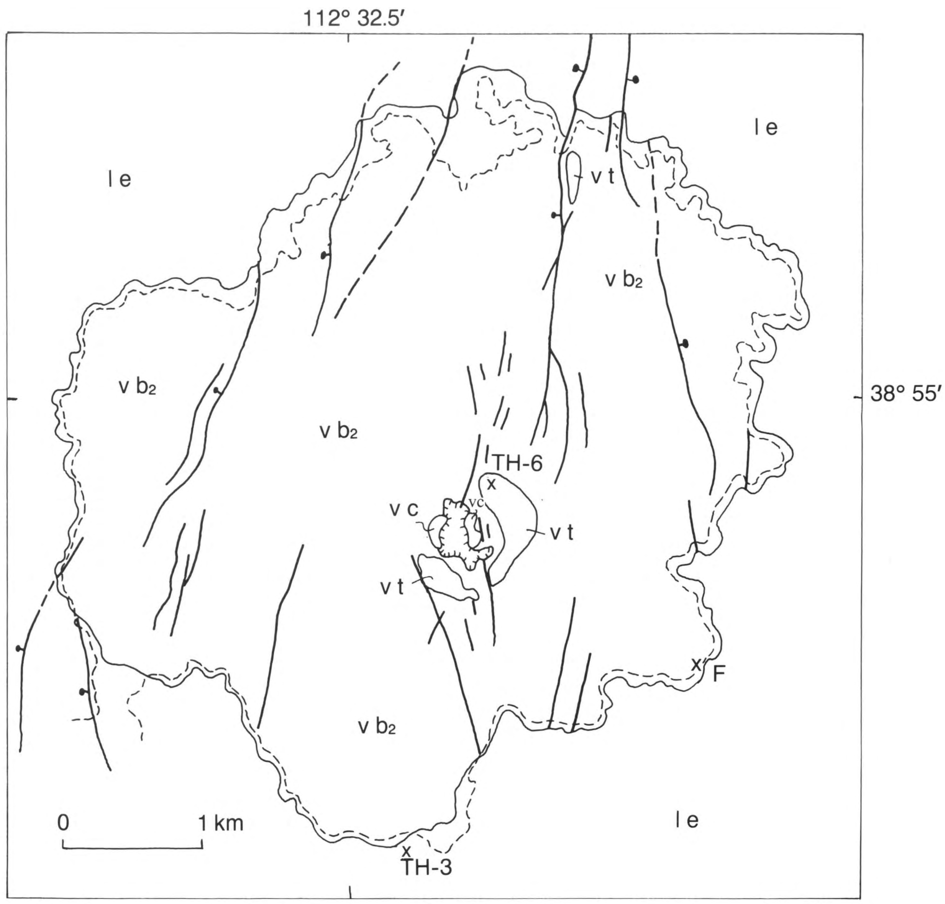


Figure 10. Map of Tabernacle Hill basalt flow and tuff ring. *The dashed line around the margin is the contour line at 4740 feet (1445 m). Ash collection sites (TH-3A, TH-6, table 6) and tufa collection locality (F) are shown. Faults, with bar and ball on the downthrown side, and fractures having minor offset are shown as heavy lines. le = lacustrine and eolian deposits; vb_2 = basalt of the Tabernacle Hill flow; vt = basaltic tuff in* ***tuff rings****; vc = basaltic cinders. Hachured line outlines the volcanic crater. Basaltic pillows are well preserved at many localities around the margin of the flow (figure 11).*

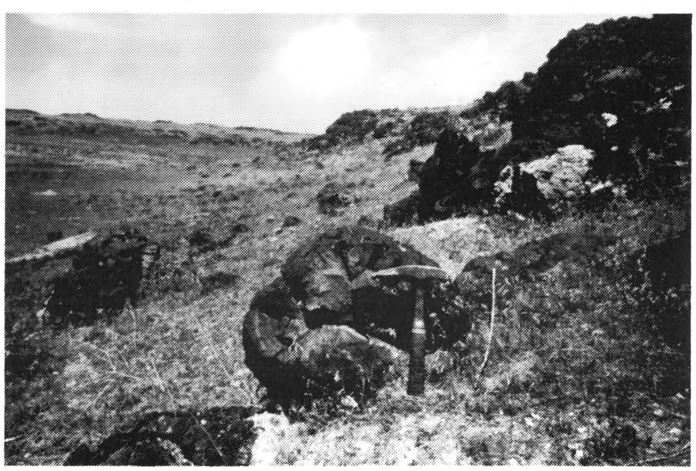


Figure 11. *A basalt pillow on the east flank of the Tabernacle Hill basalt flow about 0.6 mile (1 km) west of locality F (table 4). The light material on the black basalt up and to the right of the pillow is lacustrine tufa. The Provo shoreline is visible on the margin of the basalt flow in the background.*

information on the pre-Quaternary rocks (Maxey, 1946; Crecraft and others, 1981; Hintze, 1984; Steven and Morris, 1984; George, 1985; Nash, 1986).

Paleozoic sedimentary rocks (Ps) — Undifferentiated Paleozoic sedimentary rocks in the Cricket Mountains are mapped as Ps.

Paleozoic and Mesozoic sedimentary rocks (PMu) — Undifferentiated Paleozoic and Mesozoic sedimentary rocks are mapped in the Pavant Range (see Maxey, 1946; and George, 1985).

Tertiary sedimentary rocks (Ts) — Undifferentiated Tertiary sedimentary rocks in the Cricket Mountains are mapped as Ts. This unit is the equivalent of the "conglomerate of Red Pass" and the "breccia of Cat Canyon" of Hintze (1984). The geologic contacts between Ts and Ps on plate 1 are taken from Hintze (1984).

Basalt (Tvb) — Basalt flows of Tertiary age are mapped as Tvb. These include the lava flows at Lava Ridge and in Cove Creek dome. The basalt at Lava Ridge is about 2.2 Ma, and that in Cove Creek dome within the map area is about 2.5 Ma (table 3). These lavas are interbedded with fine-grained lacustrine deposits and limestones (QTlf and QTln; Crecraft and others, 1981; Nash, 1986).

Rhyolite and rhyodacite (Tvr) — Tertiary rhyolite and related silicic volcanic rocks are mapped as Tvr. These include the rhyolites of North and South Twin Peaks and the Coyote Hills, all of which have been studied extensively by Crecraft and others (1981) and Nash (1986). The rhyolites range in age from about 2.7 to 2.2 Ma (table 3). Silicic tephra, which is probably equivalent to the Cudahy Mine pumice (Crecraft and others, 1981; Nash, 1986), is interbedded with fine-grained lacustrine deposits mapped as QTlf at locality B south of Beaver Ridge and at DVP-1 south of the map area. The Cudahy Mine pumice is about 2.5 Ma (table 3).

STRUCTURE

The Black Rock Desert occupies a complexly faulted structural basin in the eastern part of the Basin and Range physiographic province. It is contiguous with the Sevier Desert basin to the north (Oviatt, 1989), and both basins have some structural characteristics in common with other basins in western Utah and Nevada (Anderson and others, 1983). These characteristics include: 1) a major gently west-dipping detachment surface at depth that marks the boundary between relatively shallow crustal extensional structures within about 3 miles (5 km) of the ground surface, and deeper extensional structures or pre-Basin and Range structures (Allmendinger and others, 1983; Anderson and others, 1983); 2) a broad low-lying basin floor underlain by a thick sedimentary fill that thins toward the basin margins, and that is bounded on the east and west by mountain ranges; and 3) faults that have been active during the Quaternary Period. The Black Rock Desert (and the Sevier Desert) have been volcanically active throughout the Quaternary in contrast to many of the other basins in the Basin and Range province. The structural features in the Black Rock Desert are shown in plate 1 and in figure 8.

Detachment Surface and Deep Structure

The Black Rock/Sevier Desert basin is bounded at a depth of about 1.2 to 2.5 miles (2-4 km) by a major detachment surface that dips 3° to 4° gently westward (Allmendinger and others, 1983; Anderson and others, 1983, p. 1065). Movement along the detachment surface may be controlled by deformation in a postulated zone of decoupling located far to the west of the Sevier Desert basin at a depth of 6 to 12 miles (10-20 km; Anderson and others, 1983, p. 1069, figure 8; see also figure 12, this report). The main Black Rock/Sevier Desert basin is subdivided at depth into a number of smaller basins which are separated by listric and planar faults that intersect the detachment surface and that die out upward into the sedimentary fill of the main basin (Allmendinger and others, 1983; Anderson and others, 1983, p. 1065-1066; see also figure 12, this report). Some of the Holocene faults in the interior of the main basin may be connected at depth to faults in the bedrock that merge with the detachment surface (Crone and Harding, 1984). Displacement on the late Quaternary faults may, therefore, be controlled ultimately by deep crustal deformation many miles to the west in the zone of decoupling (Anderson and others, 1983).

Near-Surface Structures

Quaternary fault scarps in the Black Rock Desert have been mapped by Hoover (1974), Anderson and Bucknam (1979), and Anderson and Miller (1979). The locations and ages of the faults shown in plate 1 and in figure 8 differ in a few cases from those shown by previous authors.

Pavant-Tabernacle-Beaver Ridge fault zone — A broad zone of faults, which primarily cut Quaternary lava flows, is referred to here as the Pavant-Tabernacle-Beaver Ridge fault zone. Hoover (1974, p. 37) referred to this zone as the "Black Rock fault zone." The faults are roughly parallel and trend in a north to northeasterly direction. All the lava flows in the area, except the Ice Springs flows (Qvb_1), are clearly cut by faults. The Ice Springs basalt, however, flowed over preexisting Quaternary fault scarps. On the older lava flows (Qvb_4 and Qvn) the faults are shown as concealed because the fault scarps are overlain by fine-grained Lake Bonneville deposits (Qlf) which are not offset. However, the scarps are clearly visible on aerial photographs.

A few faults cut Lake Bonneville deposits, such as those near Hatton Hot Springs, and those concealed by sand dunes north of Sand Ridge. The faults north of Sand Ridge represent the southern extension of the Clear Lake fault zone (Anderson and Bucknam, 1979; Oviatt, 1989). The Clear Lake fault, and other faults in that fault zone, have been active in post-Bonneville time and probably have been active through most of the Quaternary (Crone and Harding, 1984; Oviatt, 1989).

Faults in the Cove Creek dome area cut Tertiary basalt flows and lie along the same major structural trend as the Pavant-

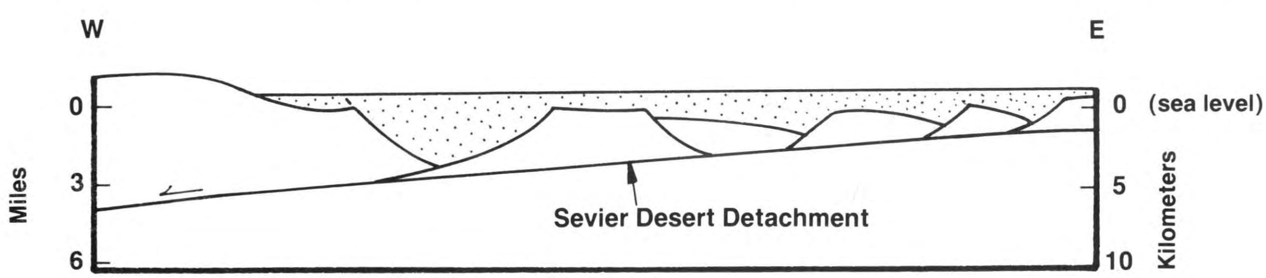


Figure 12. Schematic cross section of the Sevier Desert detachment (modified from Anderson and others, 1983, figure 8) across a line north of the Black Rock Desert in the Sevier Desert. Stippled pattern shows basin-fill deposits of Cenozoic age.

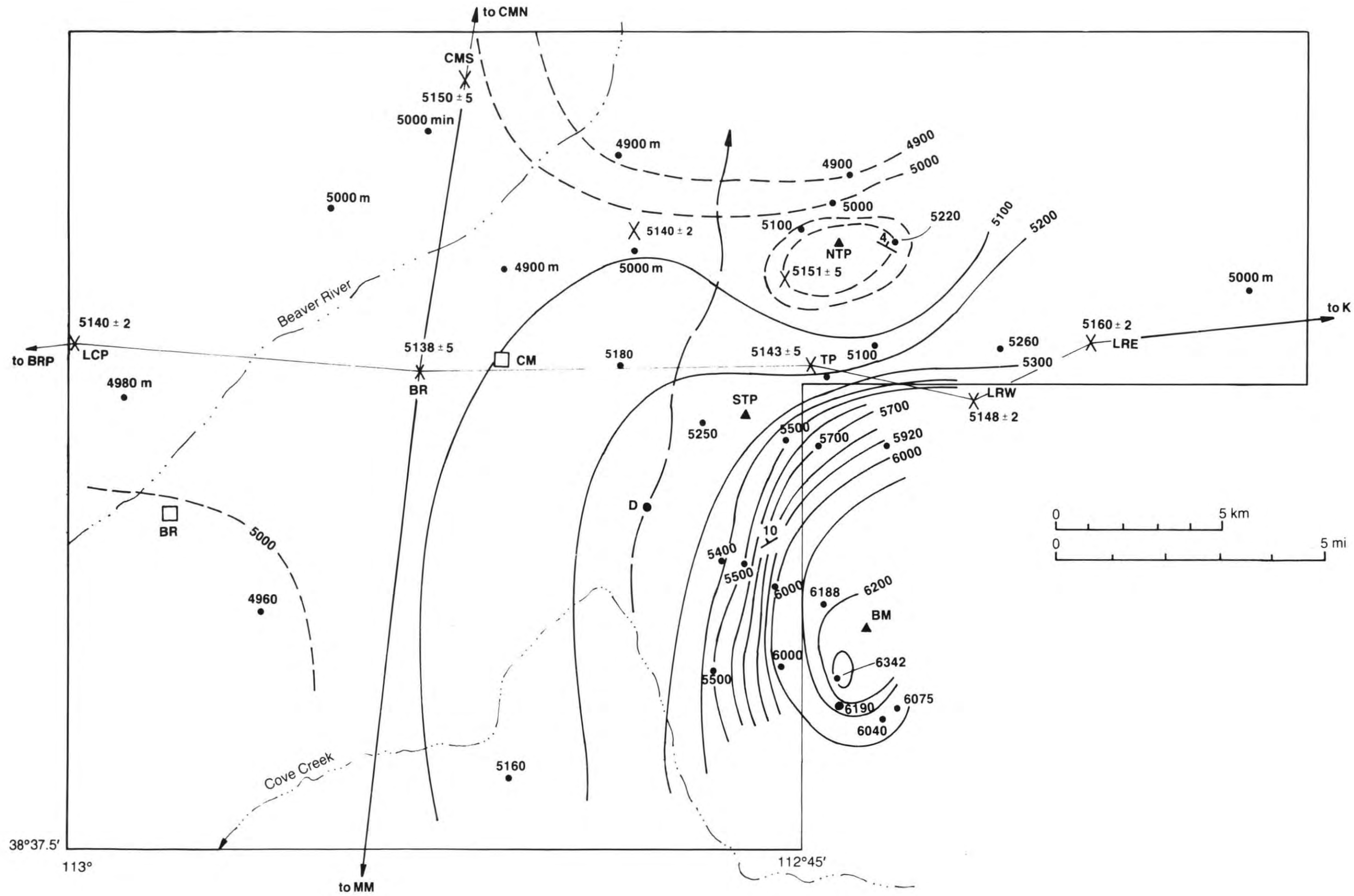


Figure 13. *Estimated structural contours on QTln in the Cove Creek dome area. Contour interval 100 feet (30 m). Altitudes are in feet: solid dots = points on QTln; m = minimum estimate (point on QTlf); lines connecting Xs = lines of profiles in this figure, and altitudes on the Bonneville shoreline (see figures 9 and 10). Strike-and-dip symbols on QTln. NTP = North Twin Peak; STP = South Twin Peak; BM = Burnt Mountain; BR = Black Rock; CM = Cudahy Mine; D = Locality D, table 4.*

Tabernacle-Beaver Ridge fault zone. A few faults of the White Sage Flat fault zone (Anderson and Bucknam, 1979), which is also along this trend, are shown in the southern part of the map area.

The Black Rock basalt flow (Qvb_4; dated about 1 Ma; table 3) is cut by faults that parallel the trend of the Minersville fault zone along the western flank of the Mineral Mountains to the south of the map area (Anderson and Bucknam, 1979).

Cove Creek dome — One of the most important structural features in the map area is the Cove Creek dome, a doubly plunging anticline in Tertiary basalt and lacustrine deposits south of the Twin Peaks. The dome has been described briefly by Crecraft and others (1981), who reported about 400 meters (1300 ft) of uplift of the Tertiary lacustrine limestones (mapped here as QTln). Figure 13 shows estimated structural contours on QTln in the vicinity of the dome. The map was constructed by plotting the approximate altitudes of outcrops of QTln at a number of points and contouring the data. The map's accuracy is largely dependent on the assumption that the altitudes that are plotted are on rocks that formed in shallow water of approximately the same age. This assumption is difficult to test because facies relationships have not been worked out, and because it is known that the complete lacustrine sequence (QTlf and QTln) spans the period from at least 2.5 to 0.73 Ma. However, figure 13 is a reasonable first approximation of the shape and total uplift of the Cove Creek dome.

The highest exposures of QTlf and QTln in the map area are at altitudes of about 6100 feet (1860 m) on the western flank of the Cove Creek dome (figure 13). Along the eastern piedmont of the Cricket Mountains the highest exposures are directly below the Bonneville shoreline (5160 ft; 1573 m). West of the Cricket Mountains on piedmont slopes surrounding Sevier Lake, the highest exposures of QTlf and QTln are directly above the Provo shoreline (about 4800 ft; 1463 m; Oviatt, 1989). QTln and QTlf are found above the Bonneville shoreline only in the vicinity of North and South Twin Peaks and the Cove Creek Dome (figure 14). The distribution of QTln and QTlf suggest that the Cove Creek dome and surrounding areas have been uplifted approximately 1000 to 1300 feet (300 to 400 m) since the deposition of the lake beds. The high estimate of 1300 feet assumes that there has been no downfaulting of QTln in the vicinity of Sevier Lake.

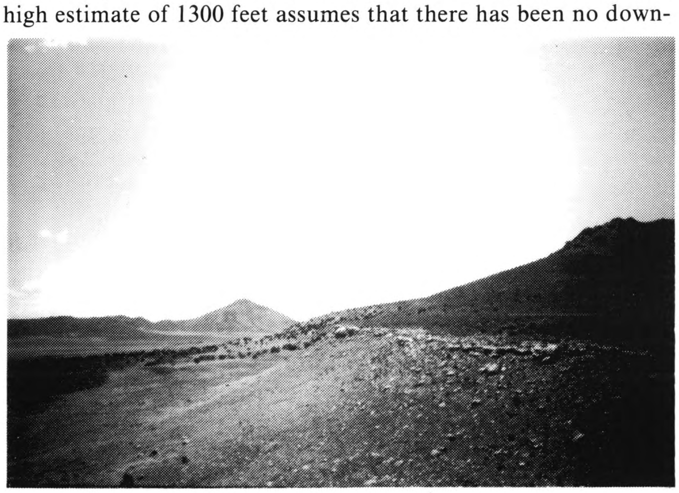


Figure 14. *Plio-Pleistocene lacustrine limestone (QTln; in foreground) on the east flank of North Twin Peak. The limestone dips northward about 4°. View is to the southwest; South Twin Peak is visible in the background.*

Most of the uplift of the Cove Creek dome probably took place during the late Tertiary. Basalt flows dated at 2.5 to 2.6 Ma, and interbedded limestone (QTln) are domed (Crecraft and others, 1981; table 3). The Burnt Mountain basalt flow (southeast of South Twin Peak; 2.1 Ma; table 3) was emplaced after at least some of the doming had taken place (Crecraft and others, 1981). Two additional sets of evidence suggest that uplift continued after the late Tertiary.

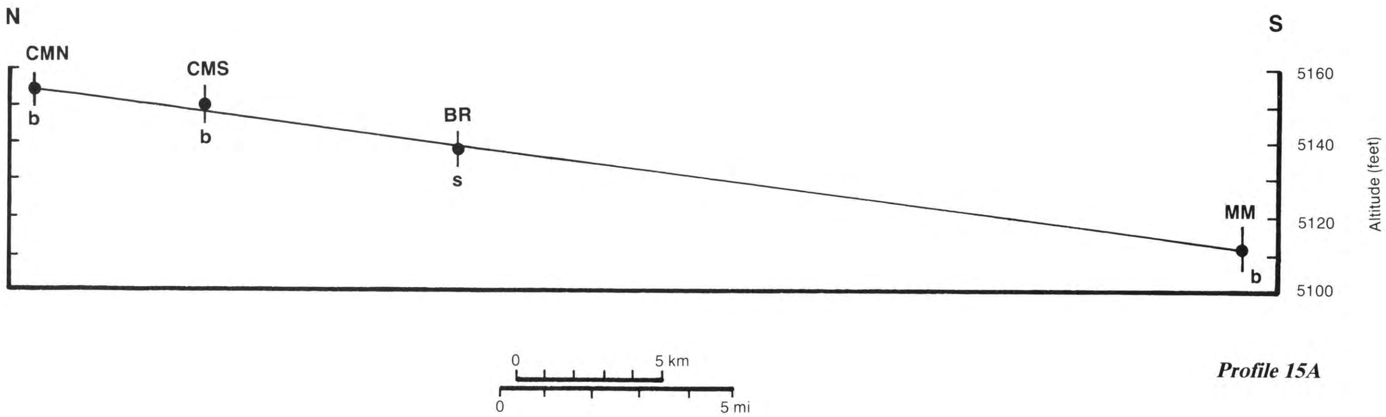
The first of these concerns the course of Cove Creek, which appears to have been diverted to the southwest from its older northerly course past the Twin Peaks (figure 13). Clasts of granitic rocks derived from the Mineral Mountains are present in the small remnant of alluvium directly north of the modern drainage divide near locality D (plate 1; figure 13). The drainage divide is formed partly on the Black Rock basalt flow, dated about 1 Ma (table 3), which apparently overlies the granite-bearing alluvium. Therefore, prior to one million years ago Cove Creek flowed northward instead of southwestward.

Three factors probably contributed to the diversion of Cove Creek: 1) the Black Rock basalt flow dammed the drainage; 2) faulting in the vicinity of Antelope Spring may have initiated headward erosion of a westward-flowing stream that pirated Cove Creek; 3) westward tilting of the western flank of the Cove Creek dome may have encouraged the stream piracy (although it is recognized that the first two factors would be sufficient to cause diversion, and that the diversion is not proof of tilting).

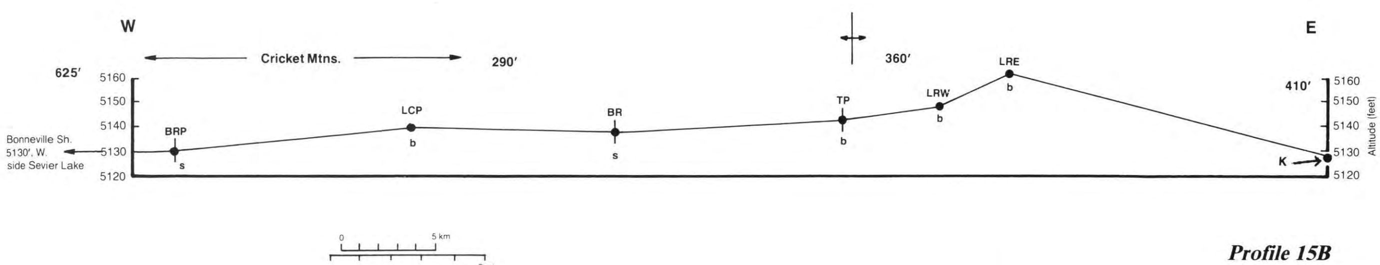
The second set of evidence for uplift in the Twin Peaks-Cove Creek area consists of measured altitudes on the Bonneville shoreline (figure 15). A few points reported by Currey (1982) and additional points surveyed in 1987 for this project are shown in figure 15. All the altitudes reported are on the crests of depositional shoreline features, either barrier beaches or spits. Barrier beaches are more likely to be superelevated with respect to the mean water plane than are spits (Currey, 1982) and, in fact, the highest surveyed altitude (1573 m; 5161 ft) is on the crest of a strongly developed barrier beach just east of Lava Ridge. However, all other barrier-beach ridge crests in the area are likely to be superelevated to some degree.

Figure 15a shows the regional north-south trend of the Bonneville shoreline due to isostatic rebound from the Lake Bonneville water load. Its gradient is a uniform 1.7 feet/mile (0.3 m/km), and the altitude of the shoreline increases to the north because the water load increased in that direction.

The east-west profile, however, shows a different pattern (figure 15b). The gradient is nonuniform, and the shoreline is highest in the east-central part of the transect. Water depths are shown for four areas close to the surveyed shorelines, and there is no correlation between local water depths and shoreline altitudes. In addition, Bills and May (1987, figures 8a and 8b) show a positive shoreline-altitude anomaly in this area in maps of the observed isostatic deflection (based on Currey's 1982 data) minus their calculated theoretical deflection. Therefore, it is unlikely that the upward-bowed east-west profile can be explained by differential isostatic rebound. I suggest that the shoreline deflection of 20 to 30 feet (6-9 m) apparent in figure 15b is best explained by post-Bonneville uplift in the Cove Creek dome area, although the cause of the uplift is unknown.



Profile 15A



Profile 15B

Figure 15. *Profiles along the Bonneville shoreline in the vicinity of the Cove Creek dome. Some of the altitudes were measured by Currey (1982). Refer to figure 13 for locations of profiles.* ***15a*** *= north-south profile showing altitudes of points on the Bonneville shoreline. Potential measurement errors are shown as vertical lines. s = point on crest of spit; b = point on crest of barrier beach; CMN = Cricket Mountains north; CMS = Cricket Mountains south; BR = near Black Rock; MM = west flank of Mineral Mountains.* ***15b*** *= East-west profile. Potential measurement errors are shown as vertical lines; points having small measurement error are shown simply as solid dots. s = point on crest of spit; b = point on crest of barrier beach; BRP = Black Rock Pass, on west slope of Cricket Mountains; LCP = Lone Cedar Pass; BR = near Black Rock; TP = Twin Peaks; LRW = Lava Ridge west; LRE = Lava Ridge east; K = Kanosh. The anticline symbol indicates the approximate northern extension of the Cove Creek dome axis after Crecraft and others (1981). Water depths (in ft.) in areas adjacent to the profile points are shown above the profile.*

GEOLOGIC HISTORY

Late Tertiary Through Middle Pleistocene

The tectonic history of the Black Rock Desert is one of the dominant controls on both the sedimentation and the volcanic eruptions in the map area. Extensional tectonism began in the Sevier/Black Rock Desert area between 20 and 7 million years ago (Lindsey, 1982), and the most recent faults are post-Lake Bonneville in age. The Black Rock Desert can be characterized as a spreading or opening basin due to the nature of movement on the low-angle Sevier Desert detachment (Allmendinger and others, 1983; Anderson and others, 1983).

The Black Rock Desert has many features in common with the Sevier Desert to the north (Oviatt, 1989). These include the following. (1) Extensive alluvial fans and bajadas of Pliocene and Quaternary age are present in the Black Rock Desert only on the east side of the basin along the Pavant Range. The Cricket Mountains piedmont is characterized by locally thick alluvial fans separated by broad pediment-like surfaces cut on fine-grained lake beds (QTlf) and mantled with a thin cover of coarse-grained alluvium (e.g., figure 5). This suggests that tectonic relief and uplift in the western part of the area have not been extreme during at least the Pliocene and Quaternary. (2) During the middle and late Pleistocene, parts of the Black Rock Desert (and most of the Sevier Desert to the north) have been generally degrading as shown by the following: (a) early Pleistocene basalt flows stand on pedestals of basin-fill deposits (such as at Black Rock); and (b) widely spaced lacustrine deposits of Pliocene and Pleistocene age (QTlf) crop out throughout the basin, including on the floor of the basin. Therefore, although some areas have received a heavy sediment load in the late Quaternary, such as along the Beaver River or the piedmont of the Pavant Range, other areas, even at low altitudes, have been degraded.

These sedimentation and erosion patterns can be explained by the changing morphometry of the basin as controlled by tectonics and the overflow threshold of the basin north of the map area (Oviatt, 1989). The overflow threshold is called the Old River Bed threshold (figure 1) and it has probably been lowered through time due to faulting and to erosion by discharge from overflowing lakes (Oviatt, 1989). As the basin threshold lowers, fine sediment in the turbid water of shallow lakes is gradually flushed from the basin floor. The process of enlargement and flattening of the desert floor, referred to by Currey (1990) as hydroaeolian planation, is an important contributing factor in the degradation of the basin floor. Even distal parts of the drainage basin (such as the Black Rock Desert) are affected, although not as much as areas closer to the threshold.

The drainage area of the Sevier Lake basin, of which the Black Rock Desert is a part, may have changed several times during the late Tertiary and Quaternary. There is some evidence that the Sevier River was captured into the Sevier Desert basin in late Tertiary time (Costain, 1960; Oviatt, 1987b), and that prior to the capture the river flowed northward through Juab Valley into Utah Valley in the Great Salt Lake basin. If the hypothesized capture did in fact occur, the Sevier and Black Rock Deserts would have suddenly received a huge increase in surface-water inflow, which would have created a lake in the closed basin if the prevailing climate were favorable. The lake in which QTlf and QTln were deposited may have been created, or at least enlarged, as a result of the Sevier River capture. A better documented change in the configuration of the drainage basin came when the Beaver River became a permanent tributary to the Sevier/Black Rock Desert basin between about 750,000 and 500,000 years ago (Machette, 1985).

The Plio-Pleistocene lake beds (QTlf) provide an excellent stratigraphic record of the early Pleistocene history of the basin. The widespread calcareous clays of QTlf suggest that a freshwater lake or series of lakes existed in this basin for at least the time period from 2.5 to 0.74 Ma as shown by the ages of interbedded lava flows and volcanic ashes. Steven and Morris (1984, p. 14) present evidence that the Plio-Pleistocene lake existed prior to 3 milion years ago. During Bishop ash time (0.74 Ma), the lake in the Sevier and Black Rock Deserts was fresh, but the lake in the Great Salt Lake basin, into which it overflowed, was shallow and saline (Oviatt and Currey, 1987). Therefore, the hydrologic balance in the Sevier Desert/Black Rock basin during the deposition of QTlf and QTln was considerably different than at present, and the climate must have been generally cooler or wetter to produce a long-lived overflowing lake. As noted elsewhere in this report, however, the history of the Plio-Pleistocene lake or lakes in which QTlf was deposited is still imperfectly known, and it seems likely that with further work more than one lake cycle will be documented during this period. In addition, other factors in the early Pleistocene hydrologic system, such as ground-water inputs and outputs, lake-surface areas, and surface-water inputs, are unknown so that a more complete reconstruction of the paleohydrology and paleoclimate of the late Pliocene and early Pleistocene in the Sevier and Black Rock Deserts is not yet possible.

The late Pliocene to early Pleistocene history of bimodal volcanism in the Black Rock Desert has been reviewed by Hoover (1974), Best and others (1980), Crecraft and others (1981), and Nash (1986). Rhyodacitic eruptions began in the Coyote Hills area about 2.7 Ma. They were followed by rhyolitic eruptions that continued until about 2.3 Ma at North and South Twin Peaks. Basaltic lavas of Pliocene age were erupted about 2.5, 2.2, and 2.1 Ma (table 3). The exposed Pliocene basalts are concentrated in the Cove Creek dome area.

Lavas of early Pleistocene age include the andesites at Beaver Ridge (1.5 Ma), the Black Rock basalt flow (1 Ma), and basalt at Beaver Ridge (0.9 Ma).

The middle Pleistocene history of the Black Rock Desert, from Bishop ash time until the deposition of the Little Valley Alloformation (about 140,000 years ago), is poorly known. It is likely that during this interval a number of lakes existed in the basin, but no lacustrine deposits of this age have been identified in the Black Rock Desert. This lack of middle Pleistocene deposits may be due to the dominantly erosional environment throughout most of the map area. The Little Valley Alloformation (about 140,000 years ago) is exposed north of the map area in the Sevier River delta (Oviatt, 1989).

Late Pleistocene

The late Pleistocene history of the Black Rock Desert is dominated by Lake Bonneville. The history of Lake Bonneville is relatively well known (figure 2), but certain aspects of Lake Bonneville history that are important in the Black Rock Desert are discussed below. See Scott and others (1983), Spencer and others (1984), Currey and Oviatt (1985), McCoy (1987), and Oviatt (1987a) for discussions of recent refinements in the chronology and stratigraphy of Lake Bonneville.

Important contributions to the chronology of Lake Bonneville have been discovered through COGEOMAP mapping in the Black Rock Desert. The contributions consist of tracing the extent of volcanic ash erupted from Pavant Butte (figure 16), and in obtaining a series of radiocarbon ages of samples collected near the Bonneville shoreline and the Provo shoreline. In addition, two basaltic volcanic ashes are now known in the white marl in the Black Rock Desert, the second being derived from the Tabernacle Hill tuff ring (Oviatt and Nash, 1989).

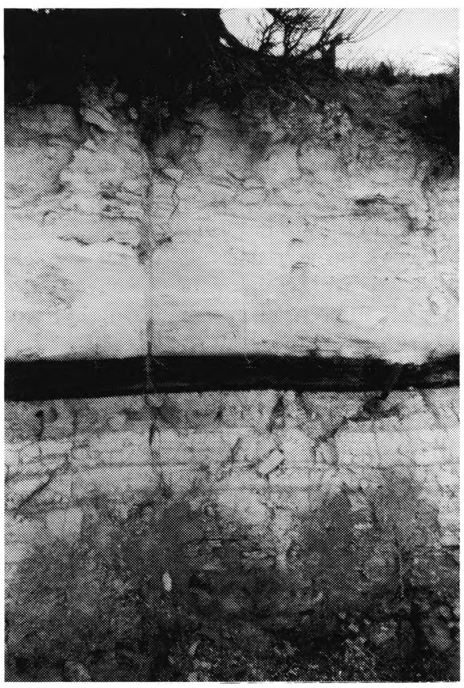


Figure 16. *An exposure of the Pavant Butte basaltic ash (black) interbedded with the white marl (Qlm) in a drainage ditch along Utah Highway 100 about 2.5 miles (4 km) west of Fillmore (at a locality marked M-6 on plate 1). The ash is about 10 cm (4 in.) thick at this locality.*

The locations and thicknesses of exposed basaltic ash layers are shown in plate 1. Some of the data plotted in plate 1 were derived from previous work (Oviatt, 1984, 1989), but most of the information was obtained for COGEOMAP in 1987. Microprobe analyses of basaltic glass (W. P. Nash, personal communication, 1987) from samples of ash collected at a number of localities in the Black Rock Desert are listed in table 6. Pavant Butte ash can be distinguished from Tabernacle Hill ash by its lower CaO and P_2O_5 content (Oviatt and Nash, 1989).

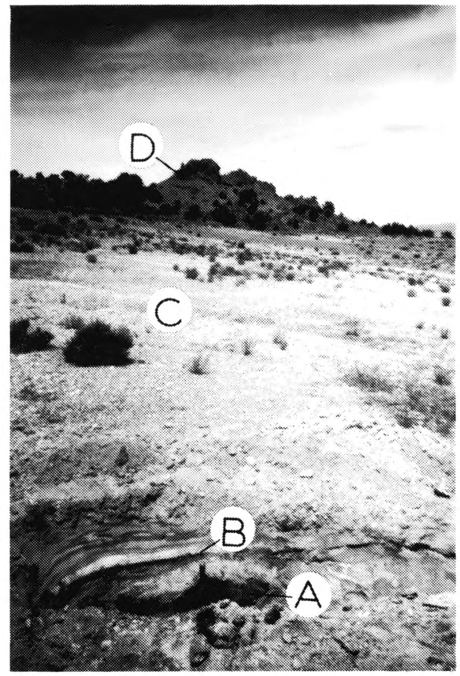


Figure 17. *A gravel-pit exposure in Lake Bonneville deposits at locality G (table 4), near the southern boundary of the map area west of Kanosh. In a shallow pit the pre-Bonneville soil (A) is overlain by the Pavant Butte ash (B), which is interbedded with lagoon marl and barrier-beach gravel (C). The gravel has been mostly removed by the gravel-pit operations. The Bonneville shoreline loops around the bedrock knob at D. Note the trowel handle near A for scale (about 4 inches; 10 cm).*

Of primary interest in this report are the highest exposures of the Pavant Butte ash (locality G; figure 17), which are valuable in determining the level of Lake Bonneville at the time of the eruption. Figure 18 shows the stratigraphic relationships at locality G, which is a gravel-pit exposure in barrier-beach gravels and the underlying pre-Bonneville soil. At this locality the Pavant Butte ash is interbedded with lagoon marl and gravelly sand of the barrier beach. The lagoon marl overlies the buried soil, which yielded radiocarbon ages of 15,900 ± 290 (Beta-22044), and 14,130 ± 100 (Beta-25233) yr B.P. from charcoal mixed with soil and sediment; the sample was collected about 10 feet (3 m) higher in altitude than the exposed ash. Because of the possibility of contamination of the samples with decomposed Holocene or modern root hairs, the older age is interpreted to be more representative of the true age of the samples. Although the charcoal was deposited before Lake Bonneville had transgressed to this altitude, the ages give a maximum limit on the age of the transgression. When considered in the context of other radiocarbon ages (see below and Currey and Oviatt, 1985), the transgression to this altitude probably occurred about 15,500 years ago. If so, Pavant Butte erupted also about this time when Lake Bonneville was about 50 feet (15 m) below the Bonneville shoreline.

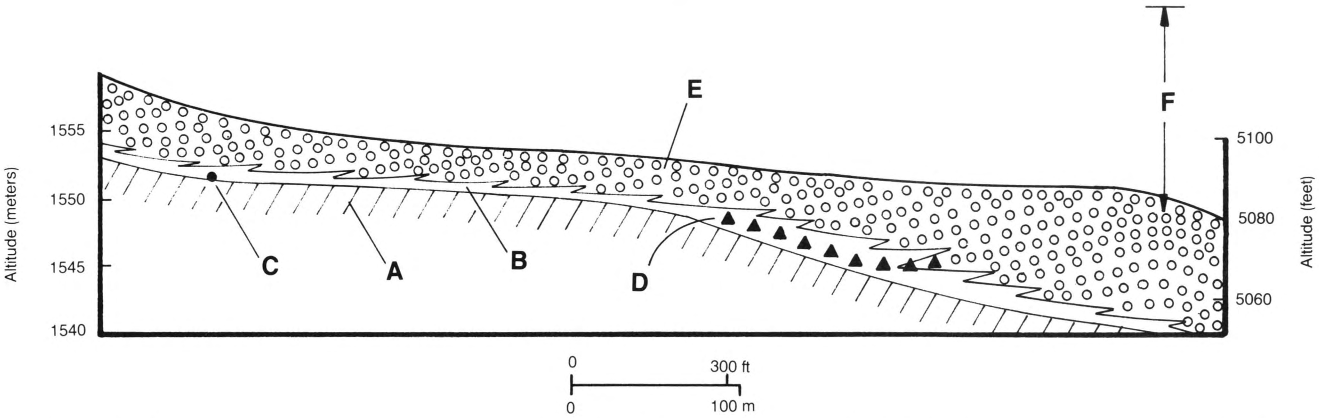


Figure 18. *Schematic cross section through the gravel barrier-beach complex exposed at locality G (table 4). A = pre-Bonneville soil; B = lagoon marl; C = collection locality of samples for radiocarbon dating (ages 2 and 3, table 1); D = Pavant Butte basaltic ash (K-5A; plate 1; table 6); E = barrier-beach gravel, which is largely excavated at the gravel pit but reconstructed for the diagram; F = distance to Bonneville shoreline from barrier-beach crest (about 50 feet; 15m).*

Additional radiocarbon ages from an even higher exposure help confirm the validity of the older age at locality G and help to define the timing of the highest transgression of Lake Bonneville. At locality H south of Kanosh, charcoal collected from the uppermost layers of pre-Bonneville soil or pond/lagoon filling (figure 19) yielded the radiocarbon ages listed in table 1. One of these ages was obtained using the AMS (accelerator mass spectrometry) technique on a single piece of charcoal that weighed less than 1 gram. The three ages indicate that Lake Bonneville did not reach its highest (overflowing) level until about 15,000 years ago. This estimate is about 1400 years younger than the estimate of Currey and Oviatt (1985), and it is consistent with similar evidence from high shoreline deposits north of Salt Lake City (Scott, 1988).

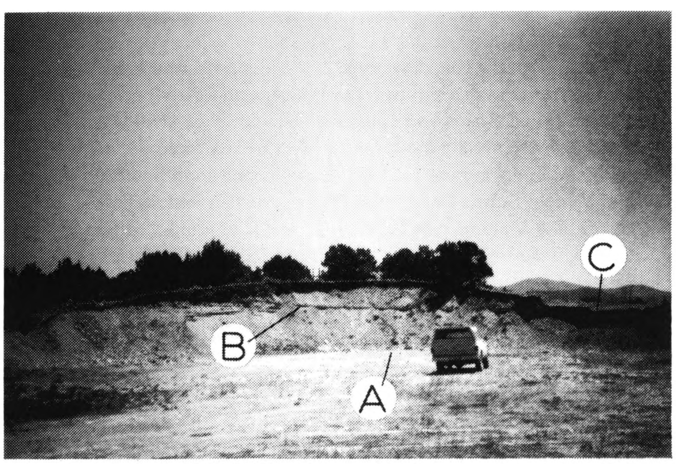


Figure 19. *A gravel pit in Lake Bonneville gravel at locality H (table 4). The gravel pit is cut into a long gravel barrier-beach at the Bonneville shoreline (rounded crest of the barrier; 5127 feet; 1563 m). A = pre-Bonneville soil and overlying thin lagoon marl exposed on floor of pit and location of samples for radiocarbon dating (ages 4, 5, and 6, table 1); B = thin lagoon marl within back-set gravel of barrier beach; C = Holocene alluvium and lagoon fill behind the barrier beach. View is to the east; Pavant Range in the background.*

An additional radiocarbon age (14,320 ± 90 yr B.P. [Beta-23803]) obtained for this study came from lacustrine tufa collected from the margin of the Tabernacle Hill basalt flow (locality F; figure 10; see discussion above under Qvb2). The sample was collected from a shallow overhang where the tufa was protected from direct exposure to meteoric water. In addition, the sample was processed in the laboratory to reduce the probability of contamination by diagenetic calcium carbonate in pores. The sample was crushed, sieved to retain sand-size fragments, and then treated with dilute hydrochloric acid to remove approximately half the remaining sample. Therefore, contamination with young carbon in the sample should be relatively minor compared with the potential contamination in tufa samples exposed to weathering at the surface. Contamination with old carbon is unlikely because the basalt substrate contains no carbon. The carbon-isotopic composition of the water from which the tufa precipitated is unknown, but any correction for this is likely to be less than 500 years (Broecker and Kaufman, 1965), and probably less than 200 years (Benson, 1978).

The Tabernacle Hill tufa was deposited at the shore of Lake Bonneville at or slightly below the Provo shoreline, and therefore the radiocarbon age is considered a reliable age on the Provo. In addition, the age places a minimum age limit on the Tabernacle Hill basalt flow.

Holocene

During the Holocene, the Black Rock Desert has been dominated by denudation caused largely by the lowering of base level following the regression of Lake Bonneville. However, sediments have been deposited in local areas such as adjacent to the young lava flows (Tabernacle Hill and Ice Springs), and in alluvial fans and floodplains. Eolian deposits of Holocene age are widespread, especially downwind from the Beaver River delta. A significant Holocene geologic event was the eruption of the Ice Springs basalts about 600 years ago.

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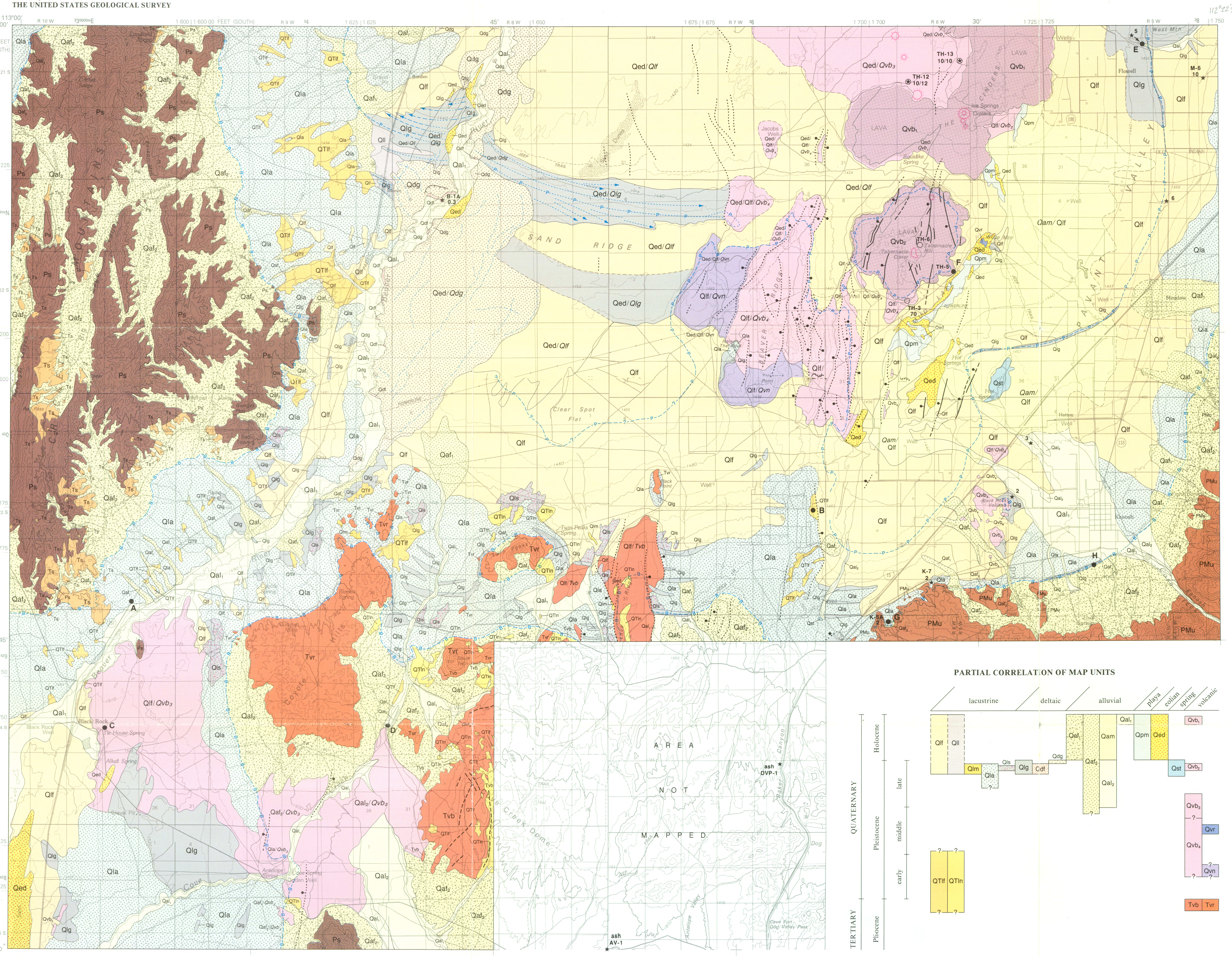
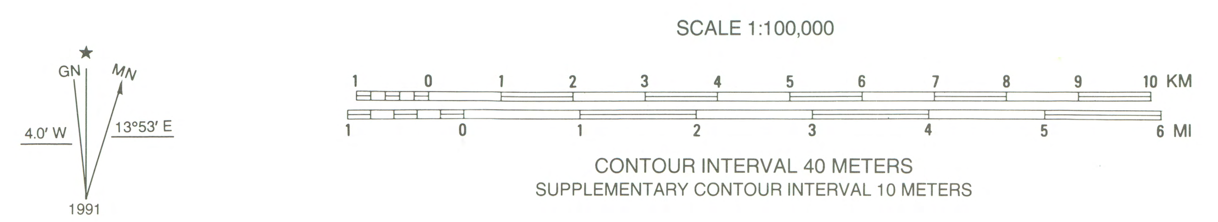
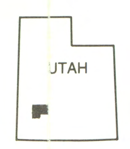
COGEOMAP — *Cooperative Project between*
UTAH GEOLOGICAL AND MINERAL SURVEY
Utah Department of Natural Resources, *and*
THE UNITED STATES GEOLOGICAL SURVEY





Base map from U.S. Geological Survey, Richfield 1:100,000 quadrangle, 1980
Geology mapped by author in 1987   Cartography by J. Parker



PARTIAL CORRELATION OF MAP UNITS

lacustrine
deltaic
alluvial
playa
eolian
spring
volcanic
QUATERNARY
TERTIARY
Holocene
Pleistocene
Pliocene
late
middle
early
Qlf
Qll
Qlm
Qla
Qls
Qlg
Qdf
Qdg
Qal₁
Qaf₁
Qaf₂
Qal₂
Qam
Qpm
Qed
Qst
Qvb₁
Qvb₂
Qvb₃
Qvb₄
Qvr
Qvn
QTlf
QTln
Tvb
Tvr

Plate 1 — Special Studies 73
QUATERNARY GEOLOGY OF THE BLACK ROCK DESERT, MILLARD COUNTY, UTAH

C.G. Oviatt
1991

DESCRIPTION OF MAP UNITS

Lacustrine (l)

- QTlf — OLDER FINE-GRAINED LACUSTRINE DEPOSITS (Plio-Pleistocene) — red, green, and light-gray calcareous silty clay, silt, and sand. Massive to thinly bedded; maximum thickness over 30 feet (10 m). Contains Bishop ash (0.74 Ma), Huckleberry Ridge ash (2.02 Ma), and Cudahy Mine ash (approximately 2.5 Ma).
- QTln — LACUSTRINE LIMESTONE (Plio-Pleistocene) — white, pebbly lacustrine limestone; thinly bedded to massive; thickness variable (5 to 20+ feet; 2 to 6+ m); may represent shore facies of QTlf.
- Qla — GRAVEL OF LACUSTRINE AND/OR ALLUVIAL ORIGIN (late Pleistocene) — mapped in piedmont areas where pre-Bonneville alluvial gravel was reworked by Lake Bonneville, but where the lacustrine gravel component is thin; includes pre-Bonneville alluvial fans etched by waves in Lake Bonneville and thin lacustrine gravel capping QTlf. Lacustrine-gravel component generally thin, average 10 feet (3 m).
- Qlg — LACUSTRINE GRAVEL (late Pleistocene) — sandy gravel composed of locally derived rock fragments; well sorted; thickness variable; beach or spit gravel deposited in Lake Bonneville.
- Qlf — YOUNGER FINE-GRAINED LACUSTRINE DEPOSITS (late Pleistocene to Holocene) — silt, sand, marl, and calcareous clay; thinly bedded to massive; thickness variable but generally less than 10 feet (3 m). Locally includes the white marl (Qlm), but also includes local Holocene alluvium composed of reworked fine-grained lacustrine deposits:
- Qlm — WHITE MARL (late Pleistocene) — (the white marl as defined by Gilbert, 1890, and redefined by Oviatt, 1987a); fine-grained white to gray authigenic sediments deposited in Lake Bonneville; finely bedded to indistinctly laminated; contains abundant ostracodes throughout, and locally contains gastropods near the base and top of the stratigraphic unit; thickness 2 to 10 meters (6.6 - 33 feet) depending on local depositional setting; also includes clastic-rich marl at the base and top of the unit.
- Qls — LACUSTRINE PEBBLY SAND (late Pleistocene) — well-sorted sand, and in places pebbly sand, overlying boulder-beach deposits or Qla; apparent massive bedding; thickness variable but less than 20 feet (6 m); deposited in Lake Bonneville at lake stages higher than the Provo shoreline.
- Qll — LACUSTRINE LAGOON DEPOSITS (late Pleistocene and Holocene) — silt, sand, and clay filling lagoons behind barrier beaches; deposited both during occupation of Lake Bonneville and alluvial infilling in Holocene time. Thickness and bedding not observed.
- Qdf — DELTAIC FINE-GRAINED DEPOSITS (late Pleistocene) — silt and fine sand in underflow fan (fine-grained delta) of the Beaver River. Locally over 30 feet (10 m) thick; thinly bedded; generally poorly sorted. Deposited in Lake Bonneville during both the transgressive and regressive phases of the lake.
- Qdg — DELTAIC SAND AND GRAVEL (late Pleistocene) — sand and gravel deposited near the mouth of the Beaver River during the Bonneville lake cycle; largely regressive-Bonneville in age. Well-sorted pebbly sand containing obsidian and other volcanic pebbles; cross-bedded to massive. Locally reworked by waves into spits and thin sheets of lacustrine gravel.

Alluvial (a)

- Qal_2 — OLDER ALLUVIAL DEPOSITS (Pleistocene) — sand, silt, and clay deposited in floodplain or overbank environments of Corn Creek and Cove Creek. Includes alluvium both older than and younger than the Black Rock lava flow (1 Ma) at locality D; probably all pre-Bonneville in age.
- Qaf_2 — OLDER ALLUVIAL-FAN DEPOSITS (late Pleistocene) — mostly coarse-grained, poorly sorted gravel in piedmont areas above, and older than, the Bonneville shoreline. Includes some minor post-Bonneville fan deposits above the Bonneville shoreline.
- Qaf_1 — YOUNGER ALLUVIAL-FAN DEPOSITS (Holocene) — poorly sorted gravel and fine sediment in post-Bonneville alluvial fans; thickness variable.
- Qal_1 — YOUNGER ALLUVIAL DEPOSITS (Holocene) — youngest alluvium underlying floodplains or low terraces along the Beaver River and smaller ephemeral streams; mostly silt, clay, and sand.
- Qam — ALLUVIAL MUD (Holocene) — mud deposited at low altitudes in Pavant Valley; poorly sorted, locally gypsiferous.

Playa (p)

- Qpm — PLAYA MUD (Holocene) — Poorly sorted clay, silt, and sand locally with gypsum, halite, and other salts.

Eolian (e)

- Qed — EOLIAN DEPOSITS (Holocene) — including well-sorted sand composed mostly of quartz in well-developed dunes, and sand-size aggregates of clay, silt, and sand that have accumulated in irregular dunes (referred to as "clay" dunes or lunettes). Locally includes gypsum dunes on the margins of playas.

Spring (s)

- Qst — SPRING TUFA (Pleistocene) — tufa or travertine deposited by hot springs; evenly banded travertine to irregular masses of weathered travertine or tufa; mostly at Hatton-Meadow tufa mound, but one small outcrop of spring tufa is exposed west of Eight Mile Point at the southern margin of the map area.

Volcanic Rocks (v)

- Qvb_4 — OLDER QUATERNARY BASALT (early and middle Pleistocene) — numerous basalt flows in the southern part of the map area; thickness undetermined.
- Qvn — ANDESITE (early Pleistocene) — Andesite flow of Beaver Ridge.
- Qvr — RHYOLITE (middle Pleistocene) — White Mountain rhyolite dome; flow-banded rhyolite and minor obsidian overlain by gypsum sand dunes.
- Qvb_3 — BASALT OF PAVANT RIDGE (late Pleistocene) — basalt of Pavant flows; pre-Bonneville in age; thickness undetermined.
- Qvb_2 — BASALT OF TABERNACLE HILL (late Pleistocene) — pahoehoe basalt flow, tuff and palagonitized tuff, and cinders erupted from Tabernacle Hill vent into Lake Bonneville at the Provo level.
- Qvb_1 — BASALT OF ICE SPRINGS (Holocene) — aa basalt flow and cinders of Ice Springs craters; less than 660 yr B.P.

Pre-Quaternary Map Units

- Ps — PALEOZOIC SEDIMENTARY ROCKS UNDIFFERENTIATED — Cricket Mountains; see Hintze (1984).
- PMu — PALEOZOIC AND MESOZOIC SEDIMENTARY ROCKS UNDIFFERENTIATED — Pavant Range; see Maxey (1946) and George (1985).
- Ts — TERTIARY SEDIMENTARY ROCKS UNDIFFERENTIATED — Cricket Mountains; see Hintze (1984).
- Tvr — RHYOLITE AND RHYODACITE (Pliocene) — Silicic volcanic rocks (table 3).
- Tvb — BASALT (Pliocene) — basalt flows (table 3).

Contact; dashed where inferred

Fault; bar and ball on downthrown side; dashed where inferred; dotted where concealed (faults in Paleozoic rocks not shown)

Fault or fracture having small or undetermined displacement

Shorelines; dotted where concealed by younger deposits; locally used as geologic contact. P = Provo; B = Bonneville.

Ridge crest of spit formed on the cuspate snout of the Beaver River underflow fan during the regressive phase of Lake Bonneville; spits overlie Qdf; dotted where overlain by eolian deposits

Abandoned stream channel having indistinct or no surface topographic expression; shown only on Qdg

Scarp of terrace; cut in Qdg during regression of Lake Bonneville

Volcanic vent

★ ○ ⊛ TH-13 10/10 — Ash samples in white marl. ★ indicates Pavant Butte ash, ○ indicates Tabernacle Hill ash, ⊛ indicates both ashes present. Alpha numeric label (if present) indicates analysis in table 6; number indicates thickness of ash (cm); fraction (10/10) indicates thickness (cm) of Tabernacle Hill ash over Pavant Butte ash.

● A — Locality listed in table 4 and and discussed in text; several coincide with ash sample locations.

Qed/Qlf/*Qvb_4* — Stacked map units; indicate thin or discontinuous cover of one unit over another unit; the most pervasive unit, *in italics*, is indicated by the color on the map.