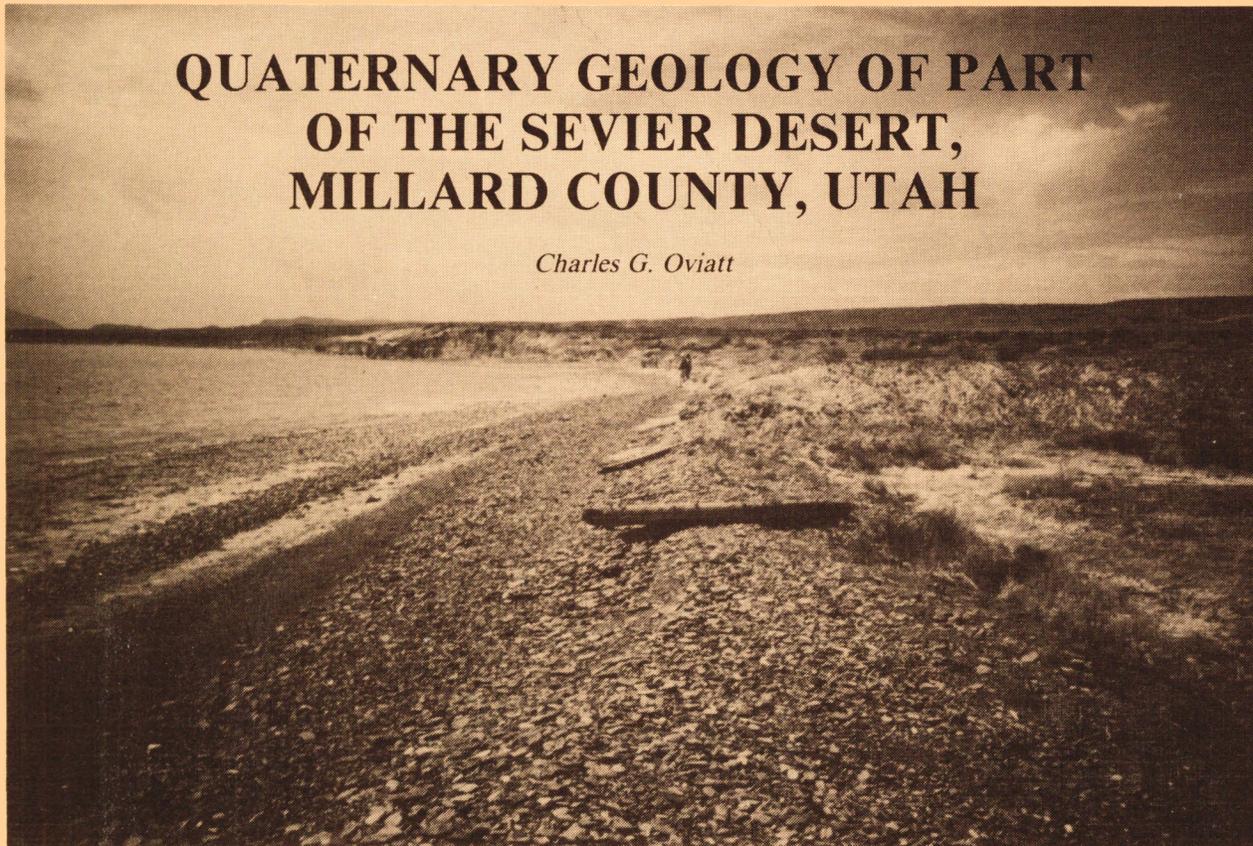


# QUATERNARY GEOLOGY OF PART OF THE SEVIER DESERT, MILLARD COUNTY, UTAH

*Charles G. Oviatt*



UTAH GEOLOGICAL AND MINERAL SURVEY  
*a division of*  
UTAH DEPARTMENT OF NATURAL RESOURCES  
SPECIAL STUDIES 70

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# QUATERNARY GEOLOGY OF PART OF THE SEVIER DESERT, MILLARD COUNTY, UTAH

by  
*Charles G. Oviatt<sup>1</sup>*

## ABSTRACT

This report describes the Quaternary geology and Quaternary geologic history of part of the Sevier Desert in east-central 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. Surficial deposits in the map area consist of fine-grained lacustrine deposits of Lake Bonneville and of pre-Bonneville lakes, vast areas of fine-grained alluvium deposited by the Sevier and Beaver Rivers, and coarser grained lacustrine and alluvial deposits in piedmont areas. Thin deposits of eolian sand or silt and clay are present throughout the map area but are concentrated in dunes in favorable localities. The map area also contains Quaternary basalt flows and volcanic vents; Quaternary faults cut deposits of all ages. The Sevier Desert basin has been periodically occupied by lakes throughout the Quaternary Period, and the geologic record of these lakes is exceptionally good. The lake deposits have been dated by interbedded volcanic ashes, lava flows, and various geochronometric methods. This report is one of the first attempts to map in a systematic way the Quaternary deposits and landforms in a large area of the Basin and Range physiographic province of western Utah.

## INTRODUCTION

The purpose of this report is to describe the Quaternary geology, and to outline the Quaternary history, of part of the Sevier Desert in east-central Millard County, Utah. With a few exceptions, the Quaternary geology of western Utah has not been mapped in as much detail as the pre-Cenozoic rocks in the region. This report is one of the first attempts to map in a systematic way the Quaternary deposits and landforms in a large area of the Basin and Range physiographic province of

western Utah. Quaternary geology in western Utah is important in studies of Lake Bonneville and other Quaternary lakes, earthquake, volcanic, and other geologic hazards, and ground water. Geologic mapping provides basic data for these and other investigations.

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, 1986, and the map and report were prepared during the fall and winter of 1986 and 1987.

The map area (plate 1) encompasses eighteen 7.5 minute topographic quadrangles or approximately 1000 square miles (2600 km<sup>2</sup>), and includes the towns of Delta, Deseret, and Hinckley, Utah (figure 1). Altitudes in the area range from about 4520 feet (1377 m) on the floor of Sevier Lake playa to about 6600 feet (2000 m) in the Cricket Mountains. Most of the map area, however, is on the floor of the Sevier Desert basin and has little relief. The map boundaries were chosen because the map area thus outlined contains surficial deposits, volcanic rocks, and structures that are typical of the Sevier Desert as a whole.

The Sevier Desert is bounded on the east by the Canyon Range and the Gilson Mountains, on the north by the Sheeprock Mountains, Simpson Mountains, and Keg Mountain, and on the west by the Drum Mountains, Little Drum Mountains, and the House Range (figure 1). The southern boundary is less well defined but is marked by the Cricket Mountains, the Mineral Mountains, and the Black Rock volcanics, which provide an arbitrary dividing line between the Sevier Desert (the southern part of which is called the Black Rock Desert) and the Escalante Desert.

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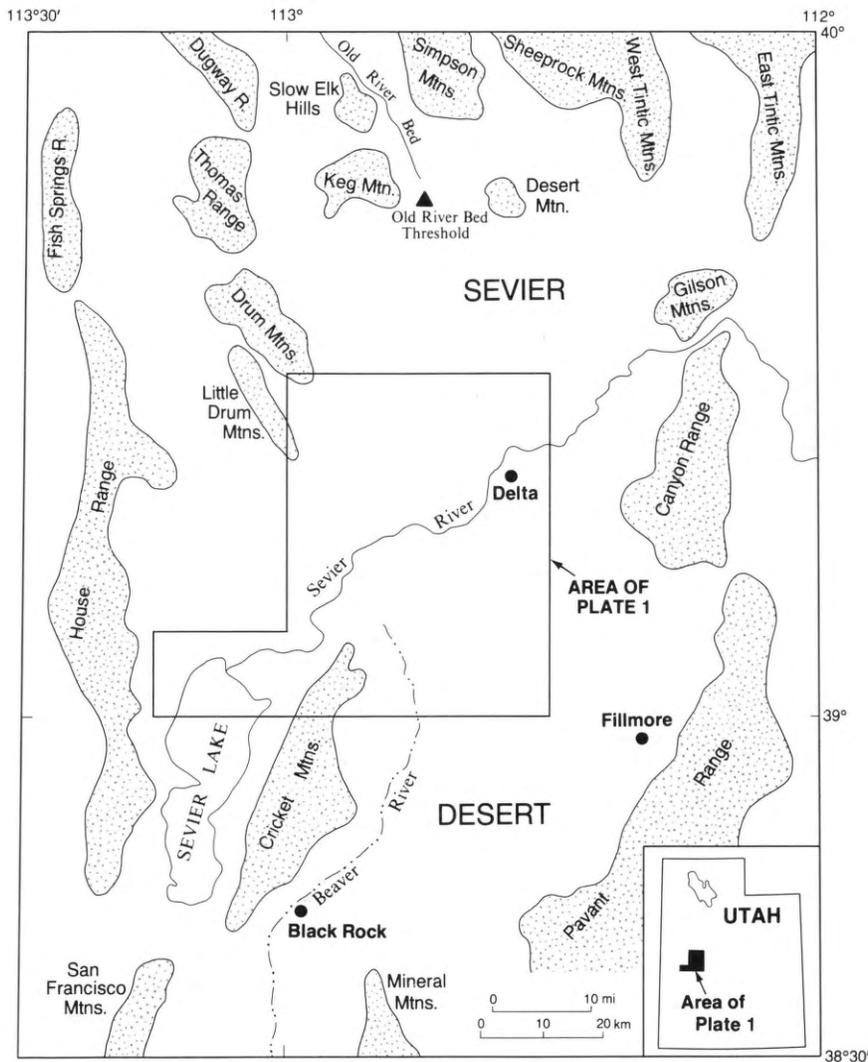


Figure 1. Location of the study area.

Surficial deposits in the map area consist of fine-grained lacustrine deposits of Lake Bonneville and of pre-Bonneville lakes, vast areas of fine-grained alluvium deposited by the Sevier and Beaver Rivers, and coarser grained lacustrine and alluvial deposits in piedmont areas. Thin deposits of eolian sand or silt and clay, scattered throughout the map area, are concentrated in dunes in favorable localities. The map area also contains Quaternary basalt flows and volcanic vents, and Quaternary faults cut deposits of all ages. The reconnaissance investigations reported on here provide a compilation of the Quaternary geology and Quaternary environmental history of the Sevier Desert. However, much more work must be done to fully understand the geologic and paleoenvironmental history of this complex area.

The climate on the floor of the Sevier Desert is arid and warm, with mean annual temperatures at Desert, Utah, of 49°F (9.4 °C) and mean annual precipitation of 6.9 inches (17.5 cm) during the period 1891-1970 (Stott, 1977, table 9, p. 74). Precipitation is concentrated in the spring and the period from late fall to early winter. Vegetation in the map area

ranges from pickle weed (*Allenrolfea occidentalis*), salt grass (*Distichlis stricta*) and other halophytes on the margins of mud flats and playas, to greasewood (*Sarcobatus vermiculatus*) on slightly higher ground, to salt bush (*Atriplex confertifolia*) and other xerophytes on piedmont slopes and uplands.

Previous work on the surficial deposits and geomorphology of the Sevier Desert area includes the efforts of Gilbert (1890), Varnes and Van Horn (1951; 1961; 1984), Gvosdetsky and Hawkes (1956), Campbell (1979), Sack (1981), Pampeyan (1984), Oviatt (1984), and Isgreen (1986). Whelan (1969) and Hampton (1978) have studied the brines and saline minerals of Sevier Lake playa. The Paleozoic bedrock geology in the Sevier Desert area has been studied by Morris (1978), Lindsey (1982), Hintze (1984), and Pampeyan (1984). The structural geology of the Sevier Desert region has been studied by Case and Cook (1979), Bucknam and Anderson (1979a), Allmendinger and others (1983, 1987), Anderson and others (1983), and Crone and Harding (1984). Gilbert (1890), Condie and Barsky (1972), Hoover (1974), Leedom (1974), Pierce (1974), Best and others (1980), Turley and Nash (1980), and Lindsey (1982) have studied the Cenozoic volcanic rocks. Hydrologic studies by the U.S. Geological Survey include those of Mower (1967), Mower and Feltis (1968), and Holmes (1984). The archaeology of the Sevier Desert has been investigated by Simms and Isgreen (1984).

## DESCRIPTION OF MAP UNITS

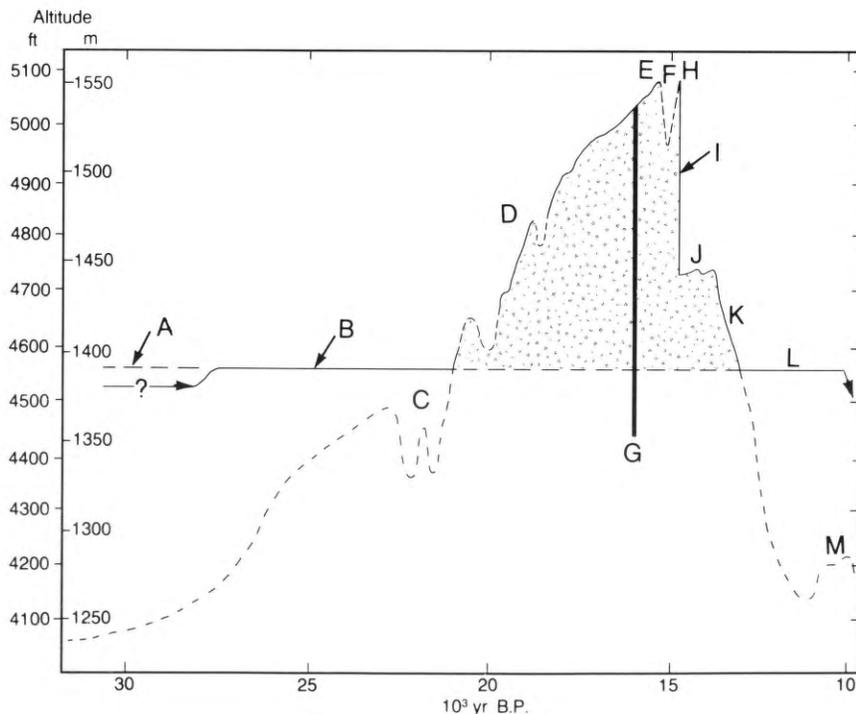
### INTRODUCTION

For mapping purposes (plate 1) the Quaternary deposits in the Sevier Desert are classified primarily on the basis of their environments of deposition. The unconsolidated Quaternary sediments were deposited in lacustrine, alluvial, deltaic, playa, and eolian environments as indicated by the first lower-case letter in the map-unit symbols. Other distinguishing characteristics, such as texture, 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 Qa<sub>1</sub> and Qa<sub>2</sub>, 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 overlying fine-grained lacustrine deposits, which overlie a pre-Bonneville basalt flow, are mapped as Qed/Qlf/Qvb<sub>2</sub>.

Plate 1 also shows Quaternary volcanic rocks and unconsolidated sediments of volcanic origin 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 are based on the following criteria: radiocarbon dates obtained for this project and from other published and unpublished sources (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 a relative 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 even greater accuracy.

The map units are described below under their major generic categories, but not necessarily in stratigraphic order. Refer to figure 35, correlation of map units, for visual stratigraphic relationships and the section on Quaternary history for the regional development.



**Figure 2.** Time-altitude diagram of Lake Bonneville showing lake-level changes in the Sevier Desert during the Bonneville lake cycle (modified from Currey and Oviatt, 1985, figure 2). A = altitude of Old River Bed threshold (long-dashed line); B = postulated lake in Sevier Desert basin that overflowed into rising Lake Bonneville in Great Salt Lake basin; C = Stansbury oscillation of Lake Bonneville; D = transgressive phase of Lake Bonneville at altitudes higher than the Old River Bed threshold; E = first overflowing stage at Bonneville shoreline; F = Keg Mountain oscillation; G = eruption of Pavant Butte basaltic tuff and ash (Qvt, Qva); H = second overflowing stage at Bonneville shoreline; I = Bonneville flood; J = overflowing stage at Provo shoreline; K = regressive, closed-basin phase below Provo shoreline; L = Lake Gunnison in Sevier Lake basin overflowing into Great Salt Lake basin along the Old River Bed; M = secondary transgression of Lake Bonneville in Great Salt Lake basin and development of Gilbert shoreline. Altitudes shown on the diagram have been corrected for the effects of isostatic rebound (Currey and Oviatt, 1985, p. 10), however, the Old River Bed threshold is shown at its postulated unrebounded altitude. The dashed lines indicate lake-level changes of Lake Bonneville in the Great Salt Lake basin independent of the Sevier Lake basin. The solid (and short-dashed) line indicates lake-level changes of Lake Bonneville above the Old River Bed threshold, and overflowing lakes in the Sevier Desert basin. The stippled area indicates the diachronous episode of the white marl (Qlm) deposition in the Sevier Desert basin and elsewhere in the Bonneville basin at altitudes higher than the Old River Bed threshold.

Table 1. Radiocarbon dates on samples from the Sevier Desert collected within the boundaries of plate 1.

No.	Significance	Lab Number	Dated Materials	Altitude <sup>a</sup>	Locality <sup>b</sup>	Depositional Setting	<sup>14</sup> C Date <sup>c</sup>	Reference
1	aggradational episode during deposition of Qal <sub>1</sub> (Sevier River)	Beta-17879	charcoal	4590 1399	I	sandy alluvium in terrace-fill of Qal <sub>1</sub>	690 ± 90	this report
2	minimum date on age of abandoned Sevier River channel	Beta-19717	alkali-soluble humic fraction	4585 1398	U	natural-levee deposits of abandoned Sevier River channel	1050 ± 80	this report
3	aggradational episode during deposition of Qal <sub>2</sub> (Sevier River)	Beta-18270	gastropod shells	4590 1399	L	alluvial mud in terrace-fill of Qal <sub>2</sub>	1330 ± 70 <sup>d</sup>	this report
4	aggradational episode during deposition of Qal <sub>2</sub> (Beaver River)	Beta-17881	gastropod shells	4630 1411	V	alluvial mud below low terrace of Beaver River	1540 ± 85 <sup>d</sup>	this report
5	expansion of Sevier Lake to 4535 ft (1382 m) caused aggradation by Sevier River	Beta-17882	gastropod shells	4543 1385	F	alluvial mud underlying terrace of Sevier River; terrace extends downstream to 4535 ft (1382 m) near shore of Sevier Lake	2560 ± 75 <sup>d</sup>	this report
6	expanded marsh environment near Topaz Slough	Beta-17884	gastropod shells	4570 1385	M	alluvial mud deposited in marsh setting beyond toe of Qal <sub>2</sub> low-gradient fan	3600 ± 85 <sup>d</sup>	this report
7	aggradational episode during deposition of Qal <sub>2</sub> (Sevier River)	Beta-17880	<u>Sphaerium</u> shells	4625 1410	K	sandy alluvium in terrace-fill of Qal <sub>2</sub>	5460 ± 100 <sup>d</sup>	this report
8	deposition by Beaver River over bed of Lake Gunnison; Sevier Lake below this altitude	Beta-8011	disseminated organic carbon	4546 1386	W	alluvial mud about 6 ft below ground surface exposed in backhoe trench	5930 ± 220	Simms & Isgreen, 1984
9	deposition by Beaver River over bed of Lake Gunnison; Sevier Lake below this altitude	Beta-12988	disseminated organic carbon	4549 1387	W	alluvial mud about 1 ft below ground surface exposed in blowout	7930 ± 110	Simms, 1985

10	deposition by Sevier River over bed of Lake Gunnison; Sevier Lake below this altitude	Beta-17878	gastropod shells	4560 1390	J	alluvial mud below clay dunes near Gunnison Massacre Monument	9345 ± 160 <sup>d</sup>	this report
11	alluvial deposition by Beaver River over bed of Lake Gunnison	Beta-12987	gastropod shells	4549 1387	W	alluvial mud about 1 ft below ground surface exposed in blowout	9570 ± 430 <sup>d</sup>	Simms, 1985
12	regression of Lake Gunnison	Beta-19455	<u>Anodonta</u> shells	4543 1385	T	lacustrine sand overlying carbonate-rich lacustrine mud	10,070 ± 130 <sup>d</sup>	this report
13	overflowing stage of Lake Gunnison	GX-6776	<u>Anodonta</u> shells	4545 1385	G	lacustrine mud that inter-fingers with spit gravel; crest of spit at 4557 ft (1389 m)	10,360 ± 225	Currey, 1980b
14	overflowing stage of Lake Gunnison	Beta-17883	<u>Anodonta</u> shells	4545 1385	S	lacustrine sand at distal end of spit; crest of spit at 4560 ft (1390 m)	11,270 ± 110 <sup>d</sup>	this report
15	deposition of Provo Shoreline sediments (minimum age)	Beta-18272	carbonate-coated gastropods	4735 1443	E	outer edge of sub-lacustrine shelf 52 ft (16 m) below Provo Shoreline on Deseret basalt flow	12,320 ± 100 <sup>d</sup>	this report
16	late regressive stage of Lake Bonneville	Beta-8348	<u>Anodonta</u> shells	4580 1396	D	lacustrine sand and gravel in a spit at Sunstone Knoll	12,490 ± 130 <sup>d</sup>	Isgreen, 1986
17	earliest transgressive-phase Lake Bonneville date in Sevier Desert	Beta-18271	<u>Amnicola</u> shells	4560 1390	C	base of white marl (Q1m) overlying transgressive-phase spit gravel	19,920 ± 230 <sup>d</sup>	this report

<sup>a</sup>Altitudes in feet and meters; uncorrected for the effects of isostatic rebound of the basin caused by the water load of Lake Bonneville; rebound effects are probably negligible except possibly for dates 15, 16, and 17.

<sup>b</sup>Refer to Table 4 for locality descriptions.

<sup>c</sup>Radiocarbon dates in yr B.P.

<sup>d</sup>Shell dates that are <sup>13</sup>C-corrected.

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

Ash	Age <sup>1</sup>	Localities	Reference
Pavant Butte basaltic ash (Qva)	15,500	see figure 21	Varnes and Van Horn, 1961, 1984; Currey, 1982; Oviatt, 1984; Currey and Oviatt, 1985; this report; Oviatt and Nash, 1989
Bishop ash	740,000	A; B; Black Rock (south of map area)	Oviatt, unpublished, 1979; Krusi and Patterson, 1980; Izett, 1982
Huckleberry Ridge	2.02 x 10 <sup>6</sup>	near Black Rock (south of map area)	Izett and Wilcox, 1982

<sup>1</sup>Age in years B.P.

Table 3. K-Ar dates on volcanic rocks exposed in the map area.

Date <sup>a</sup>	Unit	Reference
0.031 ± 0.038	Qvb <sub>2</sub>	Hoover, 1974
0.032 ± 0.051	Qvb <sub>2</sub>	Hoover, 1974
0.070 ± 0.056	Qvb <sub>2</sub>	Hoover, 1974
0.093 ± 0.078	Qvb <sub>2</sub>	Hoover, 1974
0.133 ± 0.097	Qvb <sub>2</sub>	Hoover, 1974
0.220 ± 0.260	Qvb <sub>2</sub>	Condie and Barsky, 1972
0.31 ± 0.08	Qvb <sub>2</sub>	Turley and Nash, 1980
0.4 ± 0.4	Qvb <sub>3</sub>	Best et al., 1980
3.4 ± 0.1	Tr	Turley and Nash, 1980
6.1 ± 0.3	Tb	Turley and Nash, 1980
37.3 ± 0.4	Tv	Leedom, 1974

<sup>a</sup>Date in yr (x 10<sup>6</sup>) B.P.

Table 4. List of localities discussed in text and indicated on plate 1.

Locality	Description	Significance	Lat.-Long.
A	NW shore of Sevier Lake at Miller Canyon Reservoir	Bishop ash in QTlf exposed in stream cuts and wave-cut bluffs	39° 2.00' 113° 12.97'
B	directly north of map boundary at Inter-mountain Power Plant	Bishop ash in QTlf exposed in exploratory trenches (Krusi & Patterson, 1980)	39° 30' 112° 37'
C	borrow pit on north side of Highway 50/6	white marl overlying transgressive-phase barrier beach; radiocarbon date 17	39° 6.77' 113° 8.01'
D	borrow pit on south-east side of Sunstone Knoll	radiocarbon date 16 on <u>Anodonta</u> shells (Isgreen, 1986) from spit gravel	39° 8.75' 112° 42.80'
E	gully eroded across pre-Bonneville fault scarp on Deseret basalt flow	Qlm and Qlk exposed in gully; radiocarbon date 15 on Qlk	39° 11.16' 112° 44.02'
F	cut-bank in terrace sediments on west side of Sevier River about 10 mi (16 km) west of Pot Mountain	radiocarbon date 5 on shells from Qal <sub>1</sub>	39° 8.89' 112° 57.28'
G	cut-bank of abandoned Sevier River channel at eastern end of Bitterweed spit	radiocarbon date 13 on <u>Anodonta</u> shells (Currey, 1980b) from lacustrine mud that intertongues with spit gravel	39° 6.93' 112° 56.20'
H	north shore of Sevier Lake near Mud Flat Reservoir	topographic transect across late Holocene beaches of Sevier Lake (figure 11)	39° 5' 113° 11'

I	about 1000 ft (300 m) south of Highway 50/6 bridge over Sevier R. in cutbank on east side of river	radiocarbon date 1 on charcoal from Qal <sub>1</sub>	39° 19.77' 112° 37.20'
J	about 1000 ft (300 m) southeast of Gunnison Bend Monument in cutbank on east side of river	radiocarbon date 10 on shells from Qal <sub>2</sub>	39° 46.76' 112° 16.57'
K	about 2.5 mi (4 km) north of Delta in cutbank on west side of river	radiocarbon date 7 on shells from Qal <sub>2</sub>	39° 23.25' 112° 35.30'
L	in cutbank on south side of Sevier River directly west of Deseret Fairgrounds	radiocarbon date 3 on shells from Qal <sub>2</sub>	39° 17.35' 112° 38.80'
M	in badlands about 1.3 mi (2.1 km) west of Topaz Slough	radiocarbon date 6 on shells from Qal <sub>2</sub>	39° 27.35' 112° 48.46'
N	road cut about 1 mi (1.6 km) south of IPP	good exposures of QTlf and Qal <sub>3</sub>	39° 30' 112° 37'
O	cutbank on north side of Sevier River about 1 mi (1.6 km) west of highway 50/6 bridge	good exposure of Qdf over Qlm; amino acid analyses on <u>Amnicola</u> from base of Qlm and base of Little Valley marl; see text	39° 24.25' 112° 30.60'
P	exposure of Qlm in a small valley at the north end of the Cricket Mountains	shows Qlm overlying Qlg <sub>2</sub> , and overlain by Qls, which was probably deposited during the Keg Mountain oscillation	39° 4.5' 112° 51.0'
Q	about 300 ft (100 m) north of the road to Clear Lake Springs	topographic profile across the Clear Lake fault scarp	39° 6.2' 112° 50.8'
R	about 2 mi (3 km) east of Deseret lava flow	topographic map and profile of an abandoned Sevier River channel (figure 17)	39° 12' 112° 40'
S	cutbank on west side of Sevier River about 10 mi (16 km) west of Pot Mountain	radiocarbon date 14 on shells from Lake Gunnison deposits	39° 15.80' 112° 57.05'
T	cutbank on east side of Sevier River about 10 mi (16 km) west of Pot Mountain	radiocarbon date 12 on shells from Lake Gunnison deposits	39° 8.72' 112° 57.05'
U	about 600 ft (200 m) south of Fort Deseret	radiocarbon date 2 on organics from natural-levee deposits	39° 15.80' 112° 39.15'
V	exposure on east side of Beaver River near southern boundary of Plate 1	radiocarbon date 4 on shells from Beaver River alluvium	39° 0.31' 112° 44.80'
W	in and near a blowout depression about 8 mi (13 km) west of Pot Mountain	radiocarbon dates 8, 9, and 11 from Qal <sub>2</sub> (Simms, 1985; Simms and Isgreen, 1984)	39° 9' 112° 53'

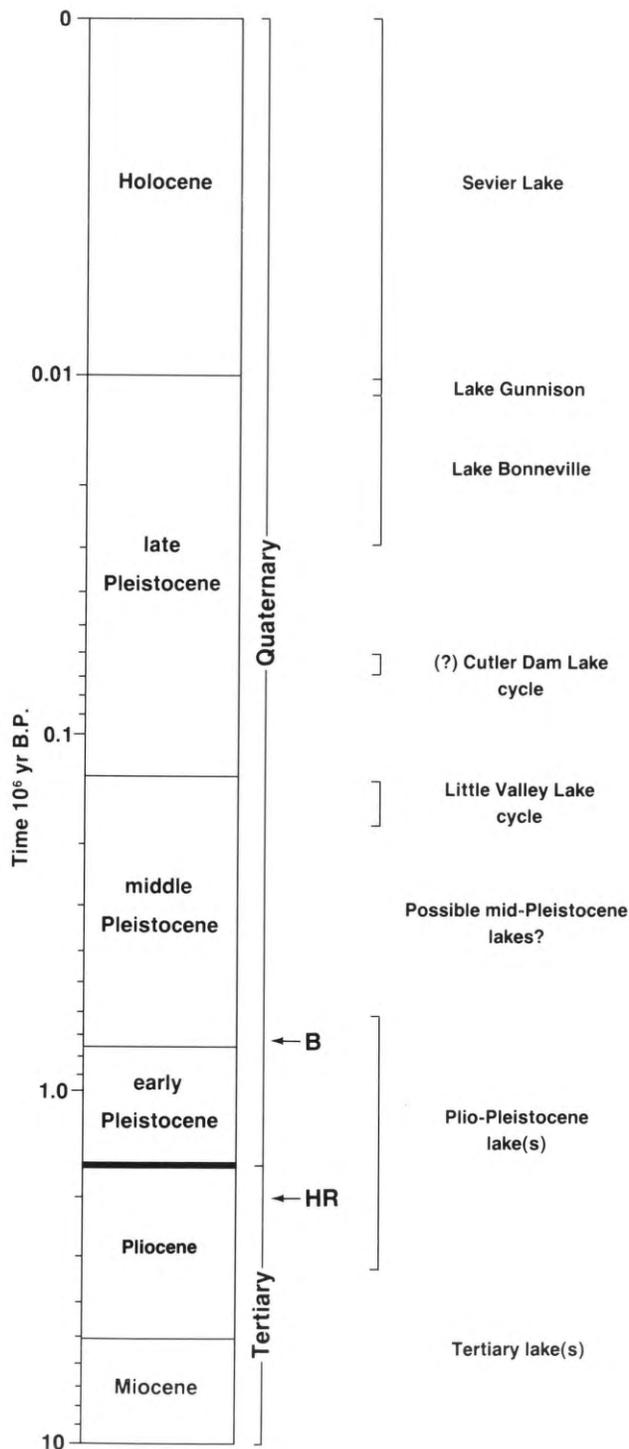


Figure 3. Diagram showing late Tertiary and Quaternary time scale and known or inferred lakes in the Sevier Desert. B = Bishop ash; HR = Huckleberry Ridge ash. Note logarithmic time scale.

## Lacustrine Deposits

**Plio-Pleistocene fine-grained lacustrine deposits** — Fine-grained lacustrine deposits of a pre-Bonneville lake or lakes are widespread in the Sevier Desert, and are mapped as QTlf. This map unit 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 Sevier Desert. The stratigraphic base of QTlf has not yet been identified in outcrops, but sand beds up to about 1 foot (0.3 m) thick interbedded with the calcareous silt in some exposures may indicate that the base of the unit is not far below the bottom of the exposure. QTlf probably overlies bedrock surfaces, alluvial-fan deposits, and possibly other upper Tertiary lake beds.

QTlf contains ostracodes, but other fossils are rare. Gastropods of the genus *Ammicola*(?) have been found at one locality. A sample of calcareous silt collected 6 inches (15 cm) below the Bishop ash at locality A (table 4) contained the following species: *Limnocythere staplini*, *L. platyforma*, *Candona patzcuaro*, *C. caudata*, *C. acuminata*?, *Cypridopsis vidua*, and *Cyprideis beaconensis* (R. M. Forester, written communication, 1987). This ostracode fauna suggests that the lake-water composition was Ca+(Mg)-HCO<sub>3</sub> dominated to Ca-enriched but Na-Cl + SO<sub>4</sub> dominated, with salinity in a range of about 500 to 2000 ppm (R. M. Forester, written communication, 1987).

The sediments sampled in a pit on the floor of Sevier Lake playa by Baer and others (1968) are probably not "recent" in age as they reported, but are more likely part of the QTlf sequence, which is exposed at the edge of the playa on the northern end. Baer and others (1968) noted that *Picea* (spruce) was one of the most common pollen genera in the samples they examined.

QTlf is mapped in piedmont areas where it is locally exposed below thin gravel deposits (Qla). Some of the best exposures of QTlf are in small badlands in the western part of the map area north and west of Sevier Lake (figure 4). The highest exposures of QTlf are at an altitude of about 4900 feet (1490 m) along the eastern piedmont of the Little Drum Mountains and on the flanks of the Cricket Mountains.

QTlf is late Tertiary to middle Pleistocene in age, as shown by dated volcanic ashes that are interbedded with the fine-grained deposits. At locality A (table 4) on the western shore of Sevier Lake, a 1-2 inch (2-6 cm) layer of white, fine-grained volcanic ash is exposed in finely bedded silt of QTlf (Oviatt, unpublished field observations, 1979). Samples of this ash have been identified as Bishop ash by Izett (1982). The Bishop ash was erupted from the Long Valley Caldera in eastern California approximately 740,000 yr B.P. (Izett, 1982). The Bishop ash has also been found in QTlf exposed in trenches at the Intermountain Power Plant site north of the town of Delta (locality B, table 4; Krusi and Patterson, 1980; Izett, 1982).

South of the map area near the railroad siding of Black Rock (figure 1), fine-grained lacustrine deposits that are lithologically similar to QTlf contain the Huckleberry Ridge ash (Izett and Wilcox, 1982). The Huckleberry Ridge ash is 2.02 x

10<sup>6</sup> years old and was erupted from the Island Park caldera in eastern Idaho (Izett and Wilcox, 1982). Although the deposits at the Black Rock locality cannot be physically traced from Black Rock to localities A or B (table 4), it is likely that the same lacustrine stratigraphic unit (QTlf), at least in a broad sense, is exposed at each of the three localities. The lithology of QTlf is similar at all three localities where volcanic ashes have been collected, and it changes very little between the numerous small isolated exposures around all flanks of the Cricket Mountains and in the east-sloping piedmont areas west and north of Sevier Lake. Thus QTlf may range in age from at least late Pliocene to early middle Pleistocene (figure 3). However, unconformities may be present within QTlf that have not yet been documented.



**Figure 4.** View to the southeast along Highway 50/6 about 5 miles (3 km) northeast of locality C (plate 1; table 4), outside of the map area. A = outcrops of QTlf composed of calcareous clay and silt; B = a thin gravel cap (Qla). Although this locality is outside the map area, the exposures of QTlf are typical of those throughout the Sevier Desert.

**Plio-Pleistocene lacustrine limestone** — White to light gray limestone locally containing abundant gastropods of the genus *Amnicola* (?) is exposed in three small outcrops along the western edge of the map area and is mapped as QTln. The limestone is thickly bedded and strongly indurated, and some beds contain pebbles of locally derived Paleozoic limestone. Remnants of QTln fill small valleys cut in Paleozoic limestone bedrock, and the bedding is horizontal, suggesting that the major features of the landscape at the time QTln was deposited were similar to those in the modern landscape, and that QTln has not been structurally tilted since its deposition. Therefore, QTln is probably not extremely ancient and could be as young as Quaternary in age.

QTln may represent a shore facies of QTlf. The outcrops of QTln are directly above the Provo shoreline at an altitude of about 4800 feet (1460 m), and outcrops of similar limestone just west of the map area about 4 miles (6.4 km) south of Highway 50/6 occur at the same altitude. South of Sevier Lake, 20 miles (32 km) south of the map area, outcrops of pre-Bonneville carbonate-cemented sand and gravel occur directly above the Provo shoreline and may also represent a

shore facies of QTlf. The exposures at all these sites exist because of prolonged wave erosion at the Provo shoreline, which created a pronounced wave-cut notch. Any softer fine-grained sediment that may have overlain or interfingered with the indurated limestone at these sites would have been removed by wave erosion.

Therefore, although it is not possible to physically trace QTln into QTlf<sup>1</sup>, QTln is inferred to be a shore facies of QTlf for two reasons. First, the two deposits have a similar degree of preservation, and second because QTln is a reasonable lithology to expect as the near-shore deposits of the fresh-water, calcium carbonate-rich lake in which QTlf was deposited. If the stratigraphic correlation with QTlf is correct QTln would be late Tertiary to middle Pleistocene in age.

**Fine-grained lacustrine deposits** — Fine-grained lacustrine sediments deposited in Lake Bonneville are widespread in the Sevier Desert, and are represented in part by the map unit Qlf. These deposits include silt, sand, marl, and calcareous clay. Qlf includes the white marl (Qlm) and reworked white marl and other lacustrine sediments that had been eroded and washed basinward during the regressive phase of Lake Bonneville. Locally it also 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. Locally Qlf is difficult to distinguish from Qaf<sub>1</sub> because the alluvial component of the deposit may be significant, or the alluvial component may be gradational with the lacustrine component. In most such cases, however, the distinction between Qaf<sub>1</sub> and Qlf is probably not extremely critical because the physical characteristics of the deposits are similar even if their depositional environ-

<sup>1</sup>South of the map area along the west side of Sevier Lake, F.D. Davis has been able to trace fine-grained clastic deposits (QTlf) up slope into shore-zone limestones (QTln) (F.D. Davis, personal communication, 1987). The intertonguing relationships between the two units are well exposed in several gulleys.

ments are different. In general, however, Qlf is finer grained than Qaf<sub>1</sub>. Qlf is Bonneville and post-Bonneville in age.

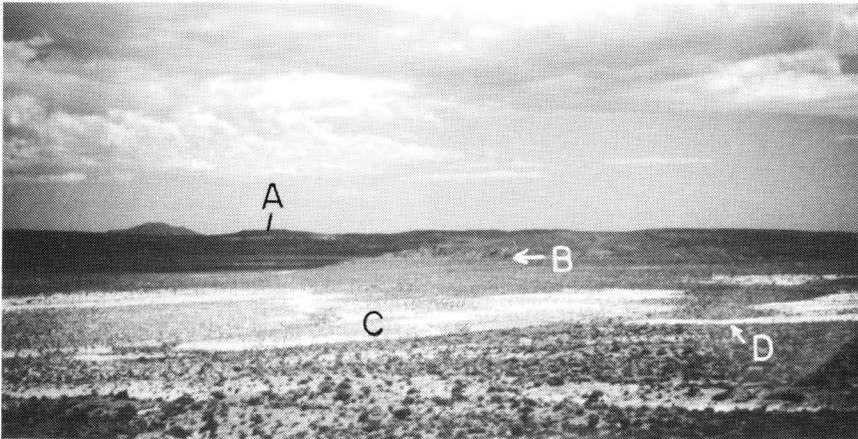
**White marl** — The open-water or deep-water deposits of Lake Bonneville are preserved at many localities in the Sevier Desert and are mapped in plate 1 as Qlm. The map unit Qlm is the same as the stratigraphic unit named the white marl, as defined by Gilbert (1890), and redefined by Oviatt (1987a). 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.

Qlm is especially thick and well preserved in localities a short distance below the Provo shoreline (figures 5 and 6). In this setting some of the extra thickness of the marl can be attributed to redeposition of marl that had been washed off the slopes of the basin between the Provo and Bonneville shorelines during the long stillstand of the lake at the Provo stage (figure 2). In addition, some of the marl is probably authigenic and was deposited during the Provo stage in the shallow water offshore from the Provo shoreline.

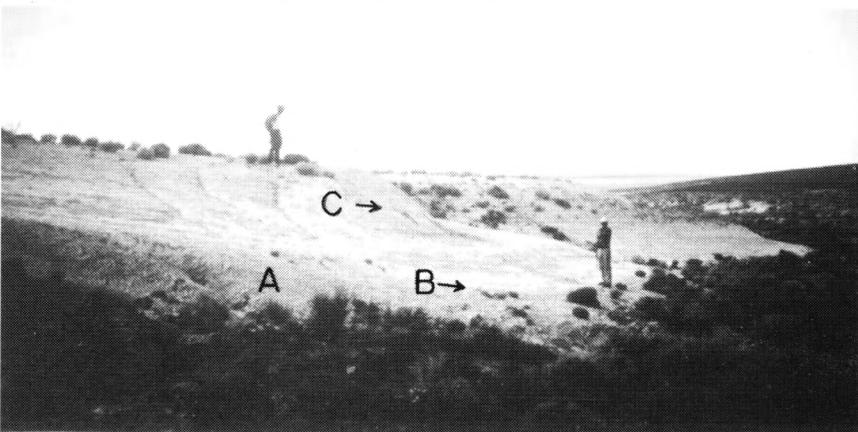
The map unit Qlm differs from Qlf in that Qlm is mapped in places where the white marl is well preserved and well exposed. Qlm has not been modified significantly by post-Bonneville fluvial activity, whereas Qlf may have a significant alluvial component consisting of reworked Qlm and other fine-grained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

In the Sevier Desert Qlm ranges in age from about 20,000 yr B.P. to about 12,000 yr B.P. At locality C (table 4) gastropods (*Amnicola*) collected from the base of the white marl yielded a radiocarbon date of  $19,920 \pm 230$  yr B.P. (Beta-18271; table 1). The white marl at this locality is truncated and is not mappable at the scale of plate 1, but it is the lowest-altitude exposure of the white marl known in the Sevier Desert that has been radiocarbon dated. The altitude here is 4560 feet (1390 m), which is about 45 feet (14 m) above the modern floor of Sevier Lake playa. Therefore, Beta-18271 provides a date on the initial transgression of Lake Bonneville into the Sevier Desert basin and the beginning of white marl (Qlm) deposition in the basin.

A radiocarbon date on *Anodonta* shells from shore-zone deposits at Sunstone Knoll (locality D; table 4) of  $12,490 \pm 130$  yr B.P. (Beta-8348; table 1; Isgreen, 1986) provides a minimum limiting date on Qlm deposition in the lower parts of the Sevier Desert basin. Shortly after 12,490 yr B.P. Lake Bonneville split into two separate lakes, a freshwater lake in the Sevier Desert (Lake Gunnison), and an increasingly saline lake



**Figure 5.** View east of the south end of Smelter Knolls showing the following features: A = Little Drum Mountains, B = the Provo shoreline sea-cliff and wave-cut terrace, and C = extensive exposures of the white marl. Figure 6 was taken near D.

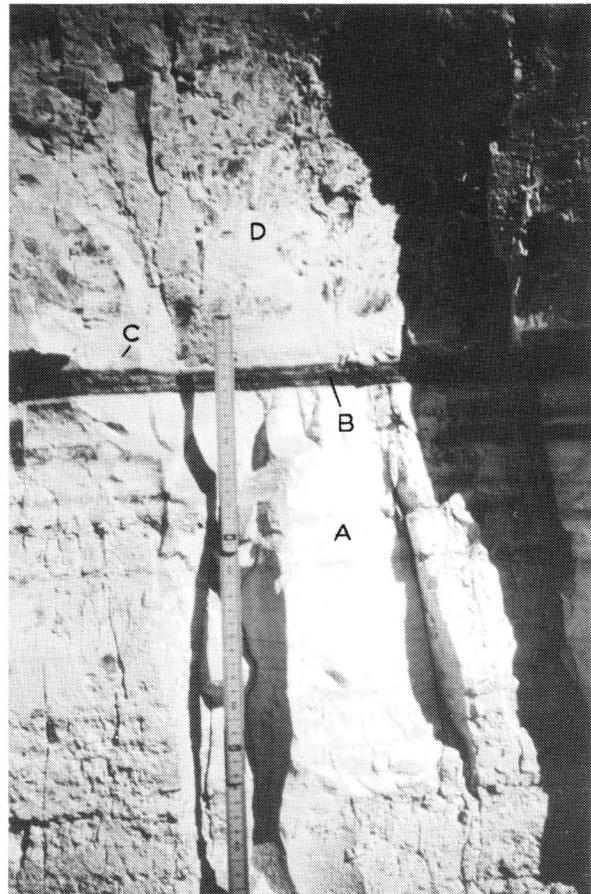
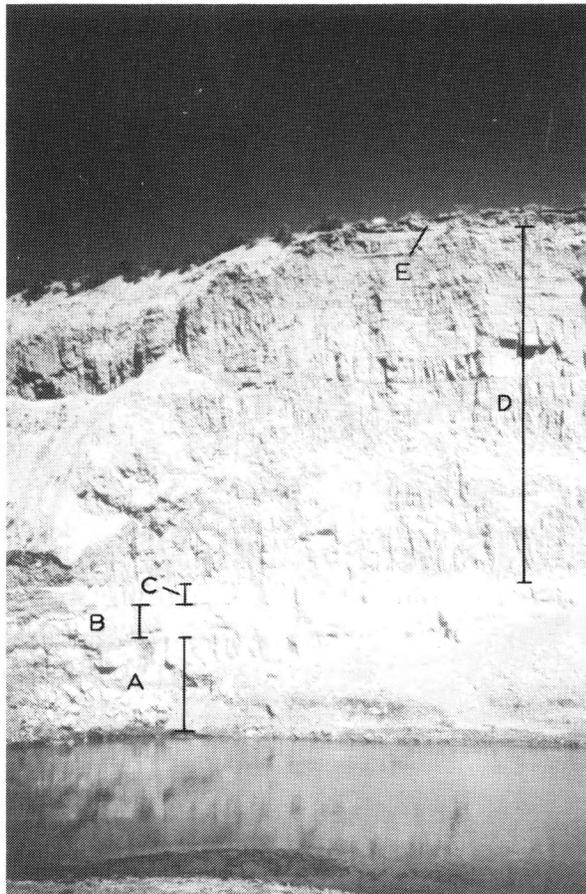


**Figure 6.** Outcrop of the white marl (Qlm) in a valley on the south side of Smelter Knolls below the Provo shoreline at an altitude of about 4720 feet (1440 m). Note that the marl was deposited on a slope and that it overlies sandy and silty, transgressive-phase, near-shore deposits labeled A, which overlie bedrock and colluvium. B = the base of the marl. C = an abrupt stratigraphic contact interpreted as marking the Bonneville flood. Clastic-rich marl above C was probably deposited during the Provo stillstand. This outcrop is typical of exposures of the white marl in the Sevier Desert below the Provo shoreline.

in the larger Great Salt lake Basin to the north (figure 2). Therefore, Qlm was deposited for almost 8000 years in the lowest parts of the Sevier Desert basin, but marl was deposited during much shorter time periods at localities approaching the Bonneville shoreline (figure 2). The base of the white marl is diachronous. However, at all altitudes between the Bonneville and Provo shorelines, the stratigraphic top of the white marl is essentially isochronous because deposition ceased abruptly due to the Bonneville flood (Gilbert, 1890; Malde, 1968), a

geologically instantaneous event.

Fine-grained basaltic ash erupted from Pavant Butte is interbedded with Qlm at many localities in the eastern part of the map area (figure 7). This ash has been dated between about 16,000 and 15,300 yr B.P. (Currey and Oviatt, 1985; Oviatt and Nash, 1989) and is a valuable stratigraphic marker. See the discussions under Qva and Pavant Butte (under Quaternary history) for more information on the Pavant Butte basaltic ash.



**Figure 7.** Photographs of the exposures along the Sevier River at locality O (plate 1; table 4).

A. Cut bank on north side of Sevier River exposing: A = pre-Bonneville Sevier River alluvium bearing a calcic soil profile below its upper contact and another buried soil near river level; B = pre-Bonneville (Little Valley) marl containing *Amnicola* gastropods and possibly bearing a truncated calcic soil profile. C = the white marl (Qlm) deposited in Lake Bonneville and containing *Amnicola* shells in a thin basal sand, and the Pavant Butte basaltic ash (Qva) near its upper contact; D = Provo-stage and post-Provo, regressive-phase underflow-fan silt and fine sand (Qdf); E = regressive-phase sand and gravel (Qdg). Distance from river level to top of exposure is approximately 90 feet (27 m).

B. Close-up of the upper part of the white marl at locality O (plate 1; table 4). A = marl deposited in deep water during stages close to and including the Bonneville shoreline; B = Pavant Butte basaltic ash, 15,500 yr B.P.; C = bedding plane interpreted as representing the catastrophic drop in lake level from the Bonneville shoreline to the Provo shoreline during the Bonneville flood; this is an isochronous surface that can be identified in exposures of the white marl throughout the Bonneville basin; D = marl containing more fine-clastic debris than A, interpreted as Provo-stage marl; D grades upward into silt and fine sand of Qdf. Scale in centimeters

**Gravel of lacustrine and/or alluvial origin.** In piedmont areas, thin lacustrine gravel deposits overlying either QTlf or pre-Bonneville alluvial fans 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 (figure 8), are etched across the pre-Bonneville alluvial fans indicating that waves in Lake Bonneville modified the alluvial-fan surfaces, and that

of Lake Bonneville and by post-Bonneville stream erosion or sheet wash. In some places thick accumulations of lacustrine gravel (Qlg<sub>2</sub>) in spits or barrier beaches are mapped with Qla if they are too small to show at a scale of 1:100,000.

**Lacustrine pebbly sand** — On the western slope of the Cricket Mountains above the Provo shoreline, pebbly sand overlies boulder-beach deposits or Qla, and is mapped as Qls. The sand is composed mostly of quartz and was derived from the dominantly quartzite alluvium in the fans. Qls is thin, probably less than 6 feet (2 m) thick in most places. The sand has been stripped from the piedmont slopes close to the Bonneville shoreline revealing the wave-etched pre-Bonneville alluvial-fan surfaces (Qla) on which it was deposited (figure 8).



**Figure 8.** Vertical aerial photograph (GS-VCMW, 3-165, 10-2-70) of part of the west piedmont of the Cricket Mountains. Scale is approximate. A = Sevier Lake playa; B = late Holocene gravel beaches (Qlg<sub>1</sub>); C = Lake Gunnison shoreline; D = exposures of white marl (Qlm); E = Qla; F = QTlf; G = Qlk; H = Qaf<sub>2</sub>; I = Paleozoic sedimentary rocks (Ps); J = Provo shoreline; K = Qls; L = bay-head gravel barrier at Bonneville shoreline; M = erosional notch at Bonneville shoreline; N = fault scarp in Cricket Mountains fault zone.

post-Bonneville fluvial activity has been negligible in these areas.

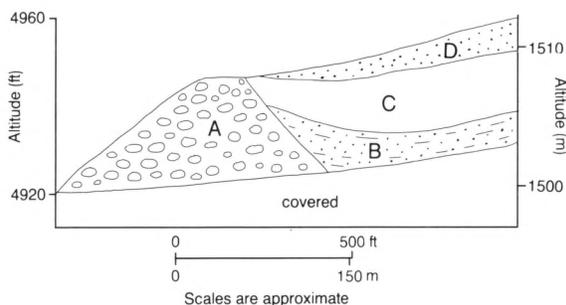
In areas between the Provo and Bonneville shorelines, Qla represents the basal transgressive boulder beach deposits of Lake Bonneville. Below the Provo shoreline, Qla represents both the basal transgressive shore-zone deposits and the regressive shore-zone deposits of Lake Bonneville. Qlm is locally preserved on Qla, but Qlm was stripped from greater than 95% of the map area by waves during the regressive phase

Qls was deposited in offshore settings in Lake Bonneville as the lake transgressed across the alluvial fans, reworked the surface layers of alluvium in the shore zone, and swept the sand-sized debris offshore to settle out in quieter water.

Qls was probably deposited almost as high as the Bonneville shoreline, but most of it was stripped off by waves and swept farther offshore during an oscillation in lake level, possibly the Keg Mountain oscillation (F in figure 2), a non-catastrophic drop in lake level of about 150 feet (45 m) from the Bonneville

shoreline. At locality P (table 4) sand that is lithologically identical to Qls, but unmappable at the scale of plate 1, overlies the white marl and transgressive-phase barrier-beach gravels (figure 9) at an altitude of 4950 feet (1510 m). This altitude is about 70 feet (20 m) below the inferred lower limit of the Keg Mountain oscillation in this area. The sand at locality P is inferred to have been deposited during the non-catastrophic drop in the lake level when waves reworked fine-grained sediments on the steep slope above the depositional site and swept them offshore. Alternatively, an oscillation during the transgressive phase of the lake could have produced a similar stratigraphic sequence.

Similar geomorphic and stratigraphic relationships have been described by Currey (1980a, figure 3) near North Ogden, Utah, and by Currey and others (1983, figure 11) at Keg Mountain, Utah. Currey (1980a, p. 74) noted that over most of the altitudinal range between the Bonneville and Provo shorelines, regressive-phase facies are not present overlying the white marl or its equivalents. The lack of regressive facies is due to the catastrophic drop in water level during the Bonneville flood, which occurred so rapidly that there was insufficient time for shore-zone facies or embankments to be deposited (Gilbert, 1890).



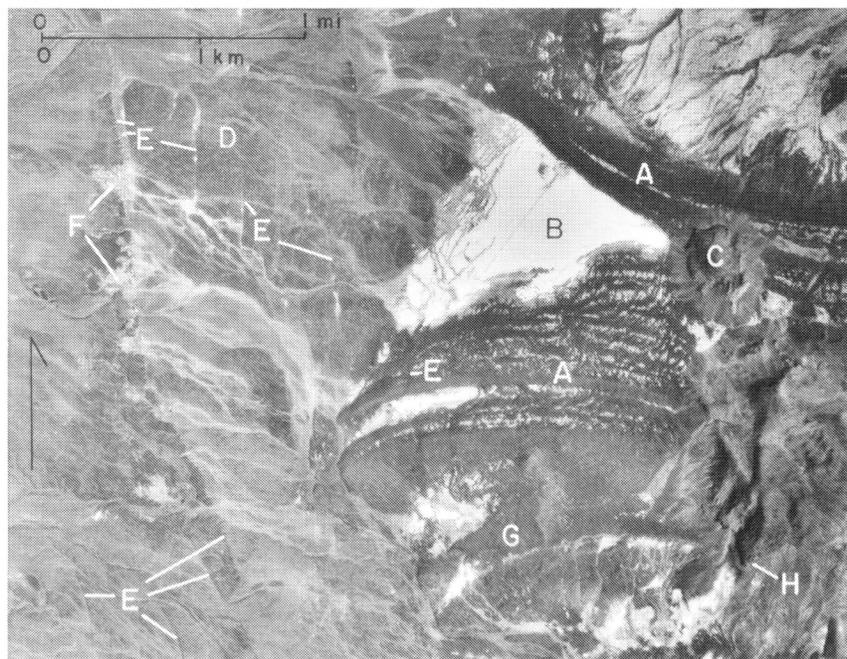
**Figure 9.** Schematic cross section through a transgressive-phase barrier-beach in the northern Cricket Mountains at locality P (plate 1; table 4) showing the following features; A = barrier-beach gravel; B = fine-grained lagoon-fill deposits; C = the white marl, which overlies the barrier beach thus showing it to have formed during the transgressive phase of Lake Bonneville; and D = well sorted pebbly sand (Qls), which may have been deposited during the Keg Mountain oscillation.

**Lagoon fill** — 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 beautifully preserved between two long barrier beaches of a double tombolo at the Provo shoreline on the west side of Smelter Knolls (figure 10).

**Lacustrine carbonate sand** — Lacustrine sand or pebbly sand composed of carbonate pellets, carbonate-coated gastropods, and ooids is mapped as Qlk. Qlk is mapped in areas about 10-60 feet (3-20 m) vertically below the Provo shoreline, and in all cases the carbonate-rich sand overlies the white marl (Qlm).

At locality E (table 4), the following stratigraphic sequence is exposed in a gully. At the base is basalt of the Deseret basalt flow. Overlying the basalt are 0-10 feet (0-3 m) of finely bedded, yellowish-brown, calcareous silt and sand that I interpret as the transgressive shore-zone deposits of Lake Bonneville. The silt and sand contain gastropods of the genus *Amnicola*, and are similar in lithology and geomorphic setting to deposits in the Old River Bed area, north of the Sevier Desert, that I have referred to as “yellow sand” (Oviatt, 1987a). The yellow sand grades upward into typical white marl (Qlm), which is truncated at the top and is overlain by about 6 feet (2 m) of coarse-sand and granule-size balls and blobs of calcium carbonate. Most of these are small gastropods that are coated with calcium carbonate. Oolitic sand locally cemented into oolite overlies the layer of carbonate-coated gastropods with a gradational contact.

The top of the stratigraphic section at locality E (table 4) has an altitude of 4740 feet (1445 m), which is 47 feet (14 m) below the Provo shoreline. Geomorphically the site is at the outer edge of a gently sloping shelf, 4500 feet (1370 m) horizontally



**Figure 10.** Vertical aerial photograph (GS-VCMW, 3-217, 10-2-70) of the east piedmont slope of the Little Drum Mountains and part of Smelter Knolls. Scale is approximate. A = lacustrine gravel (Qlg) forming a double tombolo at the Provo shoreline. Arrows indicate directions of sediment transport in longshore currents; B = lagoon fill; C = Smelter Knolls (Tr); D = Qla; E = faults in Drum Mountains fault zone; F = QTlf; G = Qlk; H = Provo shoreline erosional notch in Tr.

from the Provo shoreline. Tufa and carbonate-rich sediments similar to those described above are distributed everywhere across this shelf below the Provo shoreline. Similar stratigraphic sequences and geomorphic settings are found at all localities where Qlk is mapped. The carbonate-rich sediments are inferred to have been deposited during the long stillsand of Lake Bonneville at the Provo shoreline when the lake was overflowing and the water was fresh but rich in calcium carbonate.

A sample of the carbonate-coated gastropods from locality E (table 4) yielded a radiocarbon date of  $12,320 \pm 100$  yr B.P. (Beta-18272; table 1). This date, like most other dates on carbonate-carbon samples associated with the Provo shoreline, appears to be too young relative to other radiocarbon dates on Lake Bonneville materials that constrain the age of the Provo shoreline (Currey and Oviatt, 1985), probably as the result of contamination by  $^{14}\text{C}$ -bearing constituents in Holocene and modern meteoric water that percolates through the deposits. The true age of Qlk at locality E is therefore probably at least 1000 years older than the radiocarbon date indicates, based on a comparison with the inferred age of the Provo shoreline (Currey and Oviatt, 1985).

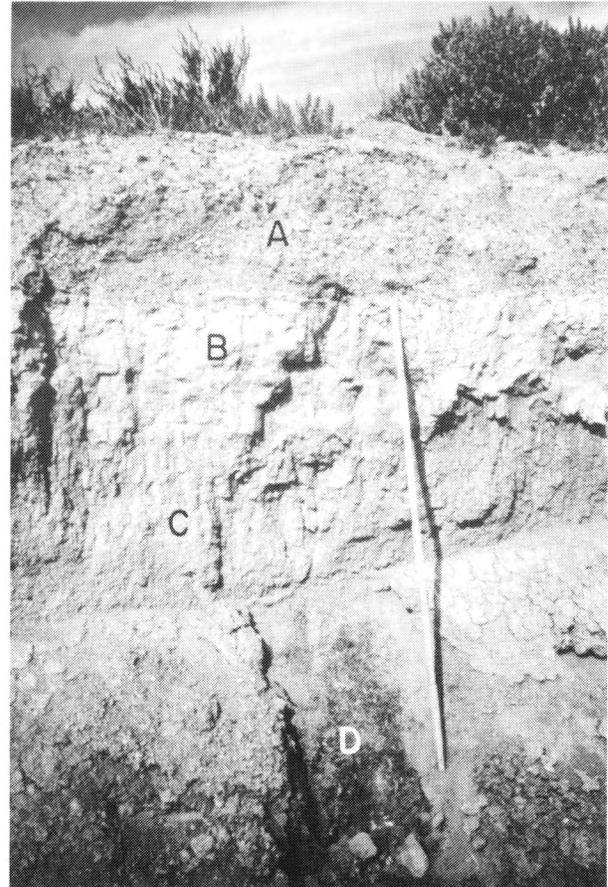
**Lacustrine gravel (late Holocene)** — Two well-preserved gravel beaches surrounding Sevier Lake at low levels are mapped collectively as Qlg<sub>1</sub> (figure 8). The gravel in these beaches is well sorted and sandy, and contains clasts of rock types commonly found in the alluvial fans surrounding Sevier Lake. Along the north shore of Sevier Lake, Qlg<sub>1</sub> contains clasts derived from the House Range, indicating long-shore sediment drift toward the east in this area.

Qlg<sub>1</sub> is thin, less than 3 feet (1 m) thick, and in most areas is not widespread. Therefore, the unit is somewhat exaggerated on plate 1 in order to depict it. However, because Qlg<sub>1</sub> is important in the Holocene history of the lake this exaggeration seems justified.

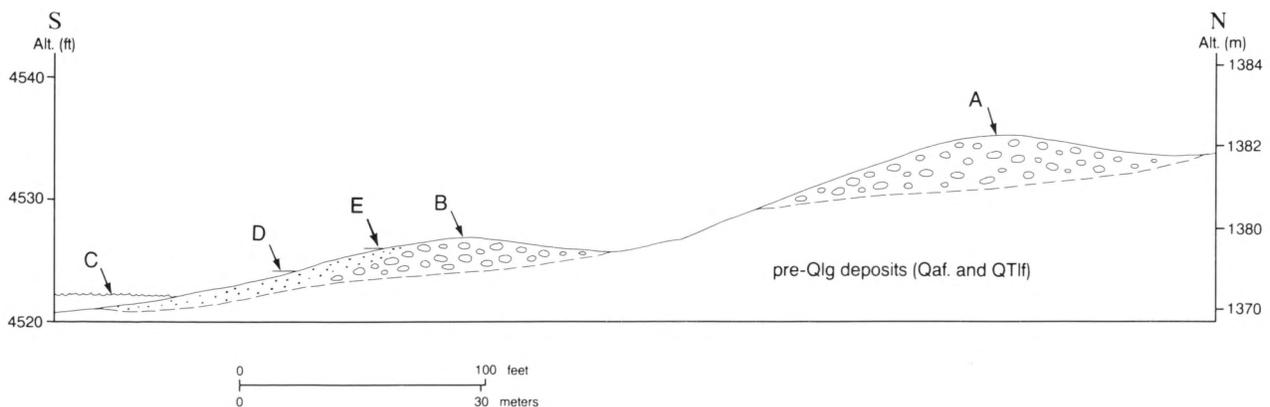
The two main beaches of Qlg<sub>1</sub> have crestal altitudes of 4535 feet (1382 m) and 4527 feet (1379.8 m) (figure 11; locality H; table 4), although locally other minor beach ridges are also present. The higher beach is larger, contains more gravel, and is more continuous, but both beaches are dissected by modern ephemeral washes. The higher beach has a greater cover of greasewood bushes and other small shrubs than the lower

beach, although the vegetation cover probably reaches a maximum of something less than 10% even on the higher beach. Eolian dust and shrub coppice dunes also cover more of the ground surface on the higher beach.

Qlg<sub>1</sub> overlies post-Bonneville alluvium and QTlf (figure 12). A weakly developed buried soil, formed in alluvium underlying

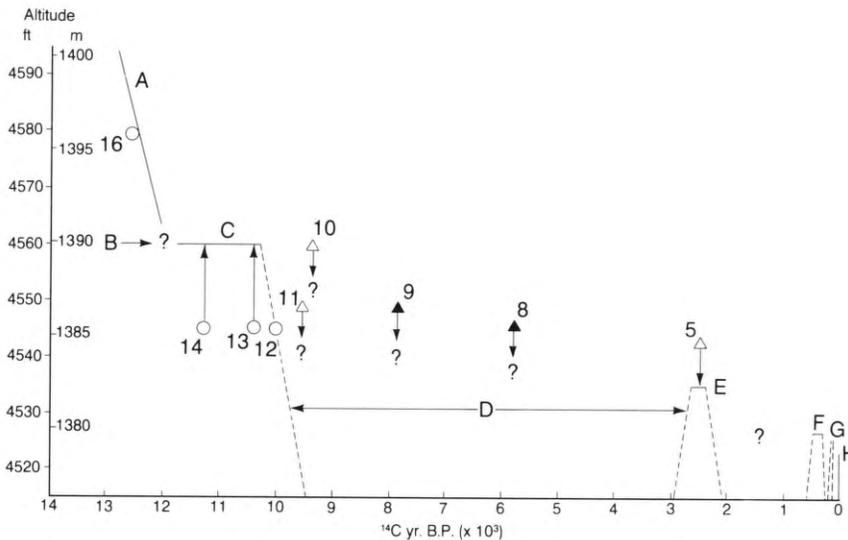


**Figure 12.** Exposure in a stream cut along the north shore of Sevier Lake, about 2.5 mi (4 km) east of locality C (plate 1; table 4). A = late Holocene beach gravel (Qlg<sub>1</sub>); B = massive poorly sorted sand, which is interpreted as lagoon fill or wind-blown sediments. C = weakly developed buried soil formed in post-Bonneville alluvium; D = QTlf exposed at the base of the section. Scale is 3.28 feet (1.0 m) long.



**Figure 11.** Profile across Sevier Lake beaches near Mud Flat Reservoir (locality H; plate 1; table 4). A = early post-Bonneville beach composed of Qlg<sub>1</sub>—beach ridge-crest at 4535 feet (1382.3 m); B = late post-Bonneville beach composed of Qlg<sub>1</sub>—beach ridge-crest at 4527 feet (1379.8 m); C = Sevier Lake level on June 15, 1986, 4522 feet (1378.3 m). D = A.D. 1872(?) high stand; E = A.D. 1984-1985 high stand, both of which produced low sandy beach ridges on the face of B at 4526 (1379.5 m) and 4524 feet (1378.9 m), respectively. Horizontal scale is approximate.

ing Qlg<sub>1</sub>, is similar in degree of development to the post-Bonneville and post-Gunnison soils at slightly higher altitudes in the area. This suggests that both beaches of Qlg<sub>1</sub> were deposited in late Holocene time after the post-Gunnison soil profile had developed near the shore of Sevier Lake (figure 13). Qlg<sub>1</sub> is late Holocene in age as shown in figure 13 and as discussed in the section on Quaternary history.



**Figure 13.** Lake Gunnison and Sevier Lake time-altitude diagram for the last 14,000 years. Open circles indicate radiocarbon dates on shells from lacustrine deposits and numbers are keyed to radiocarbon dates in table 1. The vertical arrows on dates 13 and 14 indicate that the dates are on deposits of Lake Gunnison, which stood at 4560 feet (1390 m). Date 12 is on regressive-phase shore-zone sand of Lake Gunnison. Open triangles indicate radiocarbon dates on shells from alluvial deposits in the Sevier Desert. Solid triangles indicate radiocarbon dates on disseminated organic matter in alluvial deposits in the Sevier Desert. The downward-pointing arrows indicate that in all cases Sevier Lake was below the altitude of the dated alluvial sample at the time the sample was deposited. A = regression of Lake Bonneville from the Provo shoreline. B = postulated unmodified Old River Bed threshold altitude. C = Lake Gunnison overflowing. D = Sevier Lake confined to levels below this altitude (4530 ft; 1381 m) as shown by post-Lake Gunnison soil buried by late Holocene beach gravel. E = early post-Bonneville (about 3000 to 2000 yr B.P.) beach ridge at 4535 feet (1382.3 m). F = well-preserved beach at 4527 feet (1379.8 m); age inferred to be late post-Bonneville (between about A.D. 1400 and 1700?). G = Sevier Lake in A.D. 1872 at about 4526 feet (1379.5 m); from field observations of G. K. Gilbert (1890) and mapping of driftwood beaches by Oviatt (this study). The lake may have been high continuously from about A.D. 1600 until the middle 1870s. H = 20th century high stand of Sevier Lake at 4524 feet (1378.9 m) in 1984-85.

**Lacustrine gravel (late Pleistocene)** — Beach or spit gravel deposited in Lake Bonneville and Lake Gunnison is mapped as Qlg<sub>2</sub> (see the section on Lake Gunnison below under Quaternary history). Only the thickest and most extensive accumulations of lacustrine gravel are shown as Qlg<sub>2</sub> on plate 1. Less extensive accumulations of lacustrine gravel, some of which include well-formed gravel barrier beaches or spits, are lumped with Qla. The best developed barrier beaches are found at the Bonneville and Provo shorelines (figures 8 and 10), but beautifully preserved beaches can be found at almost any level on the piedmont slopes of the basin in favorable geomorphic settings.

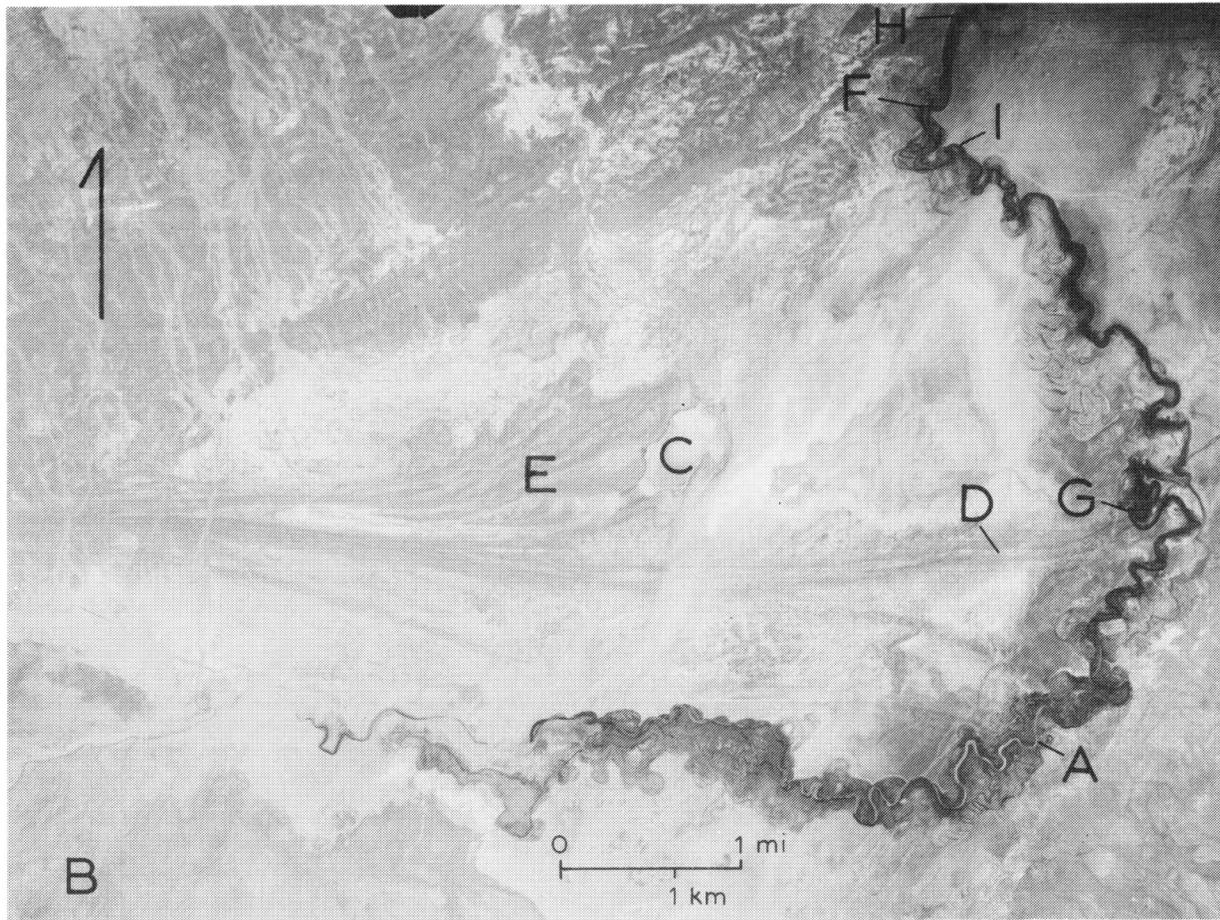
A long spit north of the present shore of Sevier Lake, referred to in this report as Bitterweed spit, has a crestal altitude of 4562 feet (1390 m), and is about 10 miles (16 km) long (figure 14). It was built by long-shore currents moving eastward along the north shore of Lake Gunnison. A radiocarbon date on *Anodonta* shells collected from shallow lacustrine deposits that interfinger with Qlg<sub>2</sub> gravel in Bitterweed spit (locality G; table 4) indicates that Lake Gunnison was overflowing about 10,300 ± 225 yr B.P. (GX-6776; table 1; Curry, 1980b). 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, Provo, and Gunnison 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<sub>2</sub>.

**Alluvial Deposits**

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

**Alluvial-fan deposits (pre-Bonneville)** — Pre-Bonneville alluvial fans are mapped as Qaf<sub>2</sub>. These deposits are composed mostly of coarse-grained debris, and occur in piedmont areas above the Bonneville shoreline. Although most of the material mapped as Qaf<sub>2</sub> was deposited prior to the development of the Bonneville shoreline, Qaf<sub>2</sub> also includes some minor post-Bonneville fan deposits in entrenched channels above the Bonneville shoreline.

**Alluvium (upper)** — The youngest alluvium along the Sevier River is mapped as Qal<sub>1</sub>. These deposits are mostly silt, clay, and sand, and occur in the modern flood plain and in low terraces adjacent to the modern channel. Qal<sub>1</sub> is mapped only near Sevier Lake and northeast of the town of Delta. Although young alluvium is present in intervening reaches of the river, it cannot be easily distinguished from older deposits because the Sevier River does not have a well-defined flood plain in this area.



**Figure 14.** Vertical aerial photograph (VVFS M 8 AMS, no. 599, 6-9-53) showing the following features: A = Sevier River; B = the northeast end of Sevier Lake playa; C = Bitterweed Lake; D = Lake Gunnison segment of Bitterweed spit; E = possible transgressive-Bonneville segments of Bitterweed spit at the same altitude as D; F = locality F (plate 1; table 4); G = locality G (plate 1; table 4); H = locality S (plate 1; table 4); and I = locality T (plate 1; table 4). Scale is approximate.

Qal<sub>1</sub> is late Holocene in age. In 1983, during an unusually wet period when the dam at the Delta (DMAD) Reservoir broke, the Sevier River flooded the entire area encompassed by Qal<sub>1</sub>, as well as a much more extensive area between the two areas mapped as Qal<sub>1</sub>. This suggests that the surface of Qal<sub>1</sub> was part of the active floodplain of the Sevier River prior to the construction of dams and the removal of water for irrigation that began after white settlers moved into the Sevier River drainage basin in the middle 1800s.

Near the point where Highway 50/6 crosses the Sevier River southwest of the town of Delta, Qal<sub>1</sub> is expressed as a terrace that stands about 13 feet (4 m) above the modern Sevier River (locality I, table 4). At locality I, charcoal collected from Qal<sub>1</sub> 4.6 feet (1.4 m) below the surface of the terrace yielded a radiocarbon date of  $690 \pm 90$  yr B.P. (Beta-17879; table 1). Gastropods collected from alluvial mud at locality F (table 4) provide a date on Qal<sub>1</sub> near Sevier Lake of  $2560 \pm 75$  yr B.P. (Beta-17882; table 1). Beta-17882 is older than some of the youngest dates on Qal<sub>2</sub> (table 1), but the two units are mapped separately because of their distinctive geomorphic expressions. Qal<sub>1</sub> is not mapped along the Beaver River; in that area

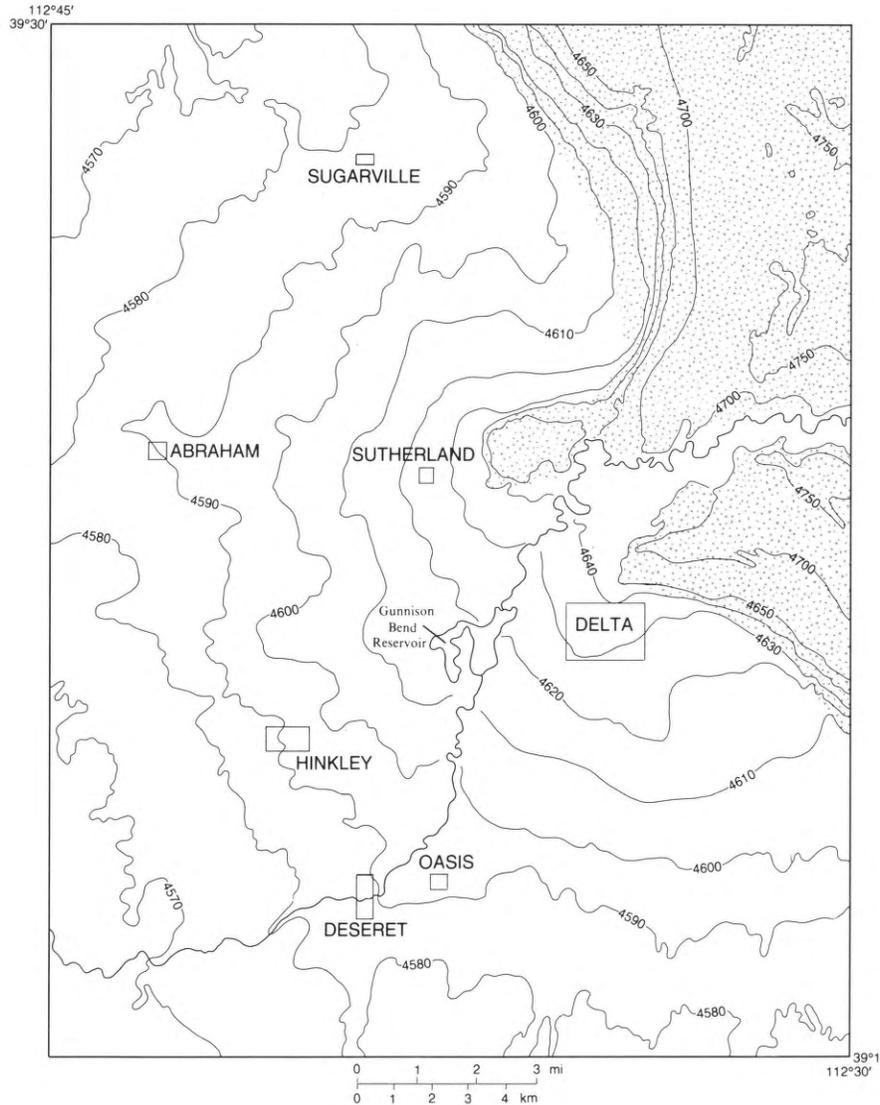
all Holocene alluvial deposits associated with the Beaver River are mapped as Qal<sub>2</sub> because terraces of different ages are difficult to distinguish at a scale of 1:100,000.

**Alluvium (middle)** — Sand, silt, and clay deposited in floodplain, channel, or overbank environments of the Sevier and Beaver Rivers are mapped as Qal<sub>2</sub>. This unit includes organic-rich muds of floodplain marshes, and poorly sorted sandy-mud of floodplains and natural levees. It also includes well-sorted sand and gravel filling paleochannels.

Qal<sub>2</sub> is the map unit that underlies the extensive low-gradient fan of the Sevier River (figure 15). The apex of this fan is directly north of the town of Delta, and the fan slopes north, west, south, and southeast from the apex an average radial distance of about 13 miles (20 km) at an average gradient of about 5 feet per mile (1 m/km). The alluvium in this fan is at least 30 feet (9 m) thick at the apex, and thins to nothing at its extremities. The Beaver River has produced a similar, but less extensive alluvial fan. It slopes with a gradient of 8 feet per mile (1.5 m/km), but the thickness of the alluvial wedge is unknown. In addition, the Beaver River fan covers fewer degrees of arc and is generally coarser grained than the

Sevier River fan. The two fans coalesce in the area north of the Cricket Mountains and west of the Deseret basalt flow. They cannot be easily separated, although obsidian pebbles indicate the presence of Beaver River alluvium because Sevier River gravel contains no obsidian and Beaver River gravel contains abundant obsidian clasts.

channel morphology preserved at the surface. These are depicted on plate 1 as dashed blue lines. Some are represented only by sinuous lines of phreatophytic plants, mostly greasewood bushes (*Sarcobatus vermiculatus*), which send roots deep into the soil and tap ground water in buried sand and gravel that fills the paleochannels (figure 10). Some of these



**Figure 15.** Topographic map of part of the low-gradient alluvial fan of the Sevier River. Light area on the map is underlain by  $Qal_2$  and  $Qal_1$  (see plate 1). Contour irregularities that point down gradient represent former Sevier River or distributary-channel positions on the fan. Stippled area indicates deposits of the late Pleistocene underflow fan ( $Qdf$  and  $Qdg$ ) deposited in Lake Bonneville by the Sevier River, and older alluvial deposits ( $Qal_3$ ).

Paleochannels of the Sevier and Beaver Rivers are evident on the surfaces of the fans, and are shown on plate 1. The channels shown on plate 1 are only a sample of the many channels that have been active on the fans in the past; many have been buried by younger deposits, and farming activities have obscured many channels in the area within about a 6 mile (10 km) radius of the apex of the Sevier River fan.

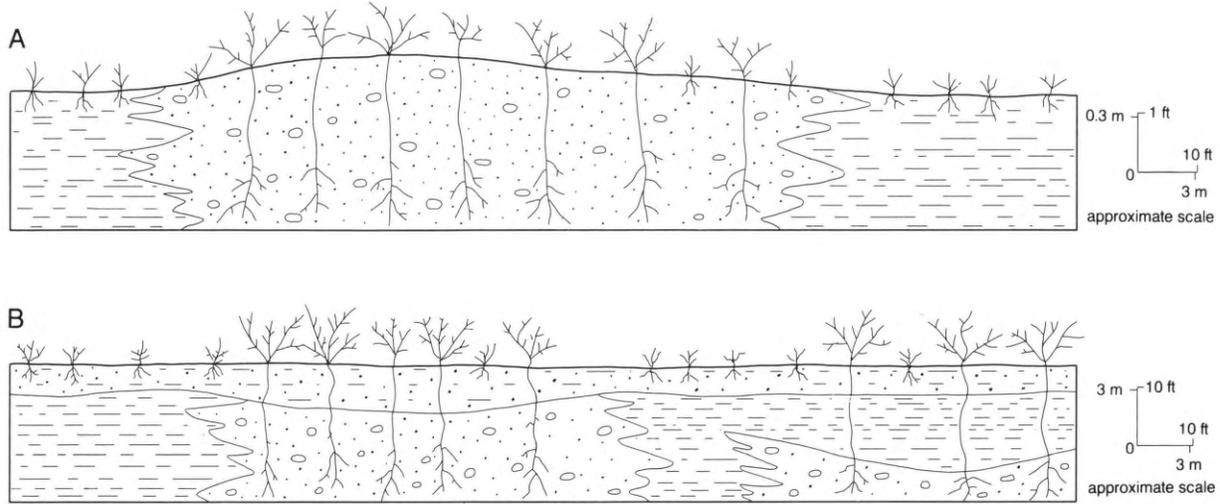
The channels can be grouped into three broad categories, although there is some overlap between the groups. The oldest channels are relatively indistinct, and many do not have clear

buried channels are clearly visible on aerial photographs because of the presence of greasewood bushes, although the strings of greasewood bushes are generally discontinuous and cannot be traced great distances. Some of these paleochannels may be pre-Bonneville in age.

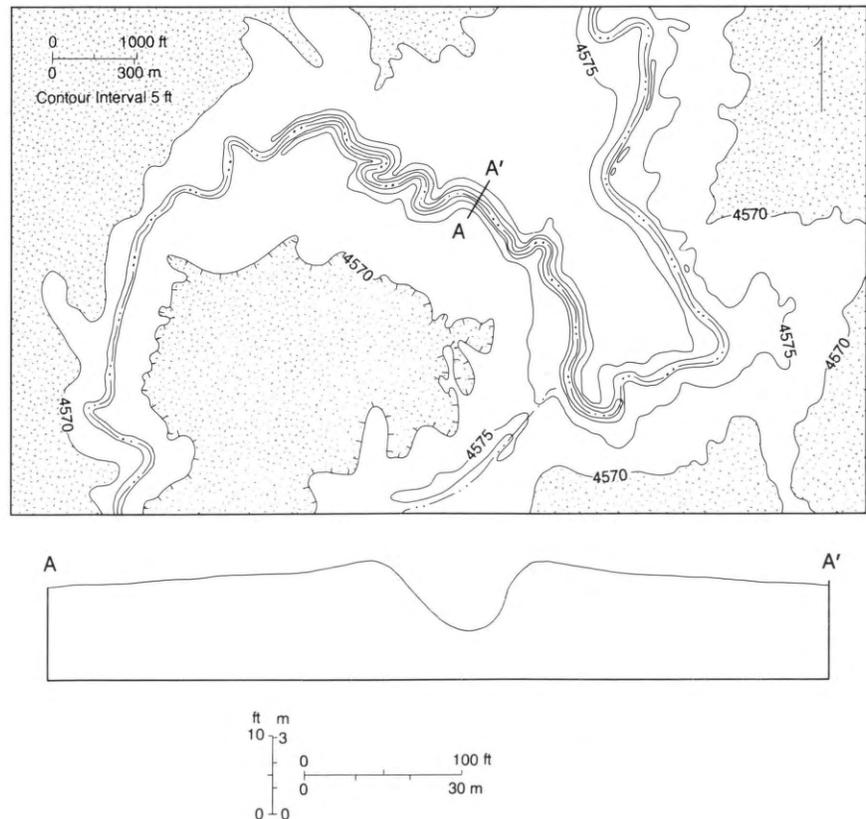
Another way the older channel forms (dashed blue lines) are preserved on the surface of  $Qal_2$  is by topographic inversion (figure 16). In these channels the sand and gravel filling the paleochannel form a lag deposit at the ground surface as the surrounding finer grained sediments are eroded away by sheet

floods and wind deflation. The degradation processes produce sinuous ridges of sand and gravel that stand as much as 1 foot (0.3 m) above the surrounding flat desert surface. The inverted channels are more common at the surface of the Beaver River fan, probably because in general the Beaver River has carried coarser grained alluvium than has the Sevier River.

Generally younger channels are preserved with better topographic expression at the ground surface. In many cases, these channels, which are shown with blue dashed and dotted lines on plate 1, have clear channel form and natural levees that are distinct enough to show up on topographic maps (figure 17).



**Figure 16.** Schematic cross sections through paleochannel deposits in Qal, showing topographic expression and effects on vegetation patterns. Note vertical scale difference between A and B. A. Paleochannel is topographically inverted at ground surface; phreatophytes (mostly greasewood) colonize coarse-grained deposits and tap ground water in paleochannel fill. B. Paleochannels are not topographically expressed at ground surface but are expressed by phreatophytes that tap ground water in coarse-grained channel-fill deposits at depth.



**Figure 17.** Topographic map and profile across abandoned channel of the Sevier River at locality R (plate 1; table 4) showing natural levees. This channel was last occupied by the Sevier River at least 1050 ± 80 yr B.P. (Beta-19717, table 1).

The youngest channels are the modern channels of the Sevier and Beaver Rivers. The Sevier River is shown with a solid blue line because it is perennial through its entire length during most years. The Beaver River is shown as an ephemeral stream because it flows only infrequently.

Qal<sub>2</sub> ranges in age from early to late Holocene, although an unknown component of Qal<sub>2</sub> in the fans of both the Sevier and Beaver Rivers could be pre-Bonneville in age and buried by younger deposits. All available radiocarbon dates have been collected from near-surface exposures and are Holocene (post-10,000 yr B.P.) dates. A radiocarbon date of 9345 ± 160 yr B.P. (Beta-17878; table 1) on gastropods from Qal<sub>2</sub> collected near Gunnison Bend (locality J; table 4) indicates that the Sevier River was actively depositing alluvium in a wet flood-plain setting at this site shortly after the final regression of Lake Gunnison. The alluvium containing the gastropods at locality J is overlain by 5 feet (1.5 m) of poorly sorted eolian silt, clay, and sand (Qed), indicating that most of the clay-dune formation at this site probably began in middle Holocene time. Other early Holocene radiocarbon dates have been obtained on materials from Qal<sub>2</sub> as part of archaeological investigations in an area near the north end of the Cricket Mountains (Simms and Isgreen, 1984; Simms, 1985; table 1). The oldest of these dates is on gastropods and is 9570 ± 430 yr B.P. (Beta-12987; table 1).

A number of middle Holocene radiocarbon dates have also been obtained on Qal<sub>2</sub>. At locality K (table 4), *Sphaerium* sp. shells collected from a small lens of shells 15 feet (4.7 m) below the surface of the Qal<sub>2</sub> terrace yielded a radiocarbon date of 5460 ± 100 yr B.P. (Beta-17880; table 1). This date supports Isgreen's (1986, p. 35-39) suggestion that the "middle stream terrace" of the Sevier River, which was first described by Gvosdetsky and Hawkes (1956) and Eardley and others (1957), is middle to late Holocene in age, rather than late Pleistocene in age. Beta-17880 also indicates that a tremendous amount of deposition (at least 30 feet, 9 m, at locality K, table 4) has taken place on the Sevier River fan during middle and late Holocene time. The Sevier River was apparently an active river carrying a huge load of sediment to the Sevier Desert before it was dammed in historic time.

The youngest available radiocarbon dates on materials from Qal<sub>2</sub> include a date of 1330 ± 70 yr B.P. (table 1; Beta-18270) on gastropods collected near the Deseret fairgrounds (locality L; table 4) 3 feet (1 m) below the terrace surface in the bank of the Sevier River. A date of 1050 ± 80 yr B.P. (table 1; Beta-19717) on the alkali-soluble humic fraction of a sample of organic debris forming a thin mat within natural levee deposits at locality U (table 4) should be considered a minimum limiting date. However, the date gives an estimate of the age of the natural levees and the river channel (see figure 17).

Another date on gastropods of 3600 ± 85 yr B.P. (table 1; Beta-17884) collected near Topaz Slough (locality M; table 4) indicates that there was perennial fresh water at this site, just beyond the distal end of the Sevier River low-gradient fan, in late Holocene times. Numerous other radiocarbon dates on Qal<sub>2</sub> have been obtained for archaeological studies north of Topaz Slough (Simms and Isgreen, 1984). The dates on gastropods from archaeological sites indicate that there were

local areas of wet conditions in the Sevier Desert during the late Holocene (Simms and Isgreen, 1984; Isgreen, 1986). A date of 1540 ± 85 yr B.P. (table 1; Beta-17881) on gastropods collected from fine-grained alluvial fill underlying a low terrace of the Beaver River suggests that the ground-water table was higher in this valley in the late Holocene than it is at present.

**Alluvium (lower)** — Sandy to pebbly alluvium of the pre-Bonneville Sevier River is exposed in small areas north of the town of Delta and is mapped as Qal<sub>3</sub>. The best exposures of Qal<sub>3</sub> are in a long road cut close to the northern boundary of the map area (locality N; table 4). In this road cut the surface deposits are sand, gravel, and marl about 3 feet (1 m) thick, which were deposited in Lake Bonneville (Qlf). The Lake Bonneville deposits overlie alluvial sand and gravel (Qal<sub>3</sub>) containing pebbles of volcanic rocks similar to those in late Pleistocene Sevier River gravels. Silty clay of QTlf is exposed at a few places along the length of the road cut. Therefore, Qal<sub>3</sub> is pre-Bonneville, but post-QTlf in age.

### Deltaic Deposits

**Underflow-fan deposits** — Silt and fine sand in the late Pleistocene (Lake Bonneville) underflow fan of the Sevier 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 primarily during the regressive phase of the lake. At locality O (table 4; figure 7), Qdf overlies the white marl (Qlm), which contains a 0.75 inch (2 cm) layer of basaltic ash that is correlated with Qva. The white marl is 3 feet (1 m) thick at this site, and overlies 3 feet (1 m) of pre-Bonneville marly lacustrine beds, which overlie a buried soil developed in Sevier River sandy alluvium. The white marl is overlain by 66 feet (20 m) of finely bedded silt and fine sand of the regressive-phase underflow fan of the Sevier River (figure 7). Sandy gravel (Qdg) at the top of the section at locality O was deposited by the Sevier River and probably reworked by waves as the lake regressed across the underflow fan surface. Pre-Bonneville and transgressive-phase Bonneville underflow-fan deposits are exposed east and north of the map boundary (Varnes and Van Horn, 1984; Oviatt, 1984; McCoy, 1987), and pre-Bonneville underflow-fan deposits could be present at depth north of the Sevier River but are not exposed at the surface.

The Qdf exposed at locality O is shown to be regressive Bonneville in age by its stratigraphic relationship with the white marl, and with the basaltic ash, which is dated between about 16,000 and 15,300 yr B.P. (Currey and Oviatt, 1985; Oviatt and Nash, 1989). Amino acid ratios of *Ammicola*

shells collected from the base of the white marl at locality O confirm that the marl unit is, in fact, the white marl (Qlm), and not some older lacustrine marl (W. D. McCoy, personal communication, 1986; see the discussion below on Qdf under Quaternary history).

**Deltaic sand and gravel** — Sand and gravel deposited near the mouths of the Sevier and Beaver Rivers during the Bonneville lake cycle are mapped as Qdg on plate 1. In the Sevier River area, Qdg is composed of sandy gravel composed of pebblesized clasts of igneous and sedimentary rocks. The gravel was transported to the front of the delta or underflow fan by the Sevier River and then was reworked by waves during the regression of the lake across the underflow fan surface. Low beach ridges are mapped on the underflow fan surface south of the Sevier River (see arrows on plate 1) where waves transported the sediment laterally away from the river mouth on the

front of the cusped underflow fan. Similar beach ridges may also have been constructed north of the Sevier River, but if they are present they are now obscured by eolian sand.

In the Beaver River area, Qdg both underlies and overlies the white marl (figure 18), and is therefore both transgressive and regressive Bonneville in age. The gravel in the Beaver River area contains a large percentage of obsidian pebbles derived from the Black Rock Desert and the Mineral Mountains to the south.

**Deltaic mud** — Deltaic mud of the Holocene delta of the Sevier River at the northeastern end of Sevier Lake is mapped as Qdm. The mud is fine grained and overlies older lacustrine and playa deposits. This mud delta is small, and suggests that most of the sediment carried by the Sevier River into the basin has been deposited farther east in the low-gradient Sevier River fan (Qal<sub>2</sub>).



**Figure 18.** Vertical aerial photograph (GS-VCMW, 3-241, 10-2-70) of part of the Clear Lake fault zone and adjacent areas. Scale is approximate. A = Sunstone Knoll; B = exposure of Pavant Butte basaltic ash (Qva) in white marl (Qlm); C = paleochannel having inverted topographic expression (compare with figure 10A); D = Qlf; E = Qlf/Qdg; F = Clear Lake fault; G = Highway 257; H = road to Clear Lake Wildlife Refuge; I = fractures or faults in Qpm/Qlf.



**Figure 19.** View north of a basalt boulder on the surface of a small playa north of Pavant Butte. Similar sliding stones and stone tracks have been observed on many playas in California and Nevada and are interpreted as having been moved by wind on the wet playa surface (Sharp and Carey, 1976). In some cases sliding stones are frozen to thin sheets of ice thus facilitating sliding on the playa (Sharp and Carey, 1976).

### Playa Deposits

**Playa mud** — 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 on the Sevier Lake playa, and in a large area of mud flats north of Pavant Butte. In both areas Qpm is thin and may be absent locally. It overlies older lacustrine deposits, such as Qlf and QTlf. Numerous small mud playas surrounded by Qva are present north of Pavant Butte (figure 19). Qpm is Holocene in age.

### Eolian Deposits

**Eolian deposits** — A variety of eolian deposits are mapped as Qed. 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. Well-sorted sand composed mostly of quartz is thin in most areas except where it has accumulated in dunes.

Barchan and parabolic dunes are well developed and active northeast of the town of Delta on the surface of the Sevier River underflow fan (Qdf). In addition, longitudinal dunes oriented in a southwest to northeast direction are prominent features of the landscape in the area southwest of Pavant Butte.

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 Qal<sub>2</sub> or Qlf are deflated by the wind and transported a short distance and deposited in irregular dunes. Clay dunes form best in places where the ground is intermittently flooded, dries out, then 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. Locally Qed includes gypsum dunes on the margins of playas, and some deposits mapped as Qed are gradational in texture to well-sorted sand.

Qed is Holocene in age as shown by its stratigraphic relationship with deposits of Holocene and late Pleistocene age. The well-sorted sand that was locally reworked into Qed was derived from the Sevier and Beaver River deltas and underflow fans.

### Volcanic Rocks

**Ice Springs basalt flow** — The Ice Springs basalt flow (Qvb<sub>1</sub>), which enters the map area only in the extreme southeastern corner, 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 or dust. Hoover (1974, p. 20-26) suggests that the Ice Springs basalt flow was erupted about 1000-4000 yr B.P., and Valastro and others (1972, p. 470) have reported a radiocarbon date of 660 ± 170 yr B.P. (Tx-1166) on root fragments from the soil beneath the lava flow.

**Pavant and Smelter Knolls basalt flows** — A series of pre-Bonneville basalt flows that were referred to by Hoover (1974, p. 13-17) as the Pavant lavas are mapped on plate 1 as Qvb<sub>2</sub>. In most places Qvb<sub>2</sub> is 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 that Qvb<sub>2</sub> may be middle or late Pleistocene in age. Hoover (1974, p. 31-32) suggests that the Pavant lavas were erupted between about 30,000 and 128,000 yr B.P. on the basis of K-Ar dates (table 3). Condie and Barsky (1972, p. 338)

report a K-Ar date of  $220,000 \pm 260,000$  yr B.P. on a sample of Pavant basalt.

A basalt flow south of Smelter Knolls having similar surface morphology and relative age to the Pavant lava flows is mostly covered by fine-grained Lake Bonneville deposits (Qlf). Turley and Nash (1980, p. 3) report a K-Ar date of  $0.31 \pm 0.08 \times 10^6$  yr B.P. on basalt from the Smelter Knolls flow (table 3). Therefore, the Smelter Knolls basalt flow is middle Pleistocene in age. A phreatic explosion crater rimmed by the basalt flow south of Smelter Knolls is younger than the basalt flow but older than the white marl, which is found on the floor of the crater.

**Deseret basalt flow** — An older basalt flow, 5 miles (8 km) south of the town of Deseret, is referred to in this report as the Deseret basalt flow and is mapped as Qvb<sub>3</sub>. The Deseret basalt flow is similar in geomorphic expression to the basalt flows near the railroad siding of Black Rock 20 miles (32 km) south of the map area (figure 1), and to the Crater Bench basalt flows 5 miles (8 km) north of the map area. Best and others (1980, table 1) report a K-Ar date of  $0.4 \pm 0.4 \times 10^6$  yr B.P. (table 3) on the Deseret basalt flow.

Pot Mountain and Sunstone Knoll are also mapped as Qvb<sub>3</sub>, although their ages are not known. Both are composed of mafic volcanic breccia and basaltic flow rocks and are probably volcanic necks from early Pleistocene volcanos. Small bodies of basaltic tuff preserved on Pot Mountain suggest that at least one eruption from this vent occurred under water, if the tuff is interpreted from the point of view of the hydrovolcanic model of Wohletz and Sheridan (1983).

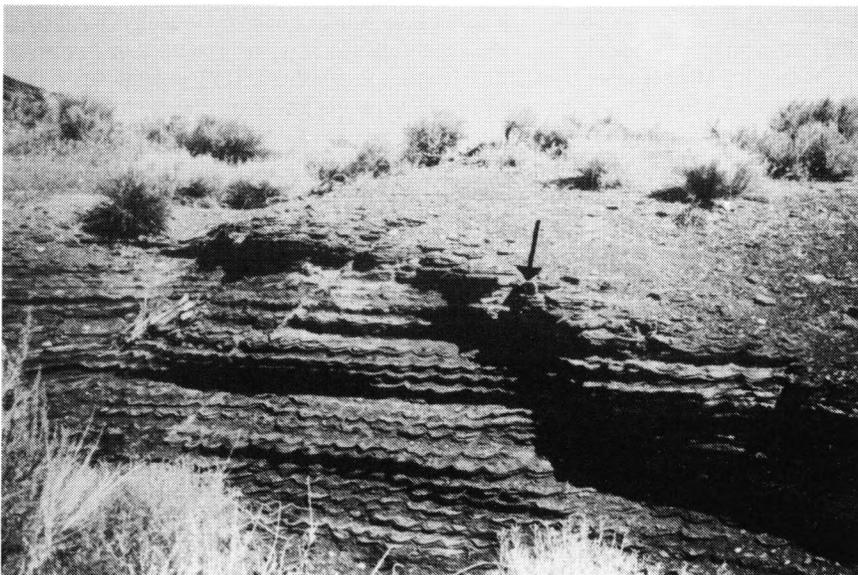
**Pavant Butte basaltic ash** — Basaltic ash erupted from Pavant Butte is mapped as Qva. It consists of loose, fresh to slightly weathered lapilli and ash of black basaltic glass ranging from fine sand to coarse gravel size. Blocks of vesicular basalt, probably derived from the basalt flows below Pavant Butte, are included in the ash where it occurs close to the vent. In localities near Pavant Butte the ash was reworked by waves during the transgressive phase of Lake Bonneville (figure 20),

during the stillstand at the Provo shoreline, and during the post-Provo regressive phase of Lake Bonneville. In post-Bonneville time Qva has been reworked by wind into dunes and sand sheets at the surface in the area north and east of Pavant Butte.

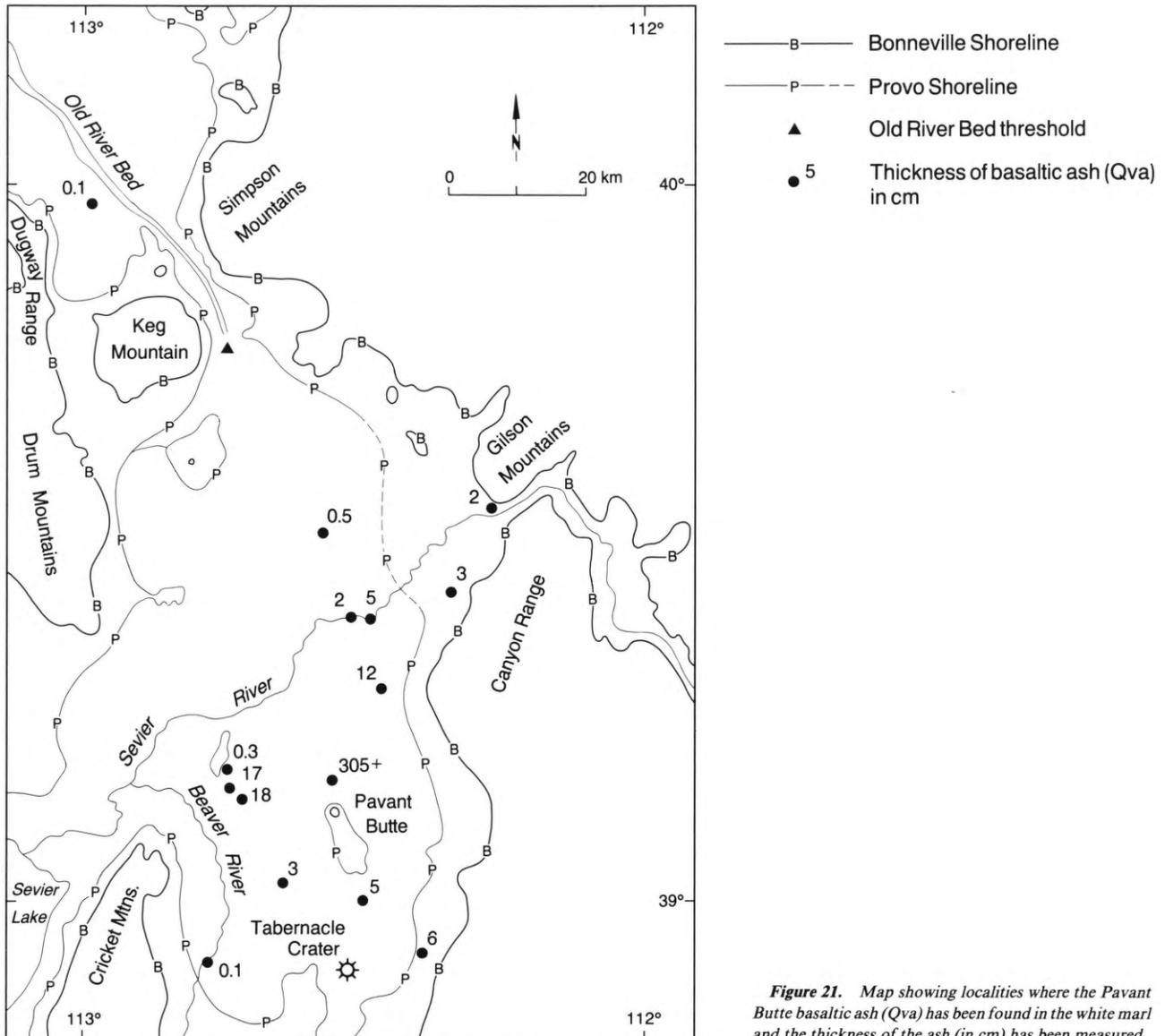
The thickest accumulations of ash are north and east of Pavant Butte, indicating that the wind blew from the southwest during the eruption. In addition, the ash is found as a very thin layer in the white marl (figure 7) as far north as the Old River Bed area, 60 miles (90 km) north of Pavant Butte. But the farthest southwest it has been found interbedded with the white marl is along the Beaver River near the railroad siding of Borden, 15 miles (25 km) southwest of Pavant Butte (Oviatt, 1984; Oviatt and Nash, 1989). The distribution of the ash in the white marl is shown in figure 21. Qva was erupted into Lake Bonneville between about 16,000 and 15,300 yr B.P. (Currey and Oviatt, 1985; Oviatt and Nash, 1989).

**Pavant Butte basaltic tuff** — Basaltic tuff, which comprises the tuff cone of Pavant Butte and which is partially altered to palagonite (Hoover, 1974), is mapped as Qvt. The palagonite is yellow and slightly indurated but friable, and the unaltered tuff is gray to black and also friable. Blocks of basalt, presumably brought up during the eruption from lava flows underlying the tuff cone, 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 occurs at depth below Pavant Butte. Cobbles of granitic rocks in the gravel spits that were constructed by waves in Lake Bonneville on the eastern flank of the cone suggest that the granite clasts were brought up from great depth by the rising magma and therefore they give a clue to the composition of the basement rocks below Pavant Butte.

Qvt is Bonneville in age if the correlation of Qvt with Qva is correct. See the section on Pavant Butte under Quaternary history in this report and Oviatt and Nash (1989) for more information.



**Figure 20.** Ripple-bedded basaltic ash (Qva) exposed in a gully on the east side of Pavant Butte about 30 feet (9 m) below the highest shoreline of Lake Bonneville. The ash in this exposure was reworked by waves in Lake Bonneville during the transgressive phase of the lake. Note Brunton compass (arrow) for scale.



**Figure 21.** Map showing localities where the Pavant Butte basaltic ash (Qva) has been found in the white marl and the thickness of the ash (in cm) has been measured.

**Basaltic cinders** — Basaltic cinders erupted from a volcanic vent south of Pavant Butte are mapped as Qvc. These cinders were noted by Hoover (1974), and represent a pre-Bonneville cinder cone that was largely destroyed by waves in Lake Bonneville. The cinder cone is younger than Qvb<sub>2</sub>, and therefore is middle or late Quaternary 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 information on the pre-Quaternary rocks (Pierce, 1974; Morris, 1978; Turley and Nash, 1980; Hintze, 1984).

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

**Coarse-grained gravel of volcanic origin** — Coarse-grained gravel, including angular to well-rounded boulders up to about 6 feet (2 m) or more in diameter, is exposed in the Little Drum Mountains and in the piedmont east of there. Mapped as Tg, it is the equivalent of the laharic breccia (Tlb<sub>1</sub>) of Pierce (1974), and was mapped as volcanic conglomerate

(Tov<sub>s2</sub>) by Morris (1978). Tg is mostly composed of large clasts of igneous rocks, but includes some clasts of Paleozoic sedimentary rocks, all in a fine-grained matrix. It is interbedded with volcanic rocks of Oligocene age (Pierce, 1974) in the Little Drum Mountains, but it also occurs in small isolated fault blocks east of the mountains, and north of Smelter Knolls (figure 22), where it may be reworked. North of Smelter Knolls Tg is locally overlain by basaltic andesite dated at  $6.1 \pm 0.3 \times 10^6$  yr B.P. (Turley and Nash, 1980, p. 3). Tg, or possibly reworked Tg, is exposed in a small gravel pit about 2 miles (3.2 km) northeast of Smelter Knolls where it is faulted and overlain by Qlg<sub>2</sub> (figure 22).



**Figure 22.** Fault in gravels mapped as Qlg<sub>2</sub>/Tg exposed in gravel pit northeast of Smelter Knolls. The fault is pre-Bonneville in age as shown by overlying unfaulted Bonneville gravels. The vertical gravel face is about 25 feet (8 m) high.

**Basaltic andesite** — Basaltic andesite that occurs in small fault blocks north of Smelter Knolls is mapped as Tb. It has been dated at  $6.1 \pm 0.3 \times 10^6$  yr B.P. (Turley and Nash, 1980, p. 3), and thus is late Miocene in age. The remnants of basaltic andesite flows that are preserved in these fault blocks dip to the east about 15°, and the buried faults between the outcrops of basalt seem to strike parallel to other faults in the Drum Mountains fault zone.

**Rhyolite of Smelter Knolls** — Rhyolite of Smelter Knolls is mapped as Tr and has been dated at  $3.4 \pm 0.1 \times 10^6$  yr B.P. (Turley and Nash, 1980, p. 3). Therefore, the rhyolite is Pliocene in age. Tr probably predates QTlf, but any QTlf that might have been deposited over the rhyolite flow has been eroded away. Well-preserved abrasion platforms of the Provo shoreline are cut into Tr on the north side of Smelter Knolls, and from a distance the rhyolite flows appear to dip about 5° to the east.

**Undifferentiated volcanic rocks** — Undifferentiated Tertiary volcanic rocks of the Little Drum Mountains are mapped as Tv. These rocks are Oligocene in age (table 3) and have been described by Pierce (1974), Leedom (1974), and Lindsey (1982).

**Undifferentiated Paleozoic rocks** — Undifferentiated Paleozoic sedimentary rocks are mapped as Ps. This includes Cambrian rocks in the Cricket Mountains (Hintze, 1984) and the Drum Mountains (Morris, 1978).

## STRUCTURE

### INTRODUCTION

The Sevier Desert basin is a complexly faulted structural basin in the eastern part of the Basin and Range province, and it has 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, 1987; 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 Sevier Desert basin has 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 Sevier Desert are shown in plate 1 and in figure 23.

### DETACHMENT SURFACE AND DEEP STRUCTURE

The Sevier Desert basin is bounded at a depth of 1.2 to 2.5 miles (2-4 km) by a major detachment surface that dips gently westward about 3 to 4 degrees (Allmendinger and others, 1983, 1987; 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 to 20 km; Anderson and others, 1983, p. 1069, figure 8) (see also figure 24 of this report). The main Sevier Desert basin is subdivided at depth into a number of smaller basins. They are separated by listric and planar faults that intersect the detachment surface and die out upward into the sedimentary fill of the main basin

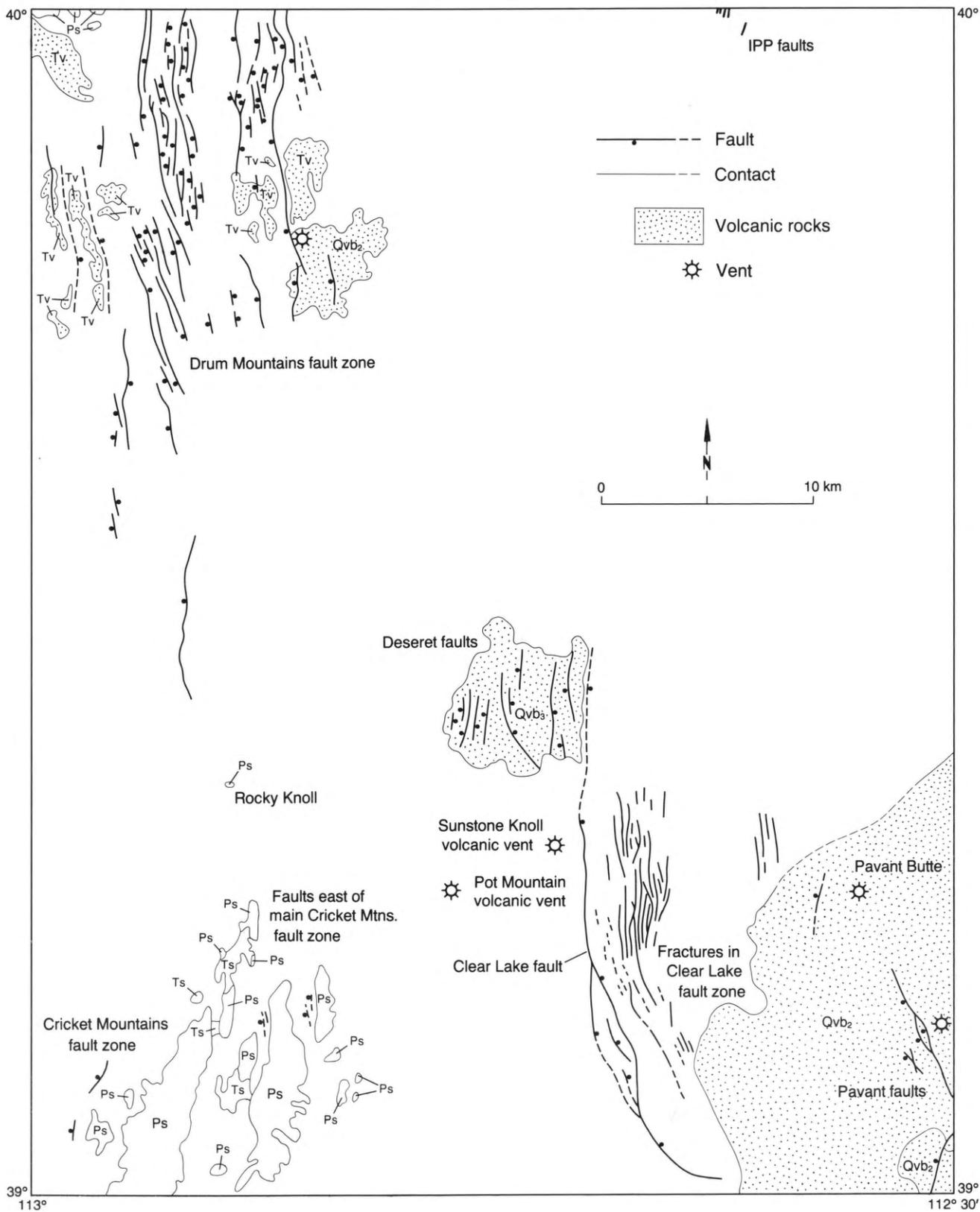
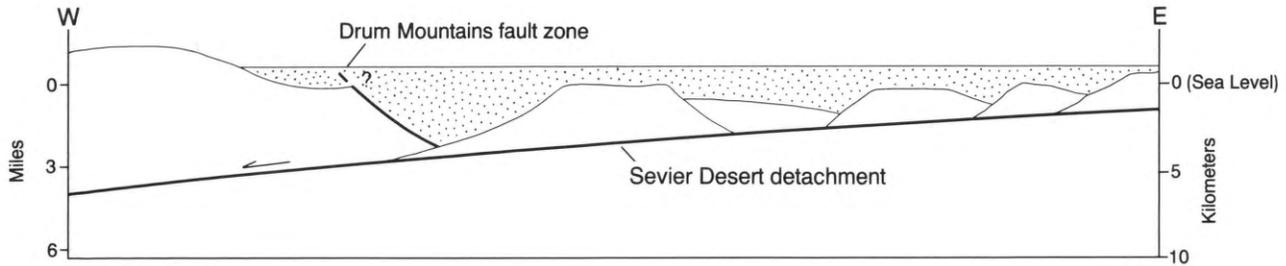


Figure 23. Map showing Quaternary structural and volcanic features in the Sevier Desert (part of area covered in plate 1). Stippled areas show volcanic rocks.



**Figure 24.** Schematic cross section through the Sevier Desert basin in the northern part of the map area (modified considerably after Anderson and others, 1983, figure 8). Faults shown are diagrammatic only and are not intended to represent actual structures. Possible relationship between Drum Mountains fault zone and underlying structures is indicated. Stippled pattern shows basin-fill deposits of Cenozoic age.

(Allmendinger and others, 1983; Anderson and others, 1983, p. 1065-1066) (see also figure 24 of 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).

The structural influence of a sequence of Oligocene salt and other evaporites, which are locally greater than 5000 feet (1600 m) thick in the Sevier Desert basin (Mitchell, 1979; Lindsey and others, 1981), is unknown (Anderson and others, 1983). Some of the faults that cut Quaternary deposits at the ground surface could be related to subsidence caused by salt flowage at depth, but at present it is not possible to make such connections with confidence. Anderson and others (1983, p. 1066) think that the major deep extensional structures above the Sevier Desert detachment could form independent of the influence of salt deformation.

## QUATERNARY FAULTS

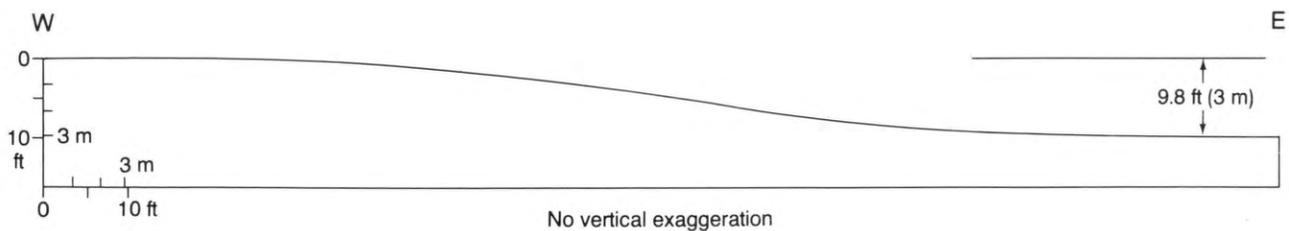
### Introduction

Quaternary fault scarps in the Sevier Desert have been mapped by Bucknam and Anderson (1979a) and Anderson and Miller (1979), and have been studied by a number of people whose work is described below. The locations and ages of the faults shown in plate 1 and in figure 23 differ in a few cases from those shown by previous authors. These differences are discussed below in the appropriate paragraphs.

**Clear Lake fault zone** — A broad zone of fractures and normal faults about 2.5 miles (4 km) wide, west of Clear Lake Springs, is referred to as the Clear Lake fault zone. The Clear Lake fault (Bucknam and Anderson, 1979a) is the largest and westernmost fault in the fault zone. It has a curved trace about 12 miles (19 km) long. Displacement on the Clear Lake fault is at least 9.8 feet (3 m) (figure 25), and the fault cuts Lake Bonneville deposits (Qdg and Qlf). Therefore, the fault has been active in post-Bonneville time but probably is a much older structure (Crone and Harding, 1984).

A swarm of fractures in Qpm and Qlf west of Clear Lake, which was not mapped by Bucknam and Anderson (1979a), is considered part of the Clear Lake fault zone (figure 18). The fractures are clearly visible on aerial photographs but are less obvious on the ground. Displacements on the fractures are unknown but are probably small, and the sense of displacement is difficult to determine without more detailed study, so on plate 1 the bar and ball symbol is not used. A morphologically similar group of fractures in deposits mapped as Qpm/Qlf near Mud Springs, north of Clear Lake, is parallel to the fractures farther west and is probably related genetically.

Unpublished seismic data cited by Crone and Harding (1984) show that the Clear Lake fault intersects the Sevier Desert detachment surface at a depth of about 2.2 miles (3.5 km). Currey (1982, p. 26-28) presents data that suggest that at least some of the vertical displacement in the Clear Lake fault zone may be due to subsidence into a magma chamber beneath Pavant Butte and the other middle and late Quaternary volcanos and basalt flows in the Pavant, Ice Springs, and Tabernacle fields. The highest Lake Bonneville shoreline and the Provo shoreline are anomalously low on Pavant Butte, as compared



**Figure 25.** Topographic profile across the Clear Lake fault scarp at locality Q (plate 1; table 4) measured with a hand level and rod. Apparent vertical displacement is 9.8 feet (3 m) across fault, but net stratigraphic displacement has not been determined.

to measured altitudes of these features on surrounding mountain ranges (Currey, 1982; Bills and May, 1987). On Pavant Butte the highest shoreline is 56 feet (17 m) lower than expected, and the Provo shoreline is 33 feet (10 m) lower than expected based on regional mapping of these shorelines and interpolation of altitudes to Pavant Butte (Currey, 1982, p. 26-27). Pavant Butte was erupted between 16,000 and 15,300 yr B.P. (Currey and Oviatt, 1985; Oviatt and Nash, 1989), and both the Ice Springs and Tabernacle Hill volcanic fields have been active in post-Bonneville time (Gilbert, 1890; Hoover, 1974). Some of the negative isostatic anomaly at Pavant Butte observed by Currey (1982) may be due to magma-chamber subsidence beneath Pavant Butte and some may be due to isostatic loading by volcanic rocks at the surface (Bills and May, 1987).

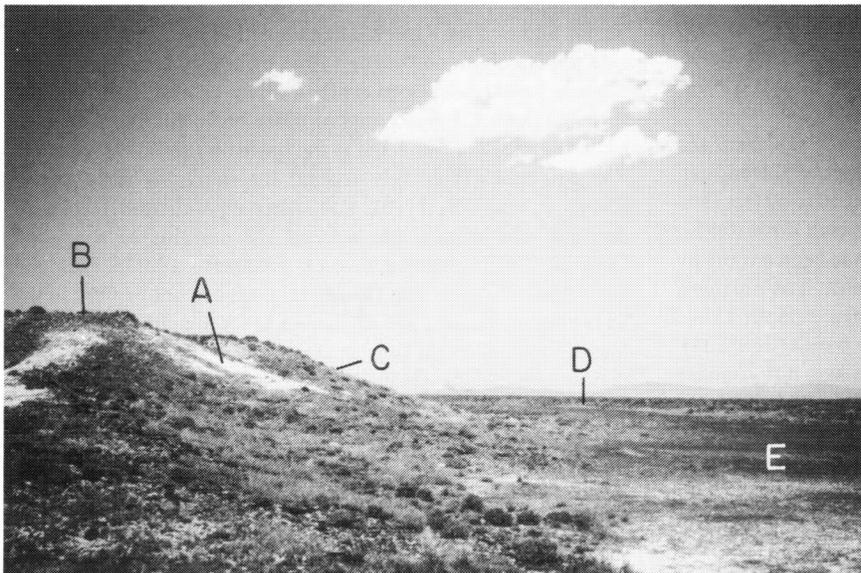
**Drum Mountains fault zone** — The Drum Mountains fault zone has been discussed by Bucknam and Anderson (1979a; 1979b), Crone (1983), Colman and Watson (1983), Crone and Harding (1984), Hanks and others, (1984), Sterr (1985), and Pierce and Colman (1986). Within the area of plate 1 the fault zone is 20 miles (32 km) long and 6 miles (10 km) wide, and the fault zone extends north of the northern boundary of plate 1 to Crater Bench (Bucknam and Anderson, 1979a). The faults are roughly parallel to each other and to the eastern front of the Drum Mountains and the Little Drum Mountains. Many of the faults are paired, and consist of major faults and antithetic faults with small grabens in between (figure 26). Fault scarps range in height from 2.3 to 24 feet (0.7 to 7.3 m) (Crone, 1983; Crone and Harding, 1984).

The faults cut late Pleistocene and Holocene deposits (Q<sub>1m</sub>, Q<sub>1a</sub>, Q<sub>1g2</sub>, Q<sub>1k</sub>, and Q<sub>1f</sub>), and are therefore late Pleistocene or Holocene in age. Crone (1983) presents evidence that the last surface-faulting event on one of the faults occurred in early Holocene time. Other estimates of the age of the faults range from 4800+yr B.P. (Colman and Watson, 1983), to 3600-5700 yr B.P. (Hanks and others, 1984), to about 9000 yr B.P. (Pierce and Colman, 1986, p. 883).

A seismic profile across the Drum Mountains fault zone indicates that some subsurface faults do not extend to the surface and are not expressed by scarps (Crone and Harding, 1984). The seismic profile does not extend deep enough to show the relationship between the surface faults and the deep structures in the basin (i.e., the Sevier Desert detachment surface), but such a relationship seems likely (Crone and Harding, 1984) (see also figure 24).

The major faults in the Drum Mountains fault zone are down-dropped to both the east and west, and there is no consistent pattern to indicate the net displacement across the fault zone. Although it is tempting to think of the Sevier Desert basin as a downthrown block and the Drum Mountains as an upthrown block because of their relative altitudes, it is more likely that the Drum Mountains fault zone represents displacement on the gently west-dipping Sevier Desert detachment. Thus, the Drum Mountains block is part of a much larger fault block or plate that is moving westward and slightly downward, as suggested by the data of Allmendinger and others (1983) and Anderson and others (1983) (see also figure 24). The topographically lowest part of the Sevier Desert on the west side of the basin is near the area showing the greatest amount of recent deformation. These observed topographic and structural patterns are consistent with the model of displacement on a low-angle detachment in the Sevier Desert.

The southernmost fault in the Drum Mountains fault zone (plate 1; figure 23), which was not mapped by Bucknam and Anderson (1979a), is downdropped to the west. It trends west of the small outcrop of Paleozoic quartzite (Prospect Mountain Quartzite ?) at Rocky Knoll, and toward the Cricket Mountains fault zone, in which the faults apparently are steep and are downdropped to the west on the eastern side of a major graben (Case and Cook, 1979). Therefore, the Drum Mountains fault zone and the Cricket Mountains fault zone are along approximately the same line of strike. The fault zones intersect in the topographically low area where the Sevier River crosses the common line of strike.



**Figure 26.** View north of fault scarps in the Drum Mountains fault zone. A = QT<sub>1f</sub>; B = Q<sub>1a</sub>; C = the main fault scarp, which faces east and is opposed by a lower west-facing scarp (labelled D) formed along an antithetic fault. E = the graben between the faults is filling with slope wash and reworked QT<sub>1f</sub> derived from small badland areas that have developed along the main scarp. The main scarp at this locality is slightly less than 20 feet (6 m) high.

**Cricket Mountains faults** — Faults along the western piedmont of the Cricket Mountains are referred to as the Cricket Mountains fault zone. These faults were mapped by Bucknam and Anderson (1979a) but have not been studied in detail. The fault scarps in this fault zone are less than 6 feet (2 m) high, and are short (less than 0.5 mi; 0.8 km). The faults cut Q1a both above and below the Provo shoreline (figure 8), and therefore are late Pleistocene to Holocene in age. The Cricket Mountains fault zone is coincident with the east Sevier Lake fault zone, as defined from gravity data by Case and Cook (1979), and marks the eastern side of the Sevier Lake graben.

Two other areas of faulting east of the Cricket Mountains fault zone have also been mapped by Bucknam and Anderson (1979a), but the age of the faults is not clear. These two areas are indicated on figure 23 and are near locality P (table 4). The faults at these localities are covered by thin Lake Bonneville gravels (Q1a) and are therefore pre-Bonneville in age. They appear to mark the boundary between the Paleozoic Prospect Mountain Quartzite and the Quaternary valley fill in two small fault blocks adjacent to the main Cricket Mountains fault block. The faults could be as young as late Pleistocene in age (Bucknam and Anderson, 1979a; Anderson and Miller, 1979). Alternatively, the scarps may be fault-line scarps exposed by wave erosion in Lake Bonneville, and thus could be much older (Tertiary ?) structures.

**Pavant faults** — Several faults in Qvb<sub>2</sub> south of Pavant Butte are referred to in this report as the Pavant faults. The faults were mapped by Hoover (1974, p. 37) as part of the "Black Rock fault zone." He referred to the main fault in this zone as the Devils Kitchen fault after Condie and Barsky (1972). The faults trend northwesterly toward Pavant Butte. The faults are pre-Bonneville in age, and fine-grained Lake Bonneville (Q1f) deposits locally overlie the fault scarps. The Devils Kitchen fault scarp is overlapped by the Ice Springs basalt flow (Qvb<sub>1</sub>), which is not offset by the fault.

The faults mapped north of Pavant Butte by Hoover (1974) could not be relocated. Most of the dark-colored deposits north of Pavant Butte, which were mapped as basalt flows by Hoover (1974, figure 4), are volcanic ash (Qva), and the only exposed basalt is in a small area northeast of Pavant Butte. The features interpreted as fault scarps by Hoover (1974) might be eolian dunes.

**Deseret faults** — A number of pre-Bonneville faults cut the Deseret basalt flows. The faults are generally north trending, and have displacements on the order of about 10 to 50 feet (3 to 15 m). The eastern boundary of the Deseret basalt flows (Qvb<sub>3</sub>) is abrupt and straight, possibly because it has been cut off by the northern extension of the Clear Lake fault. The northern end of the well-defined Clear Lake fault scarp is about 1 mile (1.6 km) south of the southeast corner of the basalt (figure 23). The Deseret faults are all pre-Bonneville in age, but younger than the basalt flows which are early to middle Pleistocene in age.

**IPP Faults** — A swarm of small faults or fractures along the northern boundary of the map area near the Intermountain Power Plant (IPP) are referred to here as the IPP faults. The faults cut pre-Bonneville alluvial deposits (Qal<sub>3</sub>) and the Plio-

Pleistocene lake beds (QT1f). Anderson and Miller (1979) have indicated that the faults are middle to late Pleistocene in age. The relationship between these faults and the underlying structures is unknown.

## QUATERNARY HISTORY

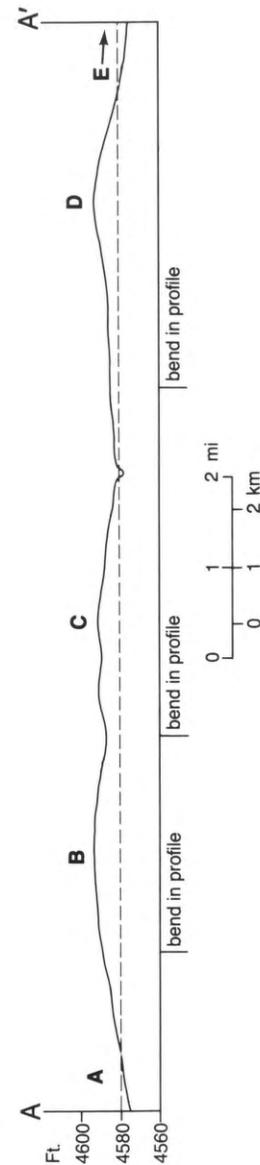
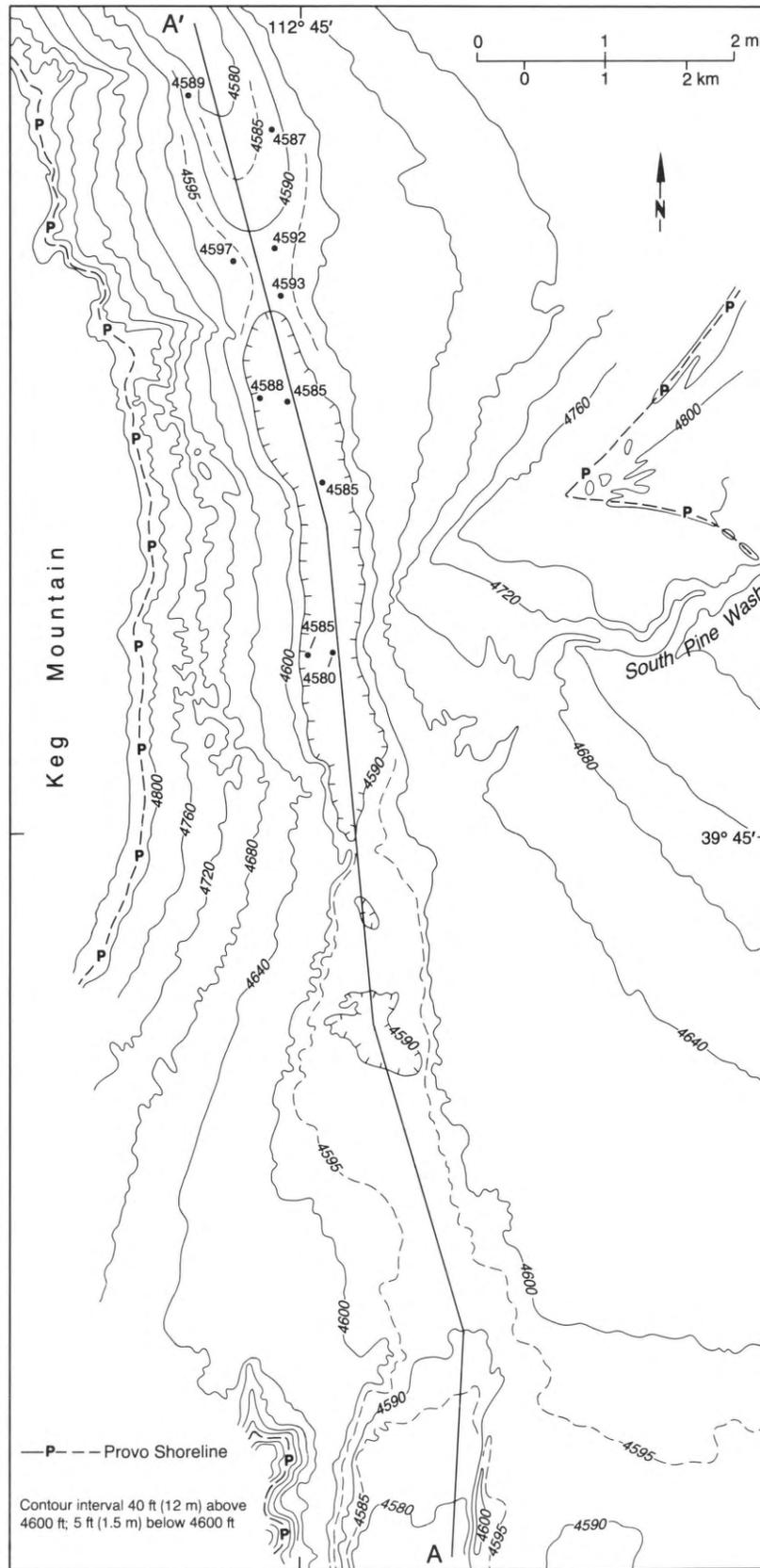
### INTRODUCTION

The Quaternary history of the part of the Sevier Desert encompassed in plate 1 is briefly outlined below. Some episodes and aspects of that history, particularly the lacustrine history, are known better than others and are discussed in greater detail. In addition, the data collected in this project have allowed for a reinterpretation or refinement of previously published ideas on certain aspects of the Quaternary geology of the Sevier Desert. Therefore, the discussion that follows is not strictly a running narrative of the Quaternary events in the Sevier Desert for the last 1.6 million years, but is punctuated by more lengthy discussions of the better known or controversial events. The reader should refer to figures 2, 3, and 13 for chronological guidance through this section.

### OVERVIEW

Extensional tectonism began in the Sevier Desert region between about  $20 \times 10^6$  and  $7 \times 10^6$  yr B.P. (Lindsey, 1982). The Sevier Desert basin can be characterized as dominantly spreading or opening, rather than as subsiding or down-dropping due to the nature of movement on the low-angle Sevier Desert detachment described above (Allmendinger and others, 1983, 1987; Anderson and others, 1983).

Certain generalizations can also be made about the sedimentation history in the Sevier Desert basin during the Neogene and Quaternary. The depositional pattern in the Sevier Desert is complex and is characterized by the following features. (1) Quaternary sedimentation has been concentrated in local depocenters such as the delta and fan systems of the Sevier and Beaver Rivers. The deposition rates in these depocenters has changed through time primarily as a function of climate, and the depocenters themselves have shifted spatially through time. (2) Remnants of older basin-fill deposits were stranded in piedmont areas as the basin opened and deepened. The Miocene (?) gravels around the flanks of the Canyon Range (Campbell, 1979), and other alluvial and lacustrine deposits of Neogene age around the margins of the basin (Hintze, 1980), attest to this. (3) Extensive alluvial fans and bajadas of Pliocene and Quaternary age are not present in the Sevier Desert basin. The piedmont areas are characterized by locally thick alluvial fans separated by broad pediment-like surfaces cut on fine-grained lake beds (QT1f) and mantled with a thin cover of coarse-grained alluvium. This suggests that tectonic relief and uplift have not been extreme during at least the Pliocene and Quaternary. (4) During the middle and late Pleistocene the Sevier Desert basin has been generally degrading as shown by the following: (a) early Pleistocene basalt flows stand on pedestals of basin-fill deposits as at Deseret,



**Figure 27.** Topographic map and profile of the Old River Bed threshold — the lowest point on the drainage divide of the Sevier Desert basin — located about 20 miles (30 km) north of the northern boundary of plate 1. The map and profile suggest that the late Pleistocene altitude of the threshold was less than 4580 feet (1396 m) by an unknown amount during the overflowing stage of Lake Gunnison. The threshold has been uplifted an unknown amount by post-Bonneville isostatic rebound and infilled by alluvial fans, which locally exceed 15 feet (4.6 m) in thickness. A = Sevier Desert basin; B = alluvial fan of unnamed washes from west; C = alluvial fan of South Pine Wash; D = alluvial fan of Judd Creek and Erickson Wash; E = arrow points in direction of outflow along Old River Bed to Great Salt Lake Desert. Dashed line in profile is drawn at 4580 feet (1396 m) for reference. Topography from U.S.G.S. 7.5-minute quadrangles: Erickson Wash SW, Keg Mountain Ranch, The Hogback, and Crater Bench Reservoir.

Black Rock (south of the map area), and Crater Bench (north of the map area); and (b) widely spaced deposits (QTlf) of Pliocene and Pleistocene age are exposed throughout the basin, including on the floor of the basin. Therefore, although some areas have received a heavy sediment load in the late Quaternary, 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. The Old River Bed threshold lies along the trend of the Drum Mountains fault zone, and faults or fractures in Quaternary deposits have been mapped in the threshold area (Pampeyan, 1984; Oviatt, unpublished field notes). Therefore, as the basin opens the threshold is also deformed and tends to be lowered. The threshold may have been initially located between the Simpson Mountains and the Slow Elk Hills, about 12 miles (19 km) north of its present position (figures 1 and 27). However, the threshold has apparently migrated southward and become lower in altitude through time as the Sevier Desert lakes overflowed into the Great Salt Lake basin.

The process of overflow has contributed to the threshold lowering and to the degradation of the basin floor. Erosion by fluvial currents at the threshold has caused it to be lowered. Waves in the shallow middle and late Pleistocene lakes would have effectively eroded the fine-grained basin-fill sediments, which were then transported by suspension in fluvial currents to the Great Salt Lake basin through the Old River Bed pass. This process produced the yellow clay underflow fan during the Bonneville episode north of the Old River Bed threshold (Oviatt, 1984; Oviatt, 1987a), and probably was active during other overflow periods of the middle and late Pleistocene. Another way that basin degradation has occurred is through wind deflation, although the rate of this process is unknown.

If the rate of threshold lowering is faster than the rate of subsidence of Sevier Lake graben as defined by gravity surveys (Case and Cook, 1979), the Sevier River eventually will be permanently diverted into the Great Salt Lake basin through the Old River Bed area. This is most likely to occur during some future major lacustrine episode.

Several major changes in the drainage area of the Sevier Desert basin during the late Tertiary and Quaternary have been suggested in the literature. 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 Desert 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. Another change in the configuration of the drainage basin came when the Beaver River became a permanent tributary to the Sevier Desert basin between about 750,000 and 500,000 yr B.P. (Machette, 1985).

#### Early Pleistocene

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  $2.02 \times 10^6$  to  $0.74 \times 10^6$  yr B.P., the ages of the Huckleberry Ridge and Bishop ashes, respectively, which are interbedded with the clay. Steven and Morris (1984, p. 14) present evidence that the Plio-Pleistocene lake was in existence prior to  $3 \times 10^6$  yr B.P. In Bishop ash time, the lake was shallower than in Huckleberry Ridge ash time. Bishop ash is present in a small depression on top of the Black Rock basalt flow (Izett, 1982) south of the map area at an altitude of 4925 feet (1500 m) and is found interbedded with QTlf within and just north of the area of plate 1 at altitudes of 4525 feet (1379 m) and 4560 feet (1417 m), respectively, indicating that the lake surface was at an intermediate altitude when the ash was deposited. The ostracodes collected at locality A (table 4) also suggest relatively shallow-water deposition at this time (R. M. Forester, personal communication, 1987). During Bishop ash time, the lake in the Sevier Desert was fresh, and therefore overflowing. But in the Great Salt Lake basin Bishop ash is found in shallow-lake deposits in deep cores (Eardley and Gvosdetsky, 1960; Eardley and others, 1973), and in alluvium at an altitude of approximately 4660 feet (1420 m) in the Promontory Range (Nash and Smith, 1977) indicating that the lake in that basin was lower in altitude and was not overflowing (Oviatt and Currey, 1987). Therefore, the hydrologic balance in the Sevier Desert basin during the deposition of QTlf was considerably different than at present, and the climate may have been generally 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 complete reconstruction of the paleohydrology and paleoclimate of the early Pleistocene in the Sevier Desert basin is not yet possible.

#### Middle Pleistocene

The middle Pleistocene history of the Sevier Desert basin, from Bishop ash time until the deposition of the Little Valley Alloformation, is poorly known. It is likely that during this interval a number of lakes existed in the basin, but few lacustrine deposits of this age have been identified because of the dominantly erosional environment throughout most of the basin. The Little Valley Alloformation, which was deposited during a major lake cycle near the end of middle Pleistocene time (140,000 yr B.P.; Scott and others, 1983; McCoy, 1987), has been identified within the area of plate 1 only at locality O (table 4; figure 7). However, underflow fan deposits of Little Valley age are present east of the map area (see the discussion below on Lake Bonneville under Quaternary history). At locality O, pre-Bonneville lacustrine marl contains *Ammicola* shells that have yielded alioisoleucine/isoleucine (aIle/Ile) ratios in the total hydrolysate averaging 0.36 (AGL-521; W. D. McCoy, personal communication, 1987). These ratios are

slightly high but fit well within the range of  $alle/Ile$  ratios on *Ammicola* shells from Little Valley deposits collected elsewhere in the Bonneville basin (McCoy, personal communication, 1987; McCoy, 1987). Deposits representing open-water environments during the Little Valley Lake cycle must have been widespread in the Sevier Desert but apparently had been largely eroded away prior to or during the transgression of Lake Bonneville.

### 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 Sevier Desert are discussed below. Recent refinements in the chronology and stratigraphy of Lake Bonneville (Scott and others, 1983; Spencer and others, 1984; Currey and Oviatt, 1985; McCoy, 1987; Oviatt, 1987a) call for a reassessment of some of the previous stratigraphic work that has been carried out in the Sevier Desert, and permit some of the depositional units and geomorphic features within the area of plate 1 to be placed in a broader context relative to Lake Bonneville. See Currey and Oviatt (1985) for an outline of the history of Lake Bonneville.

**Transgressive phase** — The transgressing Lake Bonneville in the Great Salt Lake basin did not reach the level of the Old River Bed threshold on the divide of the Sevier Desert basin until about 21,000-20,000 yr B.P. (figure 2). However, a shallow freshwater lake must have been overflowing from the Sevier Desert basin for a long period prior to this (figure 2) because the ratio of evaporative output (as indicated by lake-surface area) to surface inflow in the Sevier Desert basin was relatively small, allowing the basin to fill to overflowing long before the Great Salt Lake basin could fill to the Old River Bed threshold altitude. There is some geomorphic and stratigraphic evidence that this in fact did occur. Bitterweed spit, which was deposited in part during the regressive-phase overflowing stage (Lake Gunnison; figures 2 and 13; see discussion below), also has a transgressive-phase depositional component (figure 14). The spit has a recurved digitate distal end, the longest segment of which was deposited in Lake Gunnison (see below), but which also includes some transgressive-phase segments. At locality C (table 4) the white marl overlies spit gravel near the proximal end of the Bitterweed spit complex at an altitude of approximately 4560 feet (1390 m), and has been radiocarbon dated at  $19,920 \pm 230$  yr B.P. (table 1, radiocarbon date 17). This is the same altitude as the Lake Gunnison segment of the spit and suggests that if the transgressive-phase spit gravel at locality C was deposited in an overflowing (threshold-controlled) lake, as seems likely, the Old River Bed threshold altitude was the same during the transgressive and regressive phases of Lake Bonneville. Therefore, the threshold altitude is shown as a horizontal line in figure 2.

**High lake stages** — The Lake Bonneville time-altitude curve for the Sevier Desert basin above the altitude of the Old River Bed threshold is the same as that for the main body of the lake (figure 2), and the best-documented evidence for some segments of that curve comes from the Sevier Desert basin. Spe-

cifically, stratigraphic evidence for the Keg Mountain oscillation, a noncatastrophic drop in lake level from the overflowing stage at the Bonneville shoreline prior to the Bonneville flood (Currey and others, 1983; Oviatt, 1984), has been found at Keg Mountain, and possibly locality P (table 4). See the discussions under Qls in the section on description of map units.

**Qdf** — Some important exposures of Bonneville and pre-Bonneville deposits have been described by Varnes and Van Horn (1961; 1984) east of the area of plate 1. Some of these deposits extend into the area of plate 1 in the vicinity of locality O (table 4; figure 7). Varnes and Van Horn (1984) have mapped marl and basaltic ash, which are correlative with my Qlm and Qva, respectively, as “Alpine” in age about 2 miles (3 km) east of locality O. In addition, they have mapped the deposits that I refer to as Qdf as “Alpine” silt and sand.

However, my interpretations differ from theirs (Varnes and Van Horn, 1984) in several ways. First, their data do not support the correlation of Qdf with the Alpine Formation of Hunt and others (1953). The Alpine Formation was originally defined as the depositional record of an early Wisconsin-age lake (about 70,000-30,000 yr B.P.) that rose to an altitude within 90 feet (27 m) of the Bonneville shoreline (Hunt and others, 1953; Morrison, 1966). Later Morrison (1975) suggested that the Alpine Formation was Illinoian in age. However, at section D56 and at another (unnamed) section of Varnes and Van Horn (1984), radiocarbon dates of  $15,100 \pm 400$  (L-711B) on ostracodes and  $14,500 \pm 400$  (L-774F) on gastropods, both of which are stratigraphically close to the basaltic ash (Qva), indicate that the marl that contains the fossils and the ash are not Alpine in age, as they have mapped them, but are Bonneville in age. Thorium-230 dates of  $13,600 \pm 1400$  and  $14,700 \pm 1000$  yr B.P. on shells collected from the same location as L-774F (Varnes and Van Horn, 1984; Kaufman and Broecker, 1965, table 4), although less precise and less reliable than the radiocarbon dates, help to confirm this. All deposits overlying the marl and the basaltic ash, including the silt and sand that I map as Qdf, and which they map as the “Alpine” Formation, must therefore be Bonneville in age or younger.

A second way that my stratigraphic interpretations differ from those of Varnes and Van Horn (1984) is that the Alpine Formation is now an ambiguous stratigraphic term, and that several authors have recently recommended that it be abandoned (Scott and others, 1983; Currey and others, 1984; McCoy, 1987; Oviatt, 1987a). The early or middle Wisconsin-age lake in the Bonneville basin reached a maximum altitude of only 4400 feet (1340 m) in the Great Salt Lake basin (Oviatt and others, 1987). It probably was represented in the Sevier Desert basin by a shallow overflowing lake below an altitude of about 4600 feet (1400 m). Deposits formerly mapped as Alpine elsewhere in the Bonneville basin are now regarded as either Bonneville in age or as much older. The older deposits are now named the Little Valley Alloformation (Scott and others, 1983; McCoy, 1987). Pre-Bonneville lacustrine deposits of probable Little Valley age (about 140,000 yr B.P.), as well as Bonneville-age deposits, are exposed at locality O and upstream along the Sevier River east of the eastern boundary of plate 1. This is shown by several lines of evidence.

First, Varnes and Van Horn (1984) reported  $^{230}\text{Th}$  dates of 140,000 yr B.P. (L-1005A) and  $108,000 \pm 23,000$  yr B.P. (L-711A) on gastropods and ostracodes, respectively, from a calcareous clay unit that they mapped as "Alpine" marl (Qam), and correlated it with the marl containing the basaltic ash in other exposures. A radiocarbon date on sample L-711A of greater than 32,000 yr B.P. (Varnes and Van Horn, 1984; Broecker and Kaufman, 1965) helps to confirm the  $^{230}\text{Th}$  dates. Therefore, it is likely that the calcareous clay is part of the Little Valley Alloformation and that the suggested correlation with the marl containing basaltic ash is in error. The marl mapped as "Alpine" by Varnes and Van Horn (1984) does not contain basaltic ash.

Second, at Varnes and Van Horn's (1984) measured section R-17, east of the area of plate 1, a new amino acid analysis on *Ammicola* shells collected from the calcareous clay that was mapped as "Alpine" marl (Qam), also shows that the calcareous clay is likely to be Little Valley in age. The alloseuleucine to isoleucine (alle/Ile) ratio in the total hydrolysate of shells in this sample is 0.41 (AGL-519; W. D. McCoy, personal communication, 1987), which is slightly high, but within the range of samples of Little Valley age (140,000 yr B.P.).

Third, new amino acid analyses help confirm the suggestion of Oviatt (1984) that there is only one marl unit that contains basaltic ash, and that there is only one ash, in contrast to the interpretation of Varnes and Van Horn (1984), who suggest that two ashes are present. At locality O (table 4; figure 7) *Ammicola* shells from the base of the marl unit that contains the basaltic ash, which I correlate with the white marl (Qlm), have alle/Ile ratios in the total hydrolysate that average about 0.16 (AGL-520; W. D. McCoy, personal communication, 1987). This average ratio shows the marl and the basaltic ash to be Bonneville in age and helps to confirm the validity of radiocarbon dates L-711B and L-774F and the  $^{230}\text{Th}$  dates labelled L-774F, which are discussed above. The average of all five radiocarbon dates on samples associated with the basaltic ash in this area is 15,300 yr B.P. (Currey and Oviatt, 1985), with a standard deviation of about 220 years. This average must be considered a minimum because the radiocarbon dates are on gastropods or ostracodes, but the low standard deviation suggests that there is a high probability that there is only one basaltic ash. In addition, there is no published evidence for two ashes exposed in stratigraphic sequence at a single locality.

Therefore, Varnes and Van Horn (1984) have mapped deposits of two distinctly different ages as the Alpine Formation. Although the Qdf shown in plate 1 is lithologically similar to deposits that have traditionally been mapped as the Alpine Formation, in an allostratigraphic sense (North American Commission on Stratigraphic Nomenclature, 1983; Currey and others, 1984; Oviatt, 1987a) the Qdf exposed at locality O (table 4) and in nearby areas should be considered part of the Bonneville Alloformation. Silt and fine-sand would have been deposited by the Sevier River in underflow fans in this area during every episode in which Pleistocene lakes happened to be within the suitable altitudinal range, including during both the transgressive and regressive phases of those lake cycles. The underflow-fan facies is thus unsuitable as a marker bed for

stratigraphic correlations, especially if exposures are not continuous over long distances. In contrast, the basaltic ash, which has been repeatedly dated at about 15,300 yr B.P., which occurs in a consistent stratigraphic position in the white marl (Oviatt, 1984), which has been traced to its eruptive source (Oviatt and Nash, 1989; see below under Pavant Butte), and which is isochronous, is an ideal stratigraphic marker. Stratigraphic analyses based on the correlation of a volcanic ash that occurs in different facies allow documentation of dynamic sedimentation patterns and accurate reconstructions of geologic history.

The stratigraphic units exposed at and near locality O (table 4) show through logical extension that the Sevier River had a different course during the transgressive phase of Lake Bonneville than it has at present. To review, four major lithologic units are exposed at locality O. They are from lowest to highest, pre-Little Valley Sevier River alluvium, Little Valley open-water marl, Lake Bonneville open-water marl (the white marl), and Lake Bonneville regressive-phase underflow-fan deposits (figure 7). The deposition of the underflow-fan facies requires the Sevier River to be close by, supplying large volumes of fine sediment. The deposition of the marl facies requires the Sevier River to be emptying into the lake at some distant point or else the marl would be overwhelmed with fine clastics. The Little Valley marl is not associated with either transgressive-phase or regressive-phase underflow-fan deposits, and the Bonneville marl rests directly on the Little Valley marl, not on a transgressive-phase underflow fan. However, underflow-fan deposits of Little Valley and transgressive-Bonneville age are present elsewhere in this area (see discussion above; Oviatt, 1984; McCoy, 1987). Therefore, locality O was not near the mouth of the Sevier River during the Little Valley lake cycle nor during the transgressive phase of the Bonneville cycle. The river probably had a course almost due west of the town of Lynndyl instead of turning south at Lynndyl, as it has in post-Bonneville time. The post-Bonneville course of the river where it is entrenched into underflow-fan and alluvial deposits was established during and shortly after the Bonneville flood and during the relatively rapid regression from the Provo shoreline.

**Provo and post-Provo** — Lake Bonneville overflowed at Red Rock Pass in southern Idaho for a long, but poorly dated episode during which the Provo shoreline was formed (Gilbert, 1890; Currey and Oviatt, 1985). In the Sevier Desert the Provo shoreline as a morphostratigraphic unit is typical in its geomorphic and stratigraphic expression to occurrences elsewhere in the Bonneville basin. Typical characteristics include broad flat abrasion platforms on exposed headlands, such as on the north side of Smelter Knolls and at the north end of the Cricket Mountains; well preserved barrier beaches, spits, and tombolos, such as the huge double tombolo on the west side of Smelter Knolls; and thick deposits of marl and sand (Qlk) below the shoreline representing offshore deposition during the long stillstand.

Shore-zone and offshore facies of the Provo stage are found stratigraphically above the white marl showing that the Provo shoreline was formed after the Bonneville flood during the regressive phase of Lake Bonneville, as Gilbert (1890) noted.

In many exposed stratigraphic sections of the white marl a distinctive layer of marl can be interpreted as representing deposition during and shortly after the Bonneville flood (Oviatt, 1987a). Depending on local geomorphic conditions the character of the flood layer ranges from almost pure ostracodes to a mixture of ostracodes and reworked marl, to slightly oxidized and laminated sandy marl. The Pavant Butte basaltic ash (Qva), which was erupted into the lake prior to the Bonneville flood (Currey and Oviatt, 1985), is helpful in identifying the flood layer because the ash occurs consistently a few inches (centimeters) below the sharp lithologic break that marks the initiation of the flood. During and after the flood, fine lacustrine sediment was washed into the lake from the sides of the basin that were exposed almost instantaneously to subaerial processes. In the center of the basin during the stillstand at the Provo shoreline deep-water sedimentation reequilibrated and "normal" deep-water marl was again deposited. However, just offshore from the Provo shoreline, thick deposits of marl, reworked marl, tufa, and other carbonate-rich sediments accumulated.

During the Bonneville flood and the Provo stillstand the Sevier River reworked a large volume of transgressive-phase Bonneville and pre-Bonneville underflow fan deposits to form a segmented underflow fan that was accentuated in its cusped form during the subsequent noncatastrophic regression from the Provo shoreline. Terrace scarps on the surface of the underflow fan near the mouth of the Sevier River (plate 1) indicate short-lived stillstands of the regressing lake. A wave-cut notch on the western face of the underflow fan north of Delta, and a prominent sand and gravel spit southeast of the Sevier River, both at an altitude of 4700 feet (1430 m), suggest a short-lived stillstand of the lake during the regressive phase. This shoreline is one of many strandlines that formed during the regression from the Provo shoreline, all of which are weakly developed and indicate that the regression was relatively rapid. The regressing lake had reached an altitude of 4580 feet (1396 m; uncorrected for isostatic rebound) by about  $12,490 \pm 130$  yr B.P. (Beta-8348; table 1; Isgreen, 1986).

With the exception of one controversial locality east of the map area (section R17 of Varnes and Van Horn, 1984), there is no evidence for the Draper Formation (Morrison, 1965) in the Sevier Desert.

### Lake Gunnison

Following the long period of relatively stable water level in Lake Bonneville during the development of the Provo shoreline and the subsequent rapid drop in lake level below the Provo shoreline (figure 2), Lake Bonneville continued to regress in the Great Salt Lake basin, but a shallow freshwater lake developed in the Sevier Desert basin. Bitterweed spit, the 10-mile-long (16 km) spit at the northeast end of Sevier Lake (figure 14), was deposited in part at the shore of a regressive-phase lake that must have maintained a nearly constant water level for a long period of time. In a closed basin a lake is unlikely to maintain a constant water level for long periods because the water level is dependent on the instantaneous

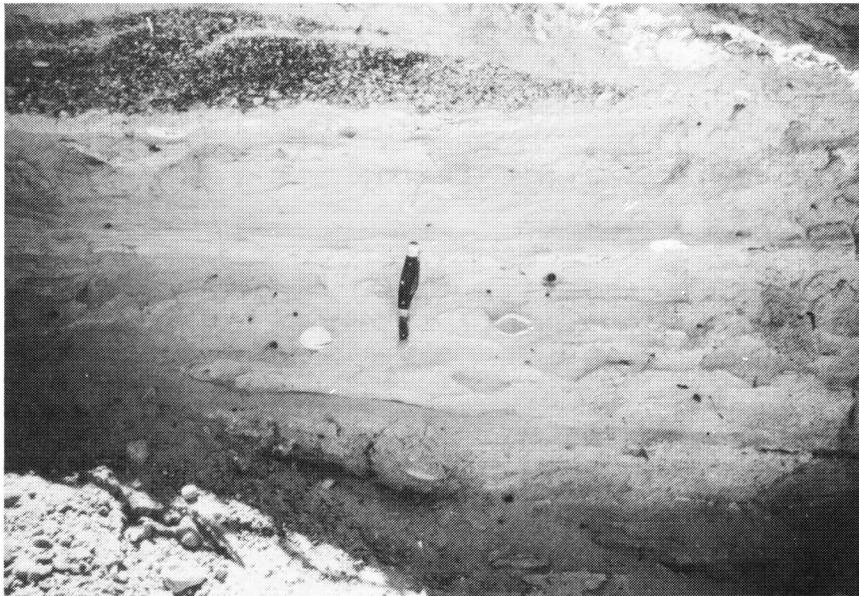
balance between the inputs, outputs, and storage of water in the lake basin. However, in an open basin lake the water level is largely controlled by the altitude of the overflow threshold. Only relatively minor changes in lake level can occur in an overflowing lake and waves are therefore able to produce strongly developed landforms in the shore zone.

An overflowing lake was postulated by Gilbert (1890, p. 183-184) to explain the abandoned river channel called the Old River Bed that leads from the Sevier Desert to the Great Salt Lake Desert (figures 1 and 16). According to Gilbert (1890, p. 183-184) the lake in the Sevier Desert continued to overflow into the lake in the Great Salt Lake Desert during the regression of Lake Bonneville because the lake in the Sevier Desert basin had a smaller surface area relative to inflow volume, and therefore could maintain a positive water balance. Gilbert did not identify beaches of the postulated lake in the Sevier Desert, but Currey (1979, personal communication) noted Bitterweed spit on aerial photographs and topographic maps and suggested that it probably marked the level of the last overflowing lake in the Sevier Desert basin. In subsequent reconnaissance investigations (Oviatt, 1979, unpublished field data; Currey, 1982) the beach, of which Bitterweed spit is a part, has been mapped around the perimeter of Sevier Lake. The overflowing lake that produced the beach has been named Lake Gunnison (Oviatt, 1979, unpublished; Currey and James, 1982, p. 34) after John Williams Gunnison, who was killed by Indians near locality J (table 4) on October 26, 1853 while leading an expedition to explore Sevier Lake.

Lake Gunnison had a surface altitude near 4560 feet (1390 m) as shown by the altitude of the prominent beach, which occurs at a consistent altitude around Sevier Lake (Currey, 1982) and includes Bitterweed spit. The Old River Bed threshold (figure 27) at the northern end of the Sevier Desert, north of the map area, has a modern altitude of about 4590 feet (1399 m). However, the late Pleistocene altitude of the threshold during the overflow of Lake Gunnison was less than this. The threshold has been isostatically rebounded an unknown amount more than the Lake Gunnison beaches at Sevier Lake, and Holocene alluvial fans have partially filled in the saddle at the threshold (Currey, 1982). Logs of two shallow auger holes drilled for this study in the alluvial fan of South Pine Wash (figure 27) showed that the fan sediments are at least 15 feet (4.6 m) thick, although it was not possible to determine the depth of the contact between the fan sediments and the underlying older deposits. The minimum-thickness data from the auger holes and the longitudinal topographic profile (figure 27) indicate that the modern (rebounded) altitude of the Lake Gunnison threshold is below 4580 feet (1396 m) by an unknown amount. More detailed work at the threshold will be required to further constrain its rebounded altitude.

The available radiocarbon dates (dates 12, 13, and 14 in table 1) and geomorphic and stratigraphic evidence suggest that Lake Gunnison overflowed continuously from about 12,000 to 10,000 yr B.P. (figures 13 and 28). However, during this same time period Lake Bonneville regressed to a level below the modern level of Great Salt Lake and then transgressed again to form the Gilbert shoreline about 10,000 yr

B.P. (figure 2; Currey and Oviatt, 1985). The contrasting histories in the two basins could be interpreted as evidence that the Sevier Desert basin is far more hydrologically sensitive to climatic changes than is the Great Salt Lake basin, but this conclusion would not be consistent with what is known about the late Holocene history of Sevier Lake and the Great Salt Lake (see below). Alternatively, it is possible that during the interval from 12,000 to 11,000 yr B.P., when Lake Bonneville was very low but Lake Gunnison was overflowing, the atmospheric circulation patterns were considerably different than during the late Holocene. For instance, during the time period in question, the high plateaus of southern Utah, which are drained by the Sevier and Beaver Rivers, could have been wet compared to the Wasatch and Uinta Mountains of northern Utah, which are drained by tributaries of the Great Salt Lake (Oviatt, 1988).



**Figure 28.** *Anodonta shells in ripple-laminated sand that was deposited at the distal end of a spit in Lake Gunnison and exposed in a cut-bank of the Sevier River at locality S (plate 1; table 4). These, and other Anodonta shells collected at this locality, yielded a radiocarbon date of  $11,270 \pm 110$  yr B.P. (Beta-17883; table 1).*

Lake Gunnison was a shallow freshwater lake that probably was fringed by extensive marshes on its eastern and southeastern margins. Stratigraphic evidence for the postulated marshes has not yet been discovered because any such deposits would be buried beneath Holocene alluvium of the Sevier and Beaver Rivers. Marsh deposits of Lake Gunnison age are likely to contain undisturbed early Holocene archaeological sites and therefore are potentially valuable sources of information on the early human history of western Utah. Archaeological sites of post-Lake Gunnison age are abundant in the Sevier Desert (Simms and Isgreen, 1984).

### Sevier Lake

Following the regression of Lake Gunnison, the Sevier and Beaver Rivers deposited large quantities of fine-grained alluvium in broad low-gradient fans in the Sevier Desert (Qal<sub>2</sub>). The oldest radiocarbon date so far obtained on Qal<sub>2</sub> ( $9570 \pm 430$  yr B.P.; Beta-12987; table 1; Simms, 1985) is on gastropod shells collected from an altitude of 4549 feet (1385 m), which is

below the overflow altitude of Lake Gunnison. This date, plus a large number of other Holocene radiocarbon dates on alluvial deposits in the Sevier Desert, indicates that there has been no overflowing lake in the Sevier Desert during post-Lake Gunnison times (post 10,000 yr B.P.; figure 7). Sevier Lake was limited to levels below about 4530 feet (1381 m) from about 10,000 to 3,000 yr B.P. (figure 13). The low levels of Sevier Lake during the middle Holocene are consistent with the record from the Great Salt Lake basin (Currey and James, 1982).

The late Holocene history of Sevier Lake based on the mapping of beach deposits (Qlg<sub>1</sub>) and other data is summarized below. No radiocarbon dates have yet been obtained on Qlg<sub>1</sub>, but a radiocarbon date on gastropods from Qal<sub>1</sub> about 9 miles (14 km) upstream along the Sevier River from the shore of Sevier Lake (locality F; table 4; figure 14) is inferred to

indicate the time of deposition of the higher beach of Qlg<sub>1</sub> (figure 13). At locality F, fine-grained alluvium of the Sevier River underlies a terrace that slopes with a gentle gradient toward Sevier Lake. The lowest mappable point on the terrace, near the shore of Sevier Lake, has an altitude of slightly less than 4535 feet (1382 m), which is very close to the altitude of the higher beach of Qlg<sub>1</sub>. Therefore, I suggest that the Sevier River was graded to Sevier Lake at a time when the lake stood at an altitude near 4535 feet (1382 m), then the lake water backed up along the entrenched river channel, causing the deposition of fine-grained sediment at locality F. Gastropods collected 3 feet (1 m) below the terrace surface at locality F yielded a radiocarbon date of  $2560 \pm 75$  yr B.P. (Beta-17882; table 1). Therefore, if this reasoning is correct, the higher beach of Qlg<sub>1</sub> was deposited during a transgression of Sevier Lake of late Holocene age (about 3000 to 2000 yr B.P.; Currey and James, 1982).

The lower beach of Qlg<sub>1</sub> has not been dated but is inferred to have been deposited during late post-Bonneville time (during about the last 500 years; figure 13). The Great Salt Lake

experienced several high stands between about A.D. 1400 and 1850 (Willet, 1977, p. 120; Currey and James, 1982, p. 41; McKenzie and Eberli, 1985, p. 33). The lower beach of Qlg<sub>1</sub> at Sevier Lake is inferred to have been formed at this same time because the drainage basins of the two lakes are within the same modern precipitation regimes (Kay, 1982, figure 1), and because the lakes seem to have behaved in a parallel fashion during other episodes of the late Holocene.

Lines of driftwood deposited by waves on the northeastern shore of Sevier Lake near the mouth of the Sevier River are slightly below the lower gravel beach of Qlg<sub>1</sub> and probably date from the mid-1800s (figure 13). The driftwood includes sticks of greasewood and other desert shrubs, but also includes large logs of cottonwood (?) and juniper (?) that had to have been derived from upstream along the Sevier River. All the logs are weathered and the outer layers are shredded from the growth of salt crystals, but the interiors of the logs are still relatively fresh. Most of the logs are short (less than 6 feet, 2 m, in length), and many of them have scars from ax cuts. Therefore, the driftwood was deposited after white settlers had arrived in the Sevier River drainage basin (middle 1800s) and had begun cutting trees. The lake was high in 1872 (Gilbert, 1890, p. 225), and it is likely that the driftwood was deposited at that time or somewhat earlier.

From 1880 until 1983 there was little or no water in Sevier Lake except for a thin film during a few unusually wet years (Gilbert, 1890, p. 225; Whelan, 1969). In 1983 the lake began to fill and in 1984 or 1985 it reached its highest level in over 100 years. A substantial gravel beach was deposited at 4524 feet (1378.9 m) in 1984 or 1985 (figure 29), and the lake still had a surface altitude of 4522 feet (1378.3 m) on June 15, 1986 (figure 13).

### Holocene Alluvium

The history of Holocene alluvial activity has been reviewed briefly above under Qal<sub>1</sub> and Qal<sub>2</sub>. Although it is tempting to draw paleoclimatic conclusions from the available radiocarbon dates on Holocene alluvium (Simms and Isgreen, 1984; Isgreen, 1986), such conclusions may not be valid in detail because of the poorly understood dynamics of the Sevier and Beaver Rivers. In regional mapping for this project, it has become apparent that channel avulsions occurred frequently on the low-gradient fans of the Sevier and Beaver Rivers during the Holocene. As a result, certain parts of the Sevier Desert could have been periodically flooded while other parts remained relatively dry simply as a function of the positions of the river channels. In a dynamic alluvial setting such as this the effects of climate would be difficult to extract from the stratigraphic record because of the conflicting effects of other variables. Until the geomorphic processes active in the Sevier and Beaver Rivers have been studied, paleoclimatic inferences based on the alluvium of these rivers should be viewed critically. Stratigraphic and process geomorphology must be combined to understand the Holocene history.

However, despite this disclaimer, certain general depositional patterns can be summarized for the Sevier River that may be related to climate changes during the Holocene. During the early Holocene, the Sevier River was actively depositing sediment in its distal reaches in the area north of the Cricket Mountains. In the middle Holocene, however, the depocenters shifted upstream. For example, much of the low-gradient alluvial fan of the Sevier River (figure 15) was deposited during the middle Holocene. In contrast, the alluvial plain of early Holocene age north of the Cricket Mountains was



**Figure 29.** View south along the shore of Sevier Lake at locality A (plate 1; table 4) showing a gravel barrier-beach in the foreground (with a wooden pole resting on its crest). This beach was deposited in 1984 or 1985, and has closed off the mouth of a small ephemeral wash, however, on August 6, 1988 a large thunderstorm caused enough discharge in the ephemeral-stream basin to overtop and breach the barrier. Bishop ash is exposed in the bluffs of QTlf along the shore south of the beach. Photo, July, 1986.

entrenched during the middle Holocene. By the late Holocene, the Sevier River had entrenched its low-gradient fan near the fan head and had begun aggrading its lower reaches depositing Qal<sub>1</sub>. In historic time the Sevier River has become entrenched and large floods rarely occur because dams and reservoirs have been constructed upstream.

Paleohydrologic interpretations can be drawn for the Sevier River from the patterns outlined above. The deposition in distal reaches during the early Holocene could be interpreted as being due to generally perennial flow conditions with relatively infrequent large floods and moderate sediment load. The middle Holocene, on the other hand, may have been characterized by lower mean annual discharge, and more frequent high-magnitude floods that carried huge volumes of sediment to be deposited primarily in the low-gradient fan. Channel avulsions occurred frequently with the large floods. The lower reaches of the Sevier River became entrenched because most of the sediment was dropped out upstream. Large floods and channel avulsions apparently continued into the late Holocene, but a significant proportion of the water and sediment discharge made it to the lower reaches, so that Sevier Lake periodically filled with water and the river channel was aggraded. Thus a general wet-dry-wet sequence can be reasoned for the Sevier Desert during the Holocene. With further work, higher frequency changes in the river system during the Holocene could be documented and the paleoclimatic suggestions of Simms and Isgreen (1984) and Isgreen (1986) could be tested.

### Volcanic Eruptions

**Basalt flows** — Basaltic eruptions have occurred periodically within the area of plate 1 from late Tertiary times to the late Holocene (Condie and Barsky, 1972; Hoover, 1974; Best and others, 1980; Turley and Nash, 1980). Refer to table 3 for

information on the ages of the volcanic rocks. Basalt flows of late Tertiary age include the faulted andesitic basalt near Smelter Knolls (Tb) and a basaltic lava flow encountered in a drill hole east of Smelter Knolls (Lindsey and others, 1981). Basaltic rocks of early Pleistocene age include the Deseret basalt flow and the vent-facies rocks at Pot Mountain and Sunstone Knoll. Middle Pleistocene basaltic rocks include the basalt flow south of Smelter Knolls and the Pavant flows. Basalt of the Ice Springs flow is the youngest volcanic rock in the map area.

**Rhyolite** — The only exposed rhyolite within the area of plate 1 is the Smelter Knolls rhyolite flow of late Tertiary age (Tr; table 3).

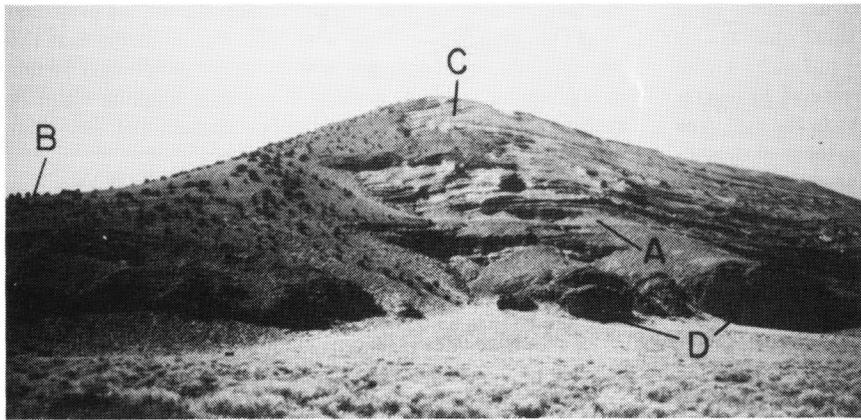
**Pavant Butte** — Pavant Butte is a basaltic tuff cone formed during a hydrovolcanic eruption into Lake Bonneville. Pavant Butte was initially studied by Gilbert (1890, p. 325-329), who described the geology of the tuff cone and its age relative to his interpretation of Lake Bonneville history. More recently the tuff cone has been studied by Hoover (1974, p. 13-16), Wohletz and Sheridan (1983), and Oviatt and Nash (1989).

Gilbert (1890, p. 327) discussed the bedding of the palagonitized tuff in the tuff cone. He showed how the tuff beds dip parallel to the slope in both directions away from the main ridge of the cone in antiformal style (figures 9 and 30). Some initial dips on the tuff beds are as great as 40° and must have been close to the angle of repose at the time of their deposition. Numerous small faults and folds within the palagonitized tuff indicate that the tuff was probably slumping actively as it was being deposited.

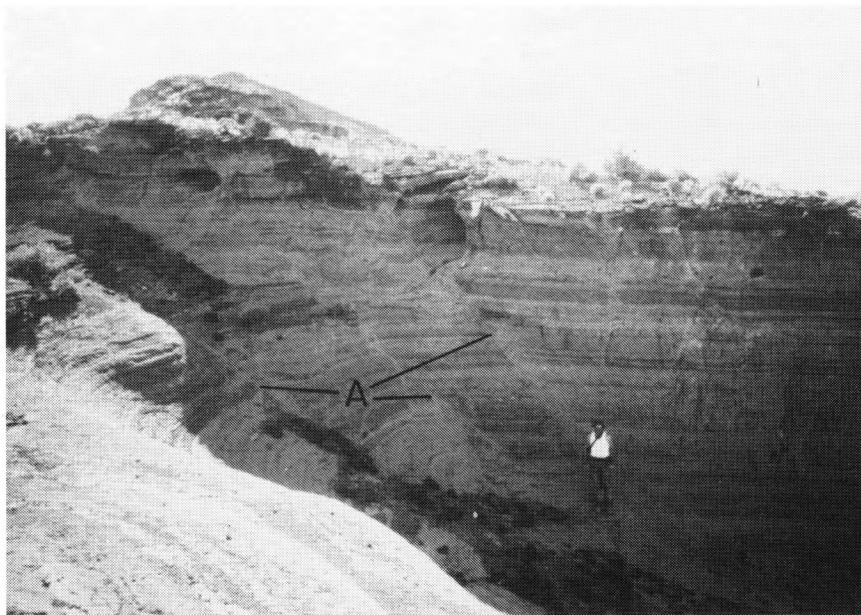
From observations of changes in dip of the tuff layers (Qvt) Gilbert (1890, figure 39) suggested that an earlier tuff cone lay slightly north of the main cone and that it had been mostly eroded away prior to the eruption that produced the main cone (figure 31). However, there is no indication of major erosion or weathering along the contacts between the overlapping tuff



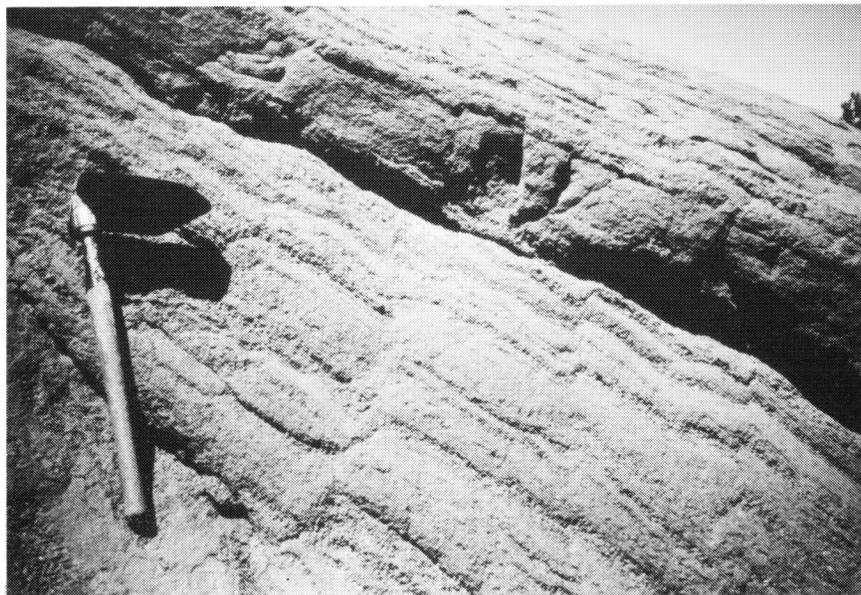
*Figure 30. View of the southeast summit ridge and the highest point on the Pavant Butte tuff cone. View is to the north, and the edge of the crater is in lower left-hand corner. Note that the layers of palagonitized tuff (light) dip parallel to the slope of the cone in both directions from the ridge crest. The resistant dark surface layer, which has been partially stripped off, is interpreted as a case-hardened crust produced by weathering of the underlying palagonite.*



**Figure 31.** View of Pavant Butte from the north. The Provo shoreline erosional notch at the base of the tuff cone (about 4750 ft.; 1450 m) is partly filled by small alluvial fans. A = Bonneville shoreline, which is a weak erosional notch and is locally filled with colluvial ash; B = the proximal end of a spit at the Bonneville shoreline, which has an altitude of 5085 feet (1550 m); C = overlapping layers of palagonitized tuff near the summit of the tuff cone; D = outcrops of dark tuff at the base of the cone, which may be the tuff units that Gilbert (1890, p. 328) interpreted as representing remnants of an older tuff cone.



**Figure 32.** Small faults (labeled A) in the palagonitized tuff (Qvt) of Pavant Butte along the western summit ridge of the tuff cone. The tuff layers are nearly horizontal along the ridge crest. The faults dip toward the crater (to the south), and are probably related to slumping during and shortly after the eruption.



**Figure 33.** Micro-folds in palagonitized tuff on the northeast flank of Pavant Butte. The layers of tuff overlying the folded beds dip to the northeast at about 40°. Shovel handle is 1.6 feet (0.5 m) long.

units observed by Gilbert. In addition, there are many more overlapping tuff units in Pavant Butte than those observed by Gilbert. Therefore, I interpret the numerous tuff units within the tuff cone, which dip in many different directions, as representing a single major eruption during which the tuff was actively slumping (figures 32 and 33) and the locus of deposition of tuff changed through time, possibly for several reasons. For example, the locus of tuff deposition would have changed if the trajectory of the erupting ash changed slightly during the eruption due to a change in wind direction, or to partial

blocking of the vent as ash or tuff slumped from the proximal flanks of the cone into the vent. It is also possible that the position of the vent changed as the eruption progressed. In this interpretation it is unnecessary to call for separate eruptive events to explain each of the many observed tuff units that compose the tuff cone.

Gilbert (1890, p. 326-327) reasoned that the tuff cone was constructed in Lake Bonneville at its highest stage. He noted that the Bonneville and Provo shorelines are notched on the flanks of the cone but that the "Intermediate shore-lines" are

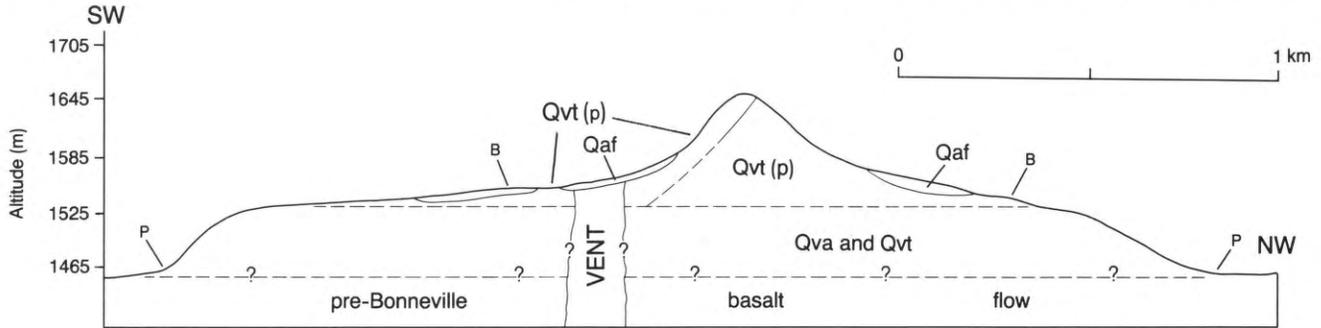


Figure 34. Geologic cross section through Pavant Butte. (Qvt(p) = basaltic tuff in main cone, largely palagonitized; Qva and Qvt = basaltic ash and unpalagonitized tuff in the pedestal underlying the palagonite tuff cone; Qaf = post-Bonneville alluvial fans; B = Bonneville shoreline on gravel composed of reworked ash and lapilli; P = Provo shoreline. Compare with Oviatt and Nash (1989, fig. 3).

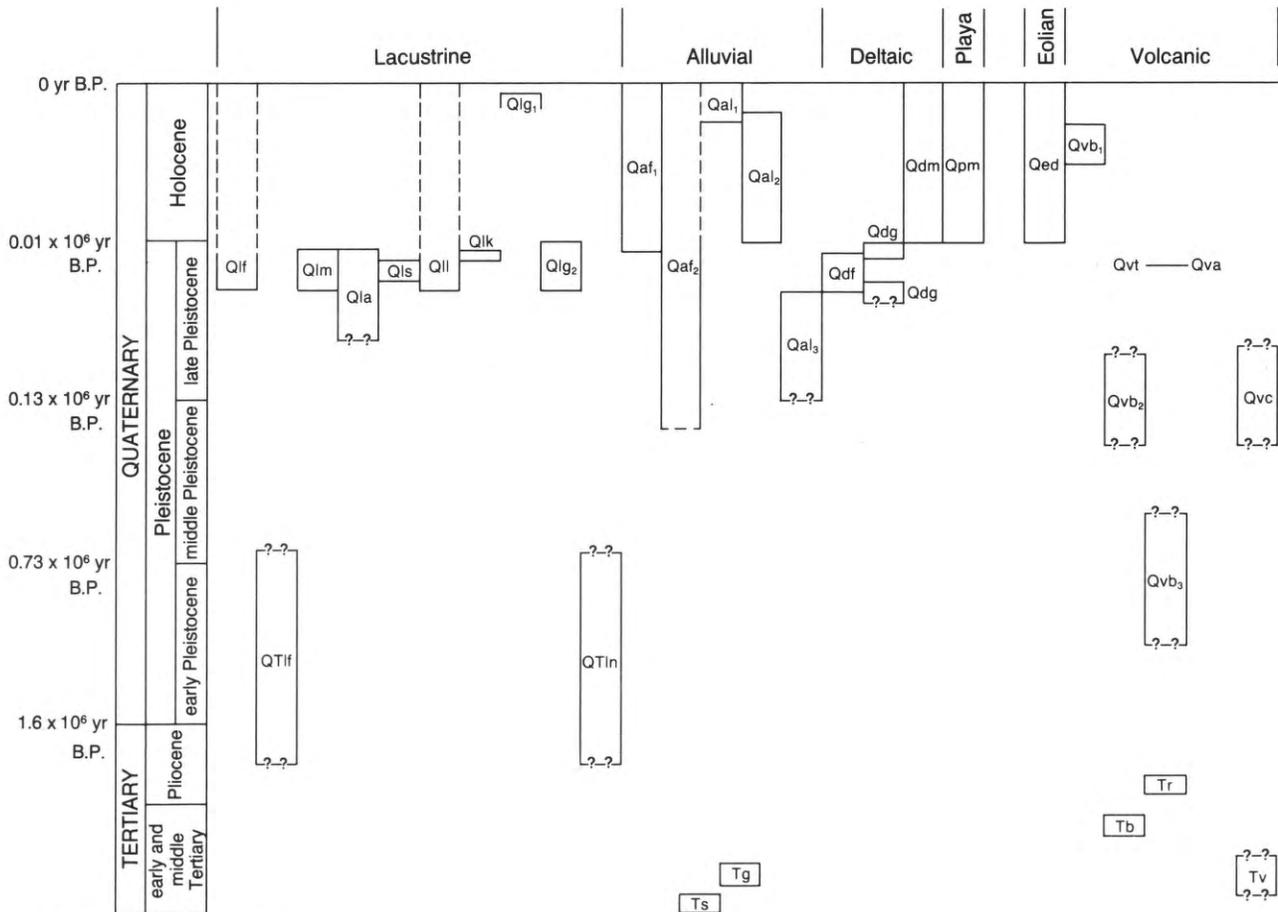


Figure 35. Correlation of map units.

not. Because the “Intermediate shore-lines” were formed prior to the formation of the Bonneville and Provo shorelines, and because Gilbert observed an angular unconformity associated with the Bonneville shoreline wave-cut notch (1890, figure 37), he thought that the eruption occurred while the lake stood at the Bonneville level (Gilbert thought that Lake Bonneville overflowed only once, in contrast to the interpretation shown in figure 2).

Figure 34 is a cross section of Pavant Butte based on geologic mapping at the site. The cone is composed of basaltic tuff (Qvt), which is locally palagonitized, especially in the higher parts of the cone above the Bonneville shoreline. The palagonitized tuff cone rests on a pedestal of unaltered basaltic ash and lapilli (Qva; Wohletz and Sheridan, 1983; Oviatt and Nash, 1989). Locally the ash has been extensively reworked by waves in Lake Bonneville into spits and shore platforms. Rippled and cross-bedded ash is exposed in gullies on the east and south-west flanks of the cone.

The tuff cone itself has been notched by the Bonneville shoreline (figure 31)(Currey, 1982; Oviatt and Nash, 1989). Evidence at Pavant Butte itself, and from exposures of Pavant Butte ash south of the map area (Oviatt, 1987c; Oviatt and Nash, 1989), suggests that the eruption occurred between about 16,000 and 15,300 yr B.P. when Lake Bonneville was within 50 feet (15 m) of the Bonneville shoreline during its transgressive phase.

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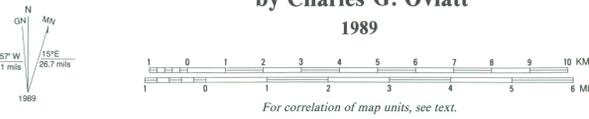
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# QUATERNARY GEOLOGY OF A PART OF THE SEVIER DESERT, UTAH

by Charles G. Oviatt  
1989



## DESCRIPTION OF MAP UNITS

### LACUSTRINE (l)

- Qlf** Fine-grained lacustrine deposits — silt, sand, marl, and calcareous clay. Locally includes the white marl (Qlm), but also includes local alluvium composed of reworked fine-grained lacustrine deposits. Bonneville and post-Bonneville in age (late Pleistocene to Holocene).
- Qlm** White marl — (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; thickness 2 to 10 m depending on local depositional setting; also includes clastic-rich marl at the base and top).
- Qla** Gravel of lacustrine and/or alluvial origin — 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.
- Qls** Lacustrine pebbly sand — quartz sand overlying boulder-beach deposits or Qla on the western slope of the Cricket Mountains; deposited in Lake Bonneville at lake stages higher than the Provo shoreline.
- Qll** Lagoon fill — silt, sand, and clay filling lagoons behind barrier beaches; Bonneville and post-Bonneville in age.
- Qlk** Lacustrine carbonate sand — sand or pebbly sand composed dominantly of calcium carbonate, including sand- to pebble-size clasts of calcium carbonate, carbonate-coated gastropods, and oolitic sand associated with the Provo Shoreline. Mapped in areas about 10-60 ft (3-20 m) vertically below the Provo shoreline; stratigraphically overlies the white marl.
- Qlg1** Lacustrine gravel — sandy gravel composed mostly of Paleozoic carbonate rock fragments; Sevier Lake beach gravel of late Holocene age.
- Qlg2** Lacustrine gravel — sandy gravel composed of locally derived rock fragments; beach or spit gravel deposited in Lake Bonneville and Lake Gunnison.
- QTlf** Plio-Pleistocene fine-grained lacustrine deposits — red, green, and light gray calcareous silty clay, silt, and sand. Contains Bishop ash (740,000 yr B.P.) in the map area, and Huckleberry Ridge ash (2.02 x 10<sup>6</sup> yr B.P.) south of the map area. Referred to informally in this report as the "Plio-Pleistocene lake beds."
- QTln** Plio-Pleistocene lacustrine limestone — white pebbly limestone locally containing abundant gastropods of the genus *Ammicola* (?); occurs in only three small outcrops along western edge of map area; may represent shore facies of QTlf; early Pleistocene or late Tertiary in age.

### ALLUVIAL (a)

- Qaf1** Alluvial-fan deposits — post-Bonneville alluvial fans. Coarse to fine-grained alluvium on piedmont slopes.
- Qaf2** Alluvial-fan deposits — pre-Bonneville alluvial fans. Mostly coarse-grained alluvium in piedmont areas above the Bonneville shoreline. Includes some minor post-Bonneville fan deposits above the Bonneville shoreline.
- Qal1** Alluvium (upper) — youngest alluvium underlying a low terrace along the Sevier River; mostly silt, clay, and sand; mapped only near Sevier Lake and northeast of the town of Delta.
- Qal2** Alluvium (middle) — sand, silt, and clay deposited in floodplain or overbank environments of the Sevier River and Beaver River. Includes organic-rich muds of floodplain marshes and poorly sorted sandy mud of floodplains and natural levees. Also includes well sorted sand and gravel in paleochannels. Early to late Holocene in age, and locally includes some modern alluvium; underlies the extensive low-gradient fans of the Sevier and Beaver Rivers.
- Qal3** Alluvium (lower) — sandy to pebbly alluvium of the ancient Sevier River; mapped north of the town of Delta. Pre-Bonneville but post-QTlf in age.

### DELTAIC (d)

- Qdf** Underflow-fan deposits — silt and fine sand in late Pleistocene underflow fan of Sevier River. Deposited in Lake Bonneville primarily during the regressive phase of the lake, but probably includes pre-Bonneville Qdf at depth and unexposed north of the Sevier River.
- Qdg** Deltaic sand and gravel — sand and gravel deposited near the mouths of the Sevier and Beaver Rivers during the Bonneville lake cycle. Qdg both underlies and overlies the white marl in the Beaver River area, but is mostly regressive (i.e., it overlies the white marl) in the Sevier River area northeast of the town of Delta. In both areas Qdg was locally reworked by waves into spits and thin sheets of lacustrine gravel.

- Qdm** Deltaic mud — deltaic mud of the Holocene delta of the Sevier River at the northeastern end of Sevier Lake.
- PLAYA (p)**
- Qpm** Playa mud — poorly sorted clay, silt, and sand locally with gypsum, halite, and other salts. Holocene in age.
- EOLIAN (e)**
- Qed** Eolian deposits — 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. In many places, clay dunes or lunettes are associated with playas, or areas of Qal2 that are frequently flooded. All mapped eolian deposits are Holocene in age.
- VOLCANIC ROCKS (v)**
- Qvb1** Ice Springs basalt flow — Post-Bonneville in age.
- Qvb2** Pavant Butte and Smelter Knolls basalt flows — Pre-Bonneville, probably early Pleistocene in age.
- Qvb3** Deseret basalt flow — Pre-Bonneville, probably early Pleistocene in age.
- Qvt** Pavant Butte basaltic tuff — gray to yellow basaltic tuff of main tuff cone, locally altered to palagonite. Erupted into Lake Bonneville about 15,500 yr B.P.
- Qva** Pavant Butte basaltic ash — black basaltic ash of fine-sand to coarse-gravel size, depending on distance from source; includes ash reworked by waves in Lake Bonneville. Locally contains fragments of Qvt and Qvb3. Qva has been reworked by wind into dunes and sand sheets over most of its outcrop area north of Pavant Butte. Erupted from Pavant Butte into Lake Bonneville about 15,500 yr B.P.
- Qvc** Basaltic cinders — erupted from a small pre-Bonneville volcanic vent south of Pavant Butte.

- PRE-QUATERNARY MAP UNITS**
  - Ts** Tertiary sedimentary rocks undifferentiated — Cricket Mountains; see Hintze (1984); probably early Tertiary in age.
  - Tg** Coarse-grained gravel of volcanic origin — including well-rounded boulders up to several meters in diameter, mostly composed of igneous rock-types, in small isolated fault blocks north and west of Smelter Knolls, and in more extensive tracts in the Little Drum Mountains. Oligocene in age (see Pierce, 1974).
  - Tb** Basaltic andesite — occurs in small fault blocks north of Smelter Knolls; dated at 6.1 ± 0.3 x 10<sup>6</sup> yr B.P. (Turley and Nash, 1980).
  - Tr** Rhyolite of Smelter Knolls — dated at 3.4 ± 0.1 x 10<sup>6</sup> yr B.P. (Turley and Nash, 1980).
  - Tv** Volcanic rocks undifferentiated — of the Little Drum Mountains; see Pierce (1974); probably Oligocene in age.
  - Ps** Paleozoic sedimentary rocks undifferentiated — Cricket Mountains and Drum Mountains; see Hintze (1984) and Morris (1978); Cambrian in age.
- Qpm/Qlf/QTlf** 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.
- Volcanic eruptive center
  - Late Pleistocene lake shorelines; dotted where concealed by younger deposits
  - P = Provo; B = Bonneville; G = Gunnison
  - Blowout depression
  - Modern perennial channel of the Sevier River
  - Modern ephemeral channel of the Beaver River
  - Abandoned channel having clear surface morphology; natural levees common.
  - Abandoned channel having indistinct or no surface topographic expression, or inverted topographic expression.
  - Fault; bar and ball on downthrown side; dashed where inferred; dotted where concealed (faults in bedrock not shown).
  - Fault or fracture having small or undetermined displacement.
  - Contact; dashed where inferred; dotted where concealed.
  - Ridge crest of spit formed on the cusped snout of the Sevier-River underflow fan during the regressive phase of Lake Bonneville; arrow represents direction of spit development.
  - Scarp of terrace; cut in Qdf during regression of Lake Bonneville.
- \*A** Locality listed in Table 4 and discussed in text.

