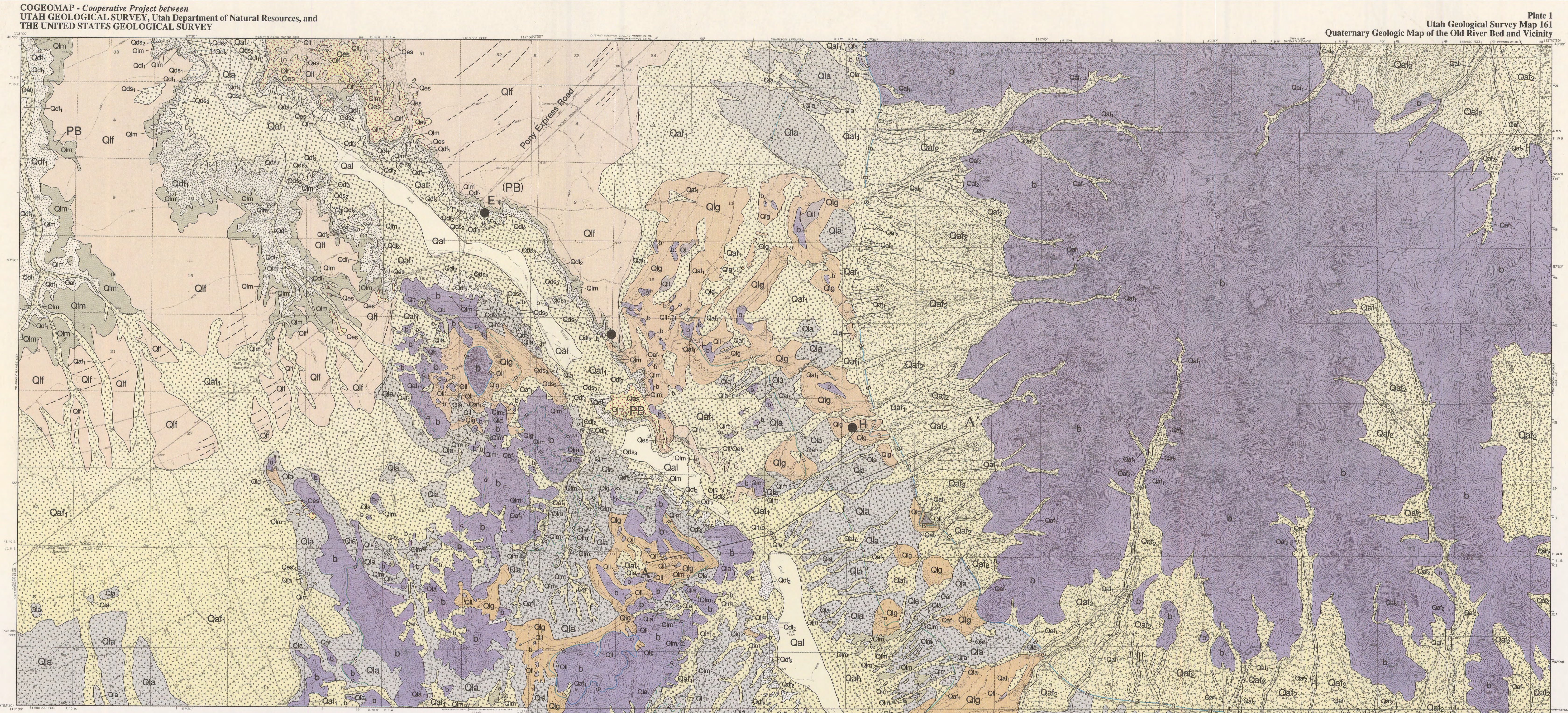
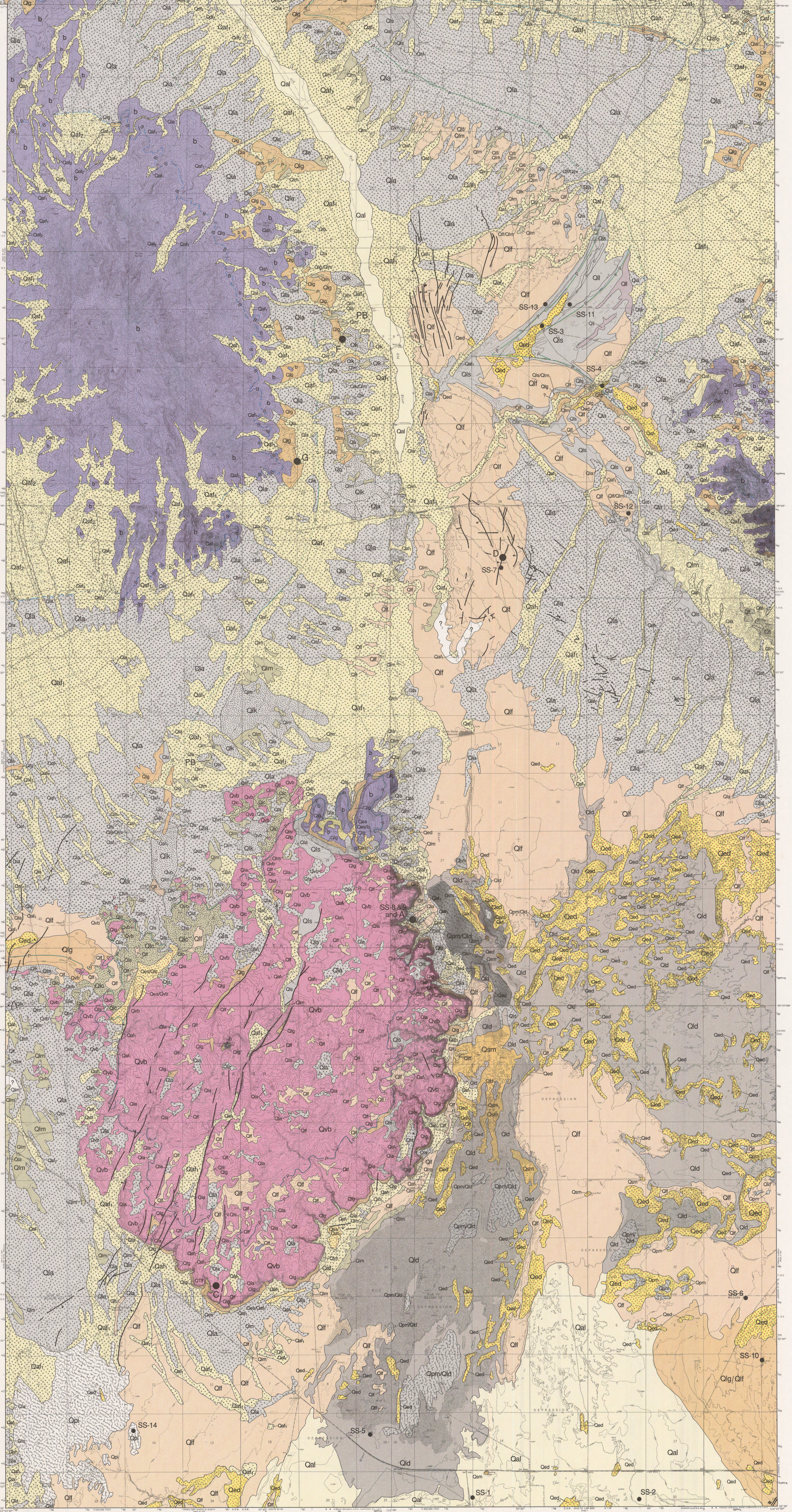
COGEOMAP - *Cooperative Project between*
UTAH GEOLOGICAL SURVEY, Utah Department of Natural Resources, and
THE UNITED STATES GEOLOGICAL SURVEY





Base map from U.S. Geological Survey 7.5′ Quadrangles

Lori J. Douglas, Cartographer

Description of Map Units

QTlf Fine-grained lacustrine deposits (Plio-Pleistocene) - *red, green, and light-gray, calcareous silty clay, silt, and sand. Massive to thinly bedded; maximum thickness over 30 feet (10 m). Contains Bishop ash (0.74 Ma), Huckleberry Ridge ash (2.02 Ma), and Cudahy Mine ash (~2.5 Ma).*

Qla Gravel of lacustrine and/or alluvial origin (late Pleistocene) - *mapped in piedmont areas where pre-Bonneville alluvial gravel was reworked by Lake Bonneville, but where the lacustrine gravel component is thin and where Lake Bonneville deposits have been incompletely reworked by post-Bonneville alluvial fans. Includes pre-Bonneville alluvial fans etched by waves in Lake Bonneville, and thin alluvial-fan deposits overlying fine- to coarse-grained lake sediments. Lacustrine-gravel component generally thin (<10 feet [3 m]).*

Qlg Lacustrine gravel (late Pleistocene) - *sandy gravel to boulders composed of locally derived rock fragments; well sorted; thickness variable, but generally less than 20 feet (6 m); gravel deposited in beaches, barriers, tombolos, or spits in Lake Bonneville.*

Qlf Fine-grained lacustrine deposits (late Pleistocene to Holocene) - *sand, silt, marl, and calcareous clay; thinly bedded to massive; thickness variable but generally <10 feet (3 m). Locally includes the white marl (Qlm), but also includes local Holocene alluvium and eolian deposits composed of reworked fine-grained lacustrine sediments.*

Qlm White marl (late Pleistocene) - *(the white marl as defined by Gilbert, 1890, and redefined by Oviatt, 1987); white to gray marl deposited in Lake Bonneville; finely bedded to indistinctly laminated; contains abundant ostracodes throughout, and locally contains gastropods near the base and top of the stratigraphic unit; thickness 6 to 30 feet (2 to 10 m) depending on local depositional setting; also includes clastic-rich marl at the base and top of the unit.*

Qls Lacustrine gravelly sand (late Pleistocene) - *well-sorted to very poorly sorted and pebbly sand overlying lacustrine shorezone gravel or Qla; apparent massive bedding; thickness variable but <20 feet (6 m).*

Qlk Lacustrine carbonate sand (late Pleistocene) - *calcareous pebbly sand; fine to coarse sand with rounded coarse sand - to granule-sized clasts, carbonate pellets, and calcium carbonate-coated gastropods; maximum thickness about 15 feet (5 m); deposited during and shortly after the development of the Provo shoreline.*

Qll Lacustrine lagoon deposits (late Pleistocene and Holocene) - *sand, silt, and clay filling lagoons behind barrier beaches and beach-ridge complexes; deposited both during occupation of Lake Bonneville, and by alluvial and eolian infilling in Holocene time. Thickness probably less than 20 feet (3 m).*

Qlc Mixed lacustrine and colluvial or regolith deposits (late Pleistocene) - *colluvial or weathered basaltic gravel moderately reworked by Lake Bonneville and generally intermixed with fine-grained deposits of Lake Bonneville; thickness probably less than 10 feet (3 m); similar to Qla but consists of lake-reworked colluvium or regolith rather than alluvial-fan deposits.*

Qld Lacustrine mud (late Pleistocene and Holocene) - *wet, calcareous silt and clay; white to light gray; located in low-elevation mud flats that have a high ground-water table; thickness probably less than 10 feet (3 m). Fine-grained lacustrine sediments of late Pleistocene Lakes Bonneville and Gunnison and local, minor Holocene water bodies.*

Qlt Lacustrine tufa (late Pleistocene) - *consolidated precipitate of calcium carbonate; coats bedrock and calcareous fine-grained lake deposits (Qlf, Qlm, and Qdf_2); maximum thickness about 6 feet (2 m).*

Qdf Deltaic fine-grained deposits (late Pleistocene) -*silt and fine sand in fine-grained delta (underflow fan) of the Sevier River in the Old River Bed area. Equivalent to the yellow clay of Gilbert (1890). Thinly bedded; generally poorly sorted. Deposited in Lake Bonneville during the transgressive phase of the lake. Qdf_1 is up to 20 feet (6 m) thick; deposited at end of Stansbury oscillation. Maximum thickness of Qdf_2 over 65 feet (20 m); pre-Stansbury in age.*

Qds Deltaic sand and gravel (late Pleistocene) - *sand and gravel deposited near the mouth of the Sevier River in the Old River Bed area during the Bonneville lake cycle; Qds_1 is regressive-Bonneville in age; Qds_2 is Stansbury in age; Qds_3 is transgressive-Bonneville in age. Well-sorted pebbly sand containing volcanic and sedimentary pebbles; cross-bedded to massive. Qds_1 reworked by waves into a thin sheet. Maximum thickness 50 feet (15 m).*

Qaf_2 Older alluvial-fan deposits (late Pleistocene) - *mostly coarse-grained, poorly sorted gravel in piedmont areas above, and older than, the Bonneville shoreline. Includes some minor post-Bonneville fan deposits above the Bonneville shoreline. Maximum thickness could be great.*

Qaf_1 Younger alluvial-fan deposits (Holocene) - *poorly sorted gravel and fine sediment in post-Bonneville alluvial fans; thickness variable.*

Qal Alluvium (Holocene) - *youngest alluvium underlying floodplains along ephemeral streams and the Old River Bed; mostly calcareous sand, silt,and clay; also includes levee, splay, marsh, and floodplain deposits of the post-Bonneville Sevier River that are locally organic rich, and may contain abundant mollusc shells; thickness variable.*

Qpm Playa mud (Holocene) - *saturated clay, silt, and sand; typically calcareous or saline; consists of primary playa deposits and playa-reworked lacustrine mud; found on those portions of the mudflats east of Crater Bench that are flooded largely by ground-water discharge. Maximum thickness probably less than 20 feet (6 m).*

Qpi Playa silt (Holocene) - *calcareous sandy silt of the Swasey Hardpan (south of Swasey Hardpan Reservoir), a surface-inflow type of playa; vesicular surface structure; maximum thickness probably less than 20 feet (6 m).*

Qed Eolian dune deposits (late Pleistocene and Holocene) - *including poorly sorted to well-sorted sand composed mostly of clastics in well-developed dunes, and gypsum grains and aggregates of clay, silt, and sand in lunettes and shrub-coppice dunes. Most dunes are less than 10 feet (3 m) high.*

Qes Sheet-like eolian deposits (late Pleistocene and Holocene) - *sand, silt, and clay deposited as sheets rather than as well-developed dunes; generally thin with massive bedding. Thickness probably less than 10 feet (3 m).*

Qsm Spring marsh deposits (Holocene) - *clay, silt, and sand; locally organic-rich, calcareous, or saline; found in saturated areas near flowing and seeping springs. Thickness undetermined.*

Qst Calcareous spring sinter (Holocene) - *clay, silt, sand, and manganese-rich calcareous travertine; light gray to reddish brown; mapped only at Abraham (Baker) Hot Springs. Thickness undetermined.*

Qvb Quaternary basalt (early Pleistocene) - *Flows and minor scoriaceous deposits of basalt at Crater Bench; approximately 1 million years old; see Peterson and Nash (1980) and Galyardt and Rush (1981). Maximum thickness probably about 500 feet (150 m).*

b Paleozoic sedimentary rocks and Tertiary volcanic rocks undifferentiated - *see Pampeyan (1989) for distributions and descriptions.*

Map Symbols

CONTACT: *dashed where inferred, dotted where concealed*

FAULTS: *bar and ball on downthrown side, dashed where inferred, dotted where concealed; faults in Paleozoic rocks not shown*

FAULTS OR FRACTURES: *having small or undetermined displacement: faults cutting basalt on Crater Bench also shown with this symbol*

PROVO SHORELINE: *dotted where concealed by younger deposits; locally used as geologic contact*

BONNEVILLE SHORELINE: *dotted where concealed by younger deposits; locally used as geologic contact*

RIDGE CREST OF LOW BEACH RIDGE: *formed on the surface of the yellow clay underflow fan in the Old River Bed area during the regressive phase of Lake Bonneville; beach ridges overlie Qlf*

H ● LOCALITY LISTED IN TABLE 1 AND DISCUSSED IN TEXT

● SS-3 SEDIMENT-SAMPLE SITE

PB LOCALITIES: *where Pahvant Butte ash has been found in the white marl (Qlm)*

A —— A′ SEE FIGURE 15 FOR THIS CROSS SECTION

SCALE 1:62,500

0 1 2 3 km

0 1 2 3 miles

N

Quaternary Geologic Map of the Old River Bed and Vicinity, Millard, Juab and Tooele Counties, Utah

by

Charles G. Oviatt, Dorothy Sack, and Tracey J. Felger

1994

QUATERNARY GEOLOGIC MAP OF THE OLD RIVER BED AND VICINITY, MILLARD, JUAB, AND TOOELE COUNTIES, UTAH

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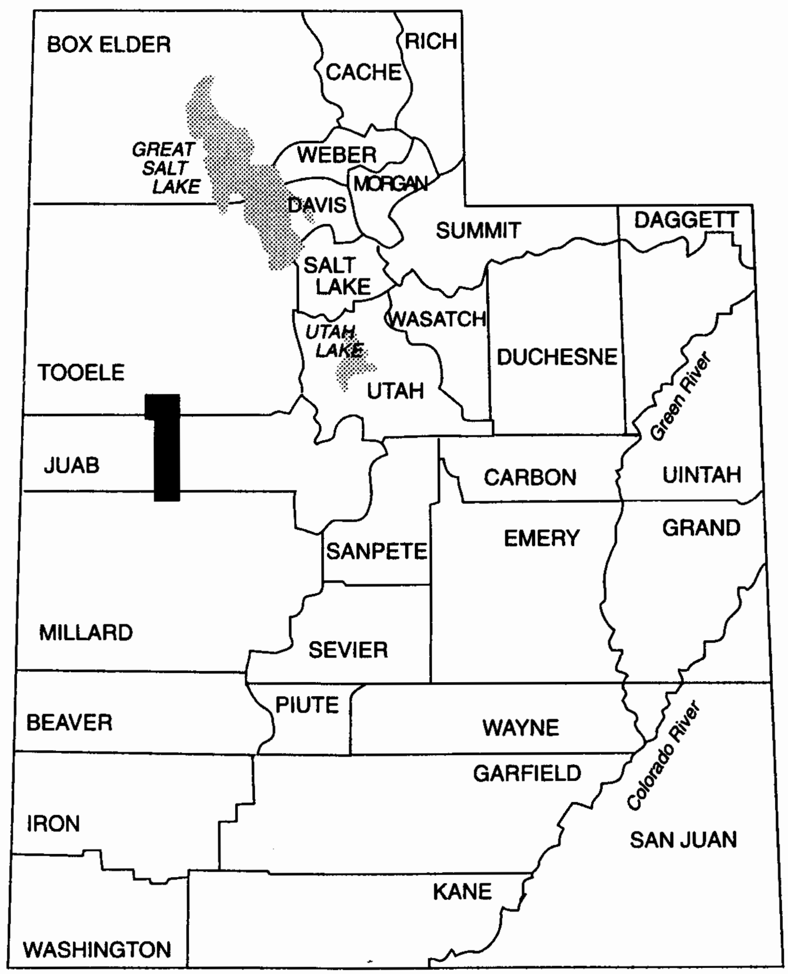

Map 161 **1994**
UTAH GEOLOGICAL SURVEY
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Oviatt, Sack, Felger
QUATERNARY GEOLOGIC MAP OF THE OLD RIVER BED AND VICINITY, MILLARD, JUAB, AND TOOELE COUNTIES, UTAH
UGS Map 161

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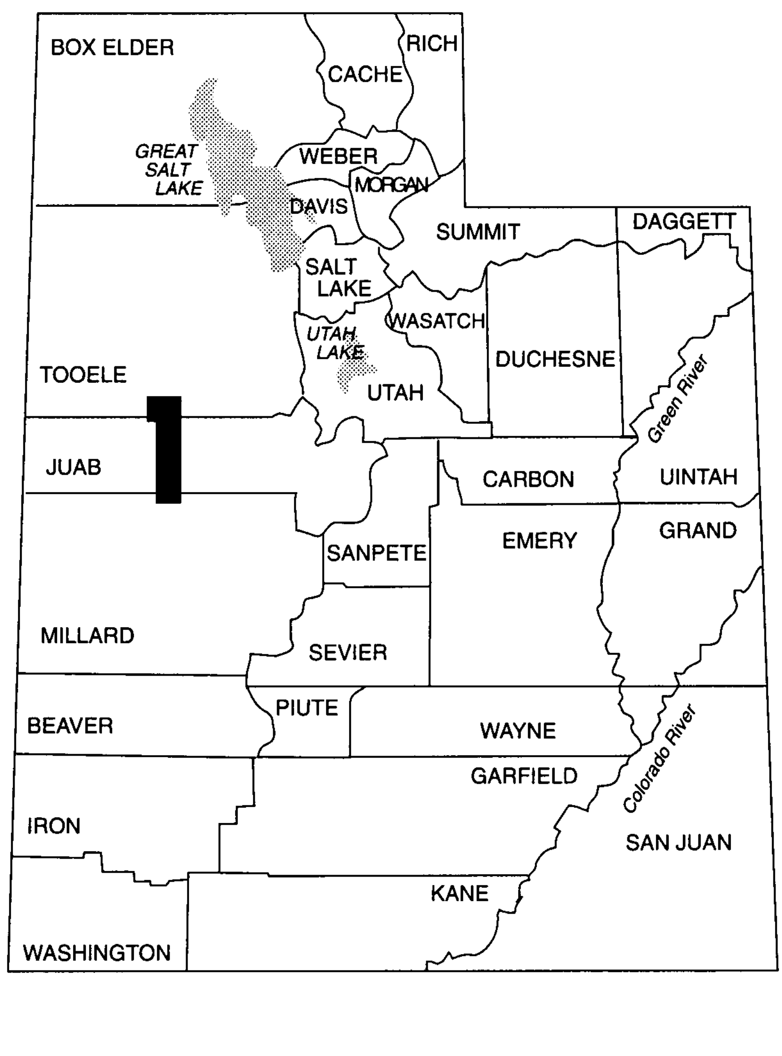

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QUATERNARY GEOLOGIC MAP OF THE OLD RIVER BED AND VICINITY, MILLARD, JUAB, AND TOOELE COUNTIES, UTAH

by

Charles G. Oviatt [1], *Dorothy Sack* [2], *and Tracey J. Felger* [3]

ABSTRACT

Quaternary deposits were mapped at a scale of 1:62,500 in an area of west-central Utah encompassed by nine 7.5-minute quadrangles. The area contains the threshold between the Sevier Lake basin and the Great Salt Lake basin, over which water flowed northward during Pleistocene episodes of high lake levels in the Sevier basin. Much of the Old River Bed, an abandoned river valley that formed during the most recent episode of overflow, is within the map area. Lake Bonneville deposits first studied by G. K. Gilbert are well exposed along the Old River Bed. Quaternary deposits in the map area include alluvium in fans, channels, and floodplains; eolian deposits; Lake Bonneville marl, fine-clastic deposits, and gravel; pre-Bonneville lacustrine deposits; playa deposits, spring deposits; and basaltic lava flows. The Sevier Desert detachment fault underlies the map area and probably controls the locations and activities of Quaternary faults in near-surface deposits. The youngest faults in the map area cut deposits of late Pleistocene and Holocene age. The Old River Bed area contains an excellent stratigraphic record of Lake Bonneville, including fine-scale details of the lake history in the offshore marl deposits, and sediments de-posited near the lake's highest level that help demonstrate the timing of a major oscillation of the lake prior to the initiation of overflow.

INTRODUCTION

The purpose of this report is to describe the Quaternary geology and Quaternary geologic history of the northern part of the Sevier Desert, north of 39°30′ N. latitude (figure 1). The geologic work was undertaken as a Cooperative Geologic Mapping (COGEOMAP) project, funded by the U.S. Geological Survey and the Utah Geological Survey. This report extends the Quaternary mapping of Oviatt (1989, 1991a) northward to and beyond the overflow threshold of the Sevier Lake basin.

The map area (plate 1) includes the following 7.5-minute quadrangles: Table Mountain, Coyote Springs, Indian Springs, Keg Mountain Ranch, Erickson Wash SW, The Hogback, Crater Bench Reservoir, Fumarole Butte, and Baker Hot Springs. These quadrangles were chosen for mapping because they include the excellent exposures of the Lake Bonneville deposits along the southern part of the Old River Bed. In addition, the southern boundary of these quadrangles abuts the northern boundary of the area mapped for COGEOMAP in 1986 (Oviatt, 1989). Surficial deposits were mapped on aerial photographs in the field during the summer of 1990, and the data were transferred to 1:24,000-scale orthophotoquads. The final map was compiled at a scale of 1:62,500.

The floor of the Sevier Desert has low topographic relief; elevations in the map area range from about 4,560 feet (1,390 m) on the desert floor to 8,200 feet (2,500 m) in the Simpson Mountains. The climate on the floor of the Sevier Desert is arid with warm summers and cold winters. Deseret, Utah, approximately 18 miles (29 km) south of the map area, had mean annual precipitation of 7.06 inches (17.9 cm) and mean annual temperature of 49°F (9.4°C) during the period 1951-1974 (NOAA, 1980). Precipitation is concentrated in the spring and late-autumn to early winter months. Vegetation in the map area is dominated by greasewood *(Sarcobatus vermiculatus)* at low altitudes, shadscale *(Atriplex confertifolia)* and other xerophytes on higher piedmont slopes and uplands, and pinyon-juniper

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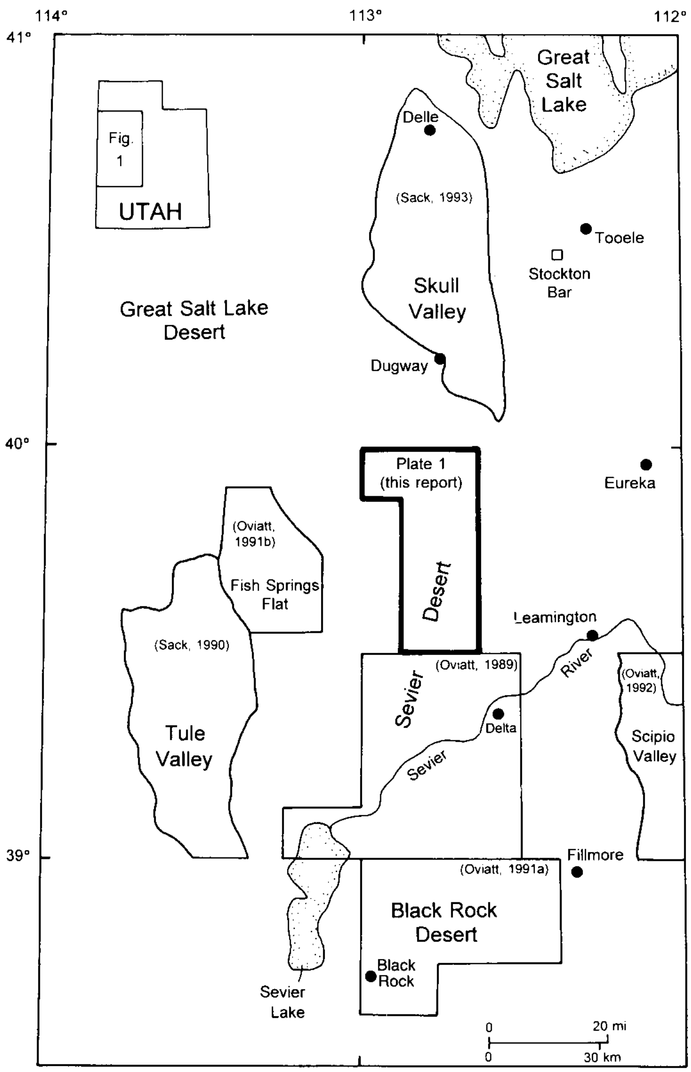

Figure 1. *Location map. The areas mapped for COGEOMAP in 1986 (Oviatt, 1989), 1987 (Oviatt, 1991a), 1988 (Oviatt, 1991b), and 1989 (Oviatt, 1992) are shown, as are two other valleys where Quaternary deposits have been mapped in western Utah (Sack, 1990, 1993).*

woodland in the mountains. *Tamarix* grows locally by springs.

Gravel and marl deposits of Lake Bonneville are widespread in the map area, and deposits of at least one pre-Bonneville Quaternary lake are exposed beneath basalt flows of known age. Other deposits include alluvium in fans, channels, and floodplains, eolian deposits, and small areas of playa and spring deposits. Faults in the northern part of the Drum Mountains fault zone and between Desert Mountain and the Old River Bed channel cut deposits of Quaternary age.

Bedrock in the mountains within the map area ranges in age from Precambrian to Tertiary, and most of it has been mapped previously (see references in Pampeyan, 1989; Shubat and Christenson, 1992; Shubat and Felger, in preparation). Quaternary deposits and volcanic rocks in the area have been studied by Gilbert (1890), Ives (1951), Varnes and Van Horn (1961), Peterson and Nash (1980), Galyardt and Rush (1981), and Oviatt (1987, 1989). Mabey and Budding (1987) have reviewed the geothermal potential of the hot springs near Crater Bench, and Stephens and Sumsion (1978) and Holmes (1984) have investigated ground water in the Sevier Desert.

Quaternary mapping in the northern Sevier Desert is important for the following reasons:

1. The area includes the Old River Bed threshold, which is the low point on the drainage divide between the Sevier Desert basin and the Great Salt Lake basin. Knowledge of the geomorphic history of the threshold area is critical to understanding the hydrography of late Tertiary and Quaternary lakes in the Sevier basin.

2. The area includes the excellent exposures of Lake Bonneville deposits along the Old River Bed that were first studied by Gilbert (1890), and which have received much subsequent stratigraphic study (Ives, 1951; Varnes and Van Horn, 1961; McCoy, 1981; Oviatt, 1987; Oviatt and McCoy, 1988), but have never been accurately mapped at any scale.

3. Quaternary faults, which previously have not been mapped in detail, cut deposits in the area.

4. Knowledge of the surficial deposits and Quaternary history of the area may be useful in studies of ground water and geothermal resources.

Because many of the deposits mapped for this project were laid down in Lake Bonneville, a brief history of the lake is summarized here. Lake Bonneville was the youngest and deepest of the large Quaternary lakes that formed in the Bonneville basin in response to cyclical climate changes (Gilbert, 1890; Morrison, 1966; Scott and others, 1983; McCoy, 1987; Oviatt and Currey, 1987; Oviatt and others, 1987; Currey, 1990; Oviatt and others, 1992). The deposits of Lake Bonneville are formally referred to as the Bonneville Alloformation (Currey and others, 1984; McCoy, 1987; Oviatt, 1987). The lake began to rise after about 30,000 years before present, and by about 25,000 years before present had transgressed to altitudes close to those in the lowest part of the study area (figure 2). Between 22,000 and 20,000 years before present the lake went through at least one, and possibly several, oscillations on the order of 150 feet (45 m), and formed the Stansbury shoreline or shoreline complex (Oviatt and others, 1990). Between 20,000 and 18,000 years before present, the lake transgressed more rapidly than during any other part of its history. This episode of rapid transgression is documented by numerous radiocarbon ages from shoreline facies (Scott and others, 1983; Oviatt and others, 1992) and by ostracode and geochemical interpretations of sediment cores from Great Salt Lake (Spencer and others, 1984; Thompson and others, 1990). After 18,000 years before present the transgression rate slowed, but the lake continued to rise until it overflowed into the Snake River drainage basin in southern Idaho about 15,000 years before present. Intermittent overflow probably continued until about 14,500 years before present, when the alluvial overflow threshold failed catastrophically and released a flood with discharge as great as 1.2×10^9 ft^3/sec (35×10^6 m^3/sec) through the Snake River valley in Idaho (Gilbert, 1890; Malde, 1968; Jarrett and Malde, 1987), an event referred to as the Bonneville flood. The flood dropped the lake level approximately 350 feet (108 m) to a stabilized overflow threshold across bedrock, and the Provo shoreline formed during continued overflow between about 14,500 and 14,200 years before present (Currey, 1982; Oviatt and others, 1992). After about

14,200 years before present the lake dropped below its overflow threshold and began to contract as a closed-basin lake; by 12,000 years before present it had dropped to very low levels. A modest rise between about 11,000 and 10,000 years before present formed the Gilbert shoreline in the Great Salt Lake basin; during this interval Lake Gunnison in the Sevier Desert overflowed along the Old River Bed into the Great Salt Lake. Deposits and landforms in the map area record much of the history of Lake Bonneville.

DESCRIPTION OF MAP UNITS

Introduction

For mapping purposes (plate 1), the Quaternary deposits in the northern Sevier Desert are classified primarily on the basis of their environments of deposition. The unconsolidated Quaternary sediments were deposited in lacustrine, alluvial, deltaic, playa, spring, and eolian environments as indicated by the first lower-case letter in the map-unit symbols. Other distinguishing characteristics, such as grain size, lithology, or geomorphic expression, are used to subdivide the deposits into mappable units, and are indicated by the second lower-case letter in the symbol. Some deposits can be grouped into map units having distinctly different relative ages. In these cases, number subscripts are used, such as in the map units Qaf_1 and Qaf_2, where the subscript 1 indicates a younger relative age than the subscript 2. Where the surface geologic materials are thin or discontinuous and the shallow subsurface deposits can be determined, map units are stacked so that more than one deposit can be shown. For example, discontinuous or thin lacustrine tufa that overlies Tertiary volcanic rocks is mapped as Qlt/b. In plate 1 stacked units have the color of the most pervasive map unit, which is indicated by italics.

Plate 1 also shows Quaternary basalt flows at Crater Bench (after Peterson and Nash, 1980; Galyardt and Rush, 1981). Where significant thicknesses of Quaternary deposits overlie older units, such as on Crater Bench, only the surface unit is indicated. Tertiary and Paleozoic rocks have not been subdivided (see Pampeyan, 1989).

The Bonneville and Provo shorelines are depicted on plate 1. Depositional and erosional segments are not distinguished except where gravel embankments are large enough to be mapped as lacustrine sand or gravel. Sediment-sample sites and other localities discussed in the text (table 1), as well as Quaternary faults, fissures on Crater Bench, and other lineaments, are also shown on plate 1.

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

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

Lacustrine Deposits

Fine-grained lacustrine deposits (QTlf): Plio-Pleistocene deposits of a pre-Bonneville lake are exposed at a few localities in the northern Sevier Desert, and are mapped as QTlf. QTlf includes brown and light-olive-gray calcareous silty clay, silt, and minor sand (samples 8 and 9, table 2). This unit is remarkably uniform in lithology in isolated exposures throughout the Sevier and Black Rock Deserts (Oviatt, 1989, 1991a). The base is not exposed in the map area. The deposits are overlain by

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

Locality	Description	Significance	Lat-Long
A	northeast side of Crater Bench	exposure of QTlf; locations of figures 3 and 14	39° 38′ 48″ 112° 44′ 32″
B	west side of Crater Bench	fault scarp cutting Provo-level tombolo (figure 6)	39° 38′ 6" 112° 56′ 26″
C	south end of Crater Bench	exposure of QTlf and pillow basalt	39° 33′ 18″ 112° 48′ 33″
D	west of Desert Mountain and northeast of Crater Bench	fault scarp cutting Qlf (figure 13)	39° 44′ 12″ 112° 42′ 17″
E	east side of the Old River Bed, south of Pony Express Road	measured section in Lake Bonneville deposits (figure 16)	39° 58′ 3″ 112° 53′ 9″
F	east piedmont of Keg Mountain	measured profile in Lake Bonneville deposits (figure 18)	39° 47′ 28″ 112° 45′ 55″
G	east piedmont of Keg Mountain	type locality of Keg Mountain oscillation (figure 20)	39° 45′ 41″ 112° 46′ 57″
H	west piedmont of Simpson Mountains	exposure of Lake Bonneville deposits (figure 21)	39° 55′ 39" 112° 47′ 45″
I	east side of Old River Bed, east of Table Mountain	exposure of white marl (Qlm; figure 17)	39° 56′ 44″ 112° 51′ 21″

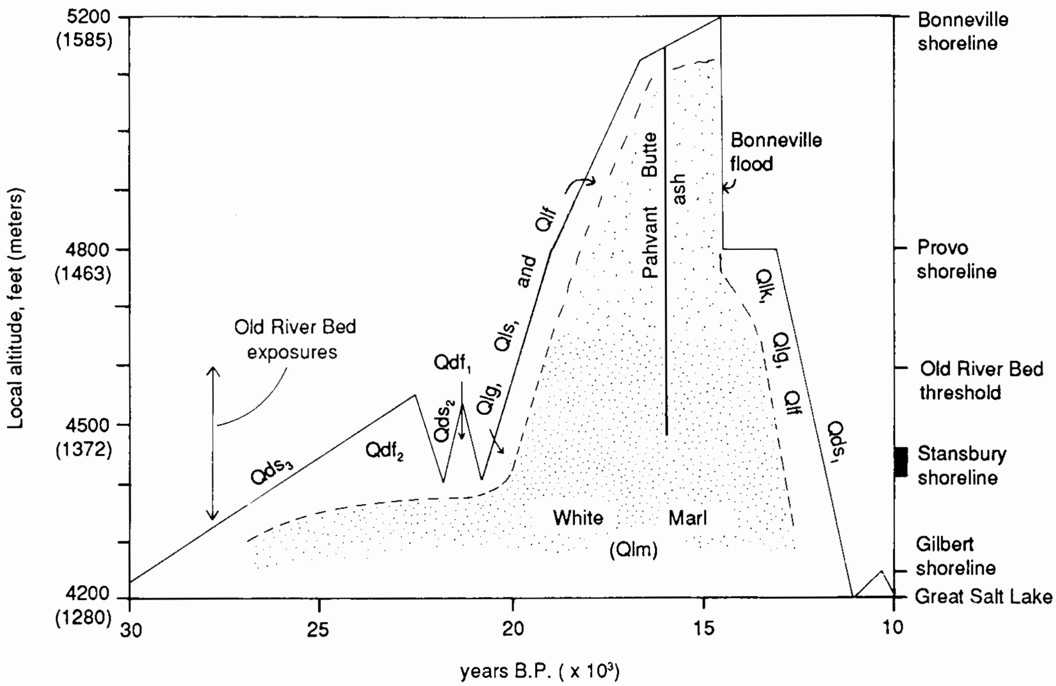

Figure 2. Lake Bonneville time-altitude diagram, modified from Oviatt and McCoy (1988, figure 5C) and Oviatt and others (1992, figure 2). The diagram also shows how some of the lacustrine and deltaic map units in plate 1 fit into the lake chronology.

Table 2.
Northern Sevier Desert grain-size data.

Sample	Map Unit	% Gravel	% Sand	% Silt	% Clay	% $CaCO_3$	Textural Classification*
1	Qal	0.0	22.8	44.2	33.0	15.2	sandy mud
2	Qal	0.0	7.6	69.4	23.0	26.9	silt
3	Qed	0.0	87.9	6.9	5.2	6.9	muddy sand
4	Qed	2.4	92.4	1.8	3.4	5.8	slightly gravelly sand
5	Qld	0.0	0.6	68.5	30.9	36.2	silt
6	Qlf	0.0	42.1	46.7	11.2	20.0	sandy silt
7	Qlf	0.0	83.1	12.8	4.1	11.9	silty sand
8	QTlf	0.0	15.7	41.4	43.0	35.7	sandy mud
9	QTlf	0.0	5.6	50.2	44.3	30.8	mud
10	Qlg/Qlf	36.4	62.2	0.3	1.1	8.5	sandy gravel
11	Qll	0.0	13.5	43.9	42.6	22.3	sandy mud
12	Qlm	0.0	0.6	55.2	44.2	30.4	mud
13	Qls	7.9	75.5	11.1	5.5	8.5	gravelly muddy sand
14	Qpl	0.0	42.0	41.8	16.2	29.8	sandy silt

* Folk (1974) *See plate 1 for collection localities.*

Quaternary basalt flows at Crater Bench, and by debris-flow deposits adjacent to Crater Bench (figure 3; localities A and C, table 1).

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

QTlf is late Tertiary to middle Pleistocene in age, as shown by dated volcanic ashes and lava flows that are interbedded with the fine-grained deposits outside the map area (Krusi and Patterson, 1980; Oviatt, 1989, 1991a). Within the map area, QTlf is overlain by the Crater Bench basalt flows, which are dated at 0.88 Ma (Peterson and Nash, 1980) and 0.95 ± 0.1 Ma (Galyardt and Rush, 1981) by K-Ar.

Gravel of lacustrine and/or alluvial origin (Qla): Two major types of piedmont deposits are mapped as Qla: Lake Bonneville deposits that have been incompletely reworked by post-lacustrine alluvial fans, and thin lacustrine gravel deposits that overlie pre-Bonneville alluvial-fan sediments. Deposits of the first type consist of thin alluvial-fan sediments overlying fine- to coarse-grained lacustrine deposits, fine- to coarse-grained la-custrine deposits that have been slightly reworked by alluvial-fan proc-

Figure 3. North wall of the stream cut at locality A (table 1) showing debris-flow deposits (Qaf₂, mapped as Qla on plate 1) overlying two Plio-Pleistocene fine-grained lacustrine units (QTlf), which are separated by a lacustrine sand and gravel bed. QTlf is not mappable on the surface here. Figure 14 is a measured columnar section of this site.

esses, and areas that consist of interfingering alluvial and lacustrine deposits, which are unresolvable at the map scale.

The thin lacustrine gravel of the second major type of Qla deposits 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. However, air photo interpretation reveals that Lake Bonneville shorelines are etched across the pre-Bonneville alluvial fans indicating that waves in Lake Bonneville modified the alluvial-fan surfaces, and that post-Bonneville alluvial-fan activity has been negligible in these areas.

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

Lacustrine gravel (Qlg): Gravel deposited in Lake Bonneville as barriers, spits, tombolos, and beaches is mapped as Qlg. Only the thickest and most extensive accumulations of lacustrine gravel are shown as Qlg on plate 1; less extensive accumulations, some of which include well-formed gravel beaches, barrier-beaches, or spits, are included with Qla.

Many of the coastal depositional features composed of gravel in the Old River Bed area were first studied by G. K. Gilbert (1885, 1890; Hunt, 1982). These include individual cuspate barriers ("V-bars" of Gilbert, 1890, plate VII), stacked cuspate barriers, such as the Snowplow (Gilbert, 1890, plate XIX), looped barriers, such as the classic example at Cup Butte (Gilbert, 1890, plates VI and VII), and inclined barrier spits (where the crests are not horizontal), such as those at Table Mountain (Reservoir Butte; Gilbert, 1890, plates XXIV and XXV; Hunt, 1982, p. 182, figure 15.11).

Deposits of Qlg range in age from approximately 20,000 to 12,000 years before present (figure 2), although it is probable that pre-Bonneville lacustrine gravel underlies the Lake Bonneville Qlg at many localities. Mappable exposures of Qlg deposited early in the Lake Bonneville transgression are found below the Provo shoreline around the edge of Crater Bench basalt flow (figure 4). Some of the best developed barrier beaches were deposited during the later part of the transgression, and are found at elevations between the Bonneville and Provo shorelines. An impressive boulder beach was created at Fumarole Butte, the volcanic neck at the highest point on Crater Bench, during lake stages within about 90 feet (27 m) of the Bonneville shoreline (plate 1; figure 5). The distal (eastern) part of a large Provo-stage tombolo ties the piedmont west of Crater Bench to Crater Bench along the southwest margin of the map area (locality B, table 1). The tombolo is cut by Holocene fault scarps (plate 1; figure 6). The area mapped as Qlg/Qlf in the extreme southeast portion of plate 1 consists of post-Provo regressive-phase lacustrine sandy gravel (sample 1, table 2) that overlies various older and generally finer grained lacustrine deposits. The Qlf component consists predominantly of late Pleistocene fine-grained lacustrine sediments, reworked marl, and white marl (Qlf and Qlm), but transgressive-phase lacustrine gravel (Qlg) and Plio-Pleistocene lacustrine fines (QTlf) are locally exposed beneath the late Pleistocene fine-grained lacustrine sediments.

Most deposits of lacustrine gravel are less than 20 feet (6 m) thick, but locally the thickness may exceed 50 feet (15 m).

Late Pleistocene fine-grained lacustrine deposits and marl (Qlf and Qlm): Fine-grained lacustrine sediments deposited in Lake Bonneville are widespread in the northern Sevier Desert, and are represented in part by the map unit Qlf. Large areas of this unit typically consist of sandy silt or silty sand (samples 6

Figure 4. Numerous beaches are visible around the margin of the Crater Bench basaltic shield volcano, such as the site shown here. Where the beach gravel is of significant extent, it is mapped as lacustrine gravel (Qlg).

Figure 5. Boulder beach (Qlg) on the south flank of Fumarole Butte. The largest boulders exceed 3 feet (1 m) in longest dimension.

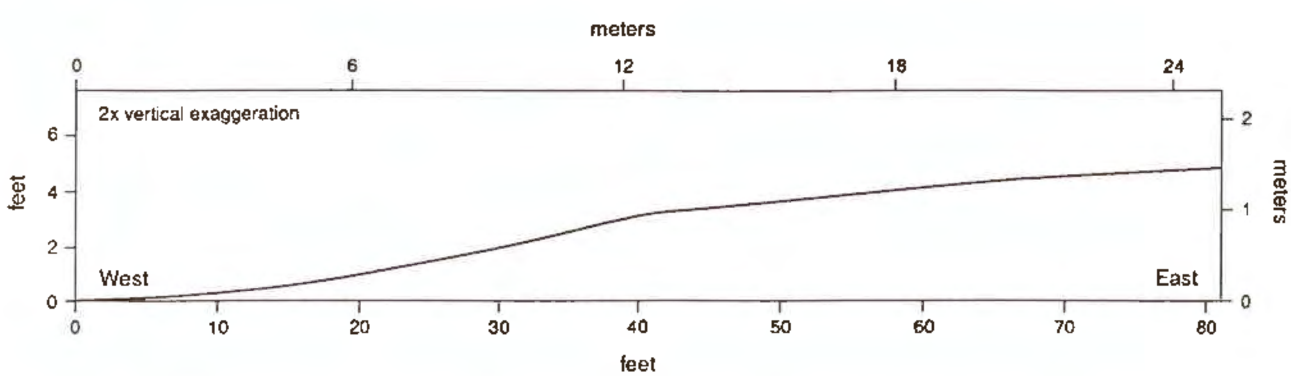

Figure 6. Topographic profile of a Quaternary fault scarp that cuts the Provo-level tombolo on the west side of Crater Bench at locality B (table 1).

and 7, table 2; figure 7), but marl and calcareous clay are also present. Grain-size analysis of a Qlf sand sample shows that it consists of fine-skewed, moderately well-sorted, very fine-grained sand (sample 7, table 3). Qlf locally includes the white marl (Qlm), reworked white marl, and other lacustrine sediments that had been eroded and washed basinward during the regressive phase of Lake Bonneville. Qlm (the white marl, see below) is distinguished as a map unit in many small exposures on plate 1. Qlf is Bonneville and post-Bonneville in age.

Figure 7. *View of sandy, late Pleistocene, fine-grained sediments (Qlf). The photograph was taken looking toward the northeast in the extensive Qlf area lying north and east of the mudflats (Qld), east of Crater Bench. The shrubs are greasewood (**Sarcobatus vermiculatus**).*

Local areas of Qlf have been reworked by post-lacustrine eolian processes. Evidence of eolian activity includes shrub-coppice and other stabilized dunes that are included within mapped areas of Qlf where they are too small to be mapped as separate eolian deposits (Qed). Areas of Qlf adjacent to lacustrine or playa mud in the south-central part of the study area have received some fine-grained eolian sediments deflated from those mud flats. A portion of that deflated material is gypsiferous.

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

The open-water or deep-water deposits of Lake Bonneville are mapped as Qlm (plate 1). The map unit Qlm is the same as the stratigraphic unit named the white marl, as defined by Gilbert (1890), and redefined by Oviatt (1987). Qlm consists of fine-grained white to gray calcium carbonate, and variable amounts of detrital sediments, which were deposited in open-water environments of Lake Bonneville. Grain-size analysis and calcium-carbonate content of a sample of white marl (sample 12) appear in table 2. The white marl is finely bedded to indistinctly laminated, and contains abundant ostracodes throughout. Gastropods are locally abundant near the base and top of the stratigraphic unit, and some exposures of Qlm contain abundant diatoms. The thickness ranges from 6 to 30 feet (2 to 10 m), depending on the local depositional setting. Qlm also includes clastic-rich marl at the base and top of the unit.

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

Table 3.
Northern Sevier Desert textural data.

Sample	Map Unit	Mean Grain Size[1]	Sorting[2]	Skewness[2]	Kurtosis[2]
3	Qed	1.36ø medium-grained sand	1.25ø poorly sorted	0.42 strongly fine skewed	1.7 very leptokurtic
4	Qed	2.21ø fine sand	0.99ø moderately sorted	0.07 nearly symmetrical	1.6 very leptokurtic
7	Qlf	3.69ø very fine-grained sand	0.67ø moderately well sorted	0.27 fine skewed	1.25 leptokurtic
13	Qls	0.95ø coarse sand	2.11ø very poorly sorted	0.33 strongly fine skewed	1.45 leptokurtic

[1] Wentworth (1922)
[2] Folk and Ward (1957)

Gilbert (1890, p. 189-190) described what he referred to as the typical section of the Bonneville beds in the bluffs of the Old River Bed near the point where it is crossed by the Pony Express Road (plate 1). In his interpretation, the white marl was deposited in the second of two deep-lake cycles. We view the white marl as an open-water, or deep-water facies of the Bonneville lake cycle. The first of the two deep-lake cycles interpreted by Gilbert (1890) was inferred from the yellow clay, which underlies the white marl, and which we regard as a deltaic facies of the Bonneville lake cycle (see discussion below under deltaic deposits).

In the northern Sevier Desert, Qlm ranges in age from about 20,000 to 12,000 years before present (figure 2). It was deposited for almost 8,000 years in the topographically lowest parts of the map area, but marl was deposited during much shorter time periods at higher localities near the Bonneville shoreline (figure 2). The base of the white marl is diachronous. However, at altitudes between the Bonneville and Provo shorelines the unconformity at the top of the white marl is essentially isochronous because deposition ceased abruptly due to the sudden lake-level drop caused by the Bonneville flood (Gilbert, 1890; Malde, 1968).

Fine-grained basaltic ash erupted from Pahvant Butte (south of the map area) is interbedded with Qlm at many localities in the map area, some of which are shown on plate 1. The Pahvant Butte ash has been radiocarbon dated at about 15,500 years before present (Oviatt and Nash, 1989; Oviatt, 1991a).

Lacustrine gravelly sand (Qls) and carbonate sand (Qlk): Lacustrine nearshore sand, including beach and offshore sand, is mapped as Qls except in those areas below the Provo shoreline where it consists of distinctive calcium carbonate-rich, fine- to medium-sand with coarse sand- to granule-sized clasts, carbonate pellets, and carbonate-coated gastropods; there it is mapped as Qlk. The composition of Qls reflects local sources, and it ranges from very poorly sorted to well-sorted, fine to very coarse sand. In many places above the Provo shoreline, Qls was deposited in offshore settings as the lake transgressed across alluvial fans or easily eroded bedrock. Waves in the shorezone eroded the alluvium or soft bedrock, and swept the sand-sized and finer sediments offshore where they settled out in the quieter water. Qls is generally less than 6 feet (2 m) thick with massive bedding. Qls is found below, at, and above the Provo shoreline, but Qlk is only found immediately below the Provo shoreline; typically Qlk is 10 to 60 feet (3 to 18 m) below the Provo shoreline, but it also is present locally at lower elevations, especially where it has been reworked by alluvial-fan processes. The carbonate-coated gastropods are generally of the genus *Amnicola*, but also include *Lymnaea*, and small bivalves *(Pisidium)* are also present. Areas mapped as Qls below the Provo shoreline may contain local deposits of Qlk, and vice versa. Both Qls and Qlk have been locally reworked by post-lacustrine eolian and fluvial processes. Qls is of Bonneville age. Qlk stratigraphically overlies the white marl; it was deposited during and perhaps slightly after the Provo phase of Lake Bonneville. Similar carbonate-rich deposits have been found elsewhere in the southern arm of Lake Bonneville (Oviatt, 1989; Sack, 1990).

The large cuspate foreland in the vicinity of South Pine Wash on the east side of the Old River Bed, the uppermost part of which was deposited during the Provo shoreline phase, consists of gravelly muddy sand (sample 13, tables 2 and 3), rather than gravel. This large foreland is on the divide between the Sevier and Great Salt Lake basins at the point where longshore currents converged from the north and south. In addition, the foreland is on the lower piedmont of an area dominated by rock types that produced large amounts of sand and finer sediment.

Lacustrine lagoon deposits (Qll): Poorly bedded deposits of sand, silt, and clay that fill lagoons on the landward sides of Lake Bonneville barrier beaches and beach-ridge complexes are mapped as Qll (sample 11, table 2). 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 from eolian sources and as slope-wash from the surrounding hillsides. Qll therefore is Bonneville and post-Bonneville in age. Numerous lagoons are preserved around the flanks of Table Mountain and near Cup Butte in the Slow Elk Hills. Rather extensive deposits of calcareous, sandy mud-fill lagoons behind Provo shoreline beaches associated with the South Pine Wash cuspate foreland. Most lagoon deposits are probably less than 20 feet (6 m) thick.

Mixed lacustrine and colluvial or regolith deposits (Qlc): Along the north and northwest edge of Crater Bench, a significant amount of basalt covers the surface as relatively angular, gravel-size colluvium and regolith that was reworked to a limited extent by Lake Bonneville, and is therefore mapped as Qlc. Fine-grained Lake Bonneville sediments (Qlf and Qlm) are typically found in association with the reworked colluvium and regolith. Where the weathered basalt was substantially reworked by the lake into beaches or other coastal landforms, it is mapped as Qlg. Qlc is of Bonneville age, and in most places is probably less than 10 feet (3 m) thick.

Lacustrine mud (Qld): A relatively large, flat zone in the low-elevation portion of the study area east of Crater Bench consists of wet, calcareous, lacustrine silt, which is mapped as Qld (figures 8 and 9; sample 5, table 2). These fine-grained sediments were deposited by Lake Bonneville, and possibly by Lake Gunnison, a very late Pleistocene lake in the Sevier Desert (Oviatt, 1988b, 1989), and small, local Holocene water bodies that may have accumulated in this area. The mudflats lie very close to the ground-water table, and collect surface water in some parts during wetter than average years. Qld is locally saline. Deflation of gypsum grains and dried mud pellets from the Qld flats provides much of the material deposited in the eolian sediments that lie generally north and east of the mud flats. Qld includes small areas of mud reworked by post-lacustrine fluvial processes, and is of latest Pleistocene to Holocene age. Thickness is unknown, but is probably less than 20 feet (6 m).

Lacustrine tufa (Qlt): Qlt consists of lithified calcium carbonate precipitated in nearshore environments on bedrock of any composition, or onto unconsolidated, generally calcareous substrates. In places just below the Provo shoreline it is typically light gray to light reddish brown and may contain cemented gastropods. The Provo tufa ranges in form from a heavy cement in coarse gravel at the outer margins of abrasion platforms to coatings 3 feet (1 m) or more thick on Paleozoic or Tertiary bedrock. South of The Shutoff at the base of the Slow Elk Hills

Figure 8. *View to the southeast across flats of lacustrine mud (Qld) toward the site of the Intermountain Power Project, which lies just beyond the southeast corner of the study area.*

Figure 9. *Surface of the mudflats (Qld) east of Crater Bench. The polygons are approximately 6 to 18 inches (15 to 46 cm) across.*

large tufa heads up to about 3 feet (1 m) in diameter (not shown on plate 1) are exposed at the contact between the lower yellow clay (Qdf_2) and the white marl (Qlm), and were probably deposited during the transgression following the Stansbury oscillation (figure 2). In the northern Sevier Desert, Qlt ranges in age from the early transgressive through the regressive phases of Lake Bonneville.

Deltaic Deposits

Deltaic sand and gravel (Qds): Sand and gravel deposited during three different episodes of the Bonneville lake cycle in the Old River Bed area is mapped as Qds_1, Qds_2, or Qds_3 on plate 1. All three Qds units are composed of pebble-sized clasts of igneous and sedimentary rocks mixed with abundant sand. Pebbles of dark and light chert, silicic and basaltic volcanic rocks, and oolitic chert believed to have been derived from the Eocene Green River Formation in central Utah, all indicate sources in the Sevier River drainage basin. The clast lithologies appear identical to those in similar sand and gravel deposits in the Sevier River delta near Lynndyl, Utah.

Figure 10 shows interpretations of the stratigraphic sequence in the Old River Bed area. The oldest deltaic sand and gravel deposits (Qds_3) underlie the lower yellow clay (Qdf^2) at the base of the Bonneville sequence. Qds_3 is exposed along both sides of the Old River Bed between The Shutoff and the Pony Express Road (plate 1). Its base is not clearly exposed, but it appears to overlie Tertiary volcanic rocks at several localities. Qds_3 is conformably overlain by silt, clay, and sand of the lower yellow clay (Qdf_2), and the contact between the two units is locally gradational. Qds_3 is at least 20 feet (6 m) thick, and is interpreted as fluvio-deltaic sand deposited by the Sevier River early in the transgressive phase of Lake Bonneville (Oviatt, 1987).

The middle sand and gravel unit (Qds_2) fills a broad channel entrenched in the lower yellow clay north of Table Mountain (plate 1). It is 40 feet (12 m) thick in places and is overlain by the upper yellow clay (Qdf_1). Qds_2 is interpreted as fluvial sand and gravel deposited during a short-lived lake regression (the Stansbury oscillation; figure 2) during the deposition of the yellow clay fine-grained delta during the transgressive phase of the lake (Oviatt, 1987; Oviatt and others, 1990).

The youngest deltaic sand and gravel unit (Qds_1) is shown at only one locality west of the Old River Bed near the northern boundary of the map area (plate 1). At this locality Qds_1 is less than 10 feet (3 m) thick, and forms low beach ridges that stratigraphically overlie the white marl (Qlm). In nearby areas it is too thin to map, but north of the plate 1 boundary it thickens in exposures along the Old River Bed (Oviatt, 1987). Qds_1 represents the final episode of fluvial/deltaic deposition in this area during the regressive phase of Lake Bonneville.

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

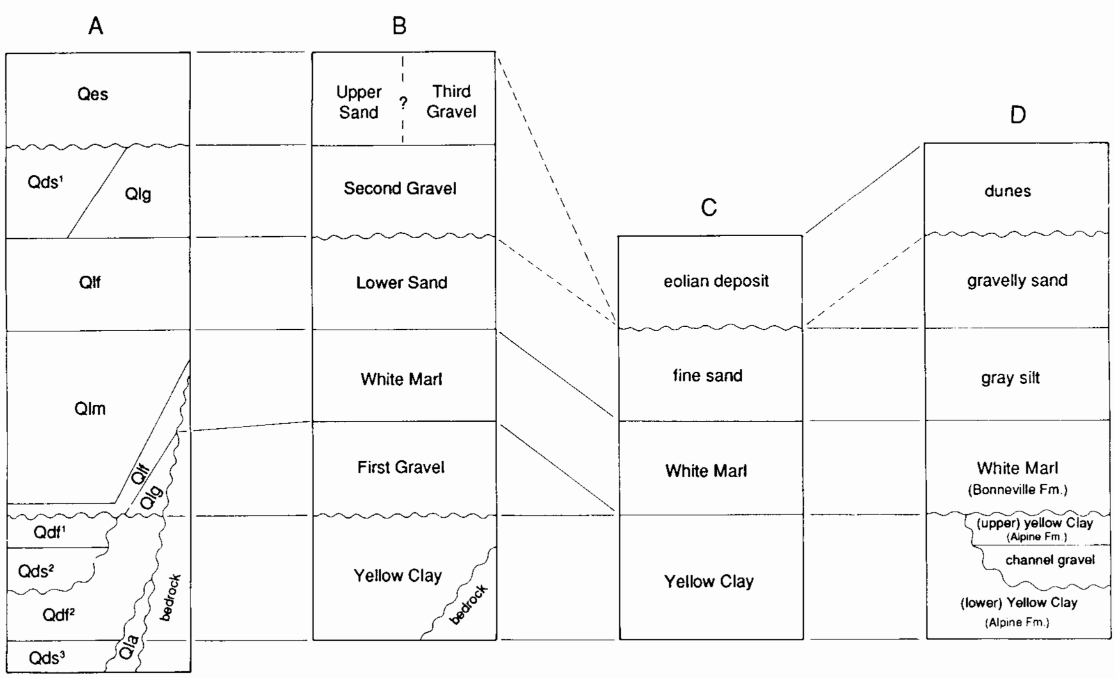

Figure 10. Diagram showing different stratigraphic interpretations of the Bonneville beds at the Old River Bed (modified from Oviatt and McCoy, 1988, figure 2). A – composite stratigraphic column for the Old River Bed area after Oviatt (1987) with the lacustrine and deltaic map units used in plate 1 of this report; B – Gilbert's (1890) interpretation of the Upper River Bed section (at The Shutoff); C – Gilbert's (1890) interpretation of the Lower River Bed section (near the Pony Express Road, locality E); D – Varnes and Van Horn's (1961) interpretation of the Lower River Bed section. Wavy lines indicate unconformities.

Oviatt (1984; 1987). More work should be done to test this hypothesis, but from the available sedimentological, paleontological, geochronometric, stratigraphic, and paleogeomorphic evidence (Oviatt, 1984, 1987), it is clear that the Qdf units were deposited in relatively shallow water at the margin of Lake Bonneville during the transgressive phase (figure 2).

The fine-grained deltaic deposits exposed along the Old River Bed were referred to by Gilbert (1890) as the yellow clay (figures 10B and 10C), and he interpreted them as representing a long-lived deep lake. Varnes and Van Horn (1961) showed that there are actually two yellow clay units that are separated by sand and gravel (Qds_2) (figure 10D). Oviatt (1987) referred to these as the upper and lower yellow clay, and they are mapped as Qdf_1 and Qdf_2, respectively, on plate 1.

The lower yellow clay (Qdf_2) is over 65 feet (20 m) in maximum thickness on the west side of the Old River Bed near the Pony Express Road. It consists of silt and fine sand in laminated to ripple-laminated to massive beds. It has a marsh/pond to marginal-lacustrine ostracode fauna (Oviatt, 1987) and is lithologically similar to the fine-grained deltaic deposits along the Sevier River near Leamington, Utah (figure 1). The lower yellow clay overlies Qds_3, pre-Bonneville alluvial fans, or bedrock, and is overlain by deltaic sand and gravel (Qds_2), the upper yellow clay (Qdf_1), or the white marl (Qlm). It is interpreted as representing deltaic deposition during the early transgressive phase of the lake prior to the Stansbury oscillation (figure 2).

The upper yellow clay (Qdf_1) reaches a maximum thickness of about 20 feet (6 m). It is generally sandier than the lower yellow clay, especially in its lower part, but overall they are lithologically very similar. The distribution of the upper yellow clay is much less extensive than the lower yellow clay, and it is confined to elevations below about 4,500 feet (1,370 m). It is underlain by either the lower yellow clay or deltaic sand and gravel (Qds_2), and is overlain by the white marl. The upper yellow clay is interpreted as representing deltaic deposition by the Sevier River during the late stages of the Stansbury oscillation (Oviatt, 1987; Oviatt and others, 1990).

Alluvial Deposits

Older alluvial-fan deposits (Qaf_2): Pre-Bonneville alluvial fans are mapped as Qaf_2. These deposits are composed mostly of coarse-grained debris, and are mapped in piedmont areas above the Bonneville shoreline. Although most of the material mapped as Qaf_2 was deposited prior to the development of the Bonneville shoreline, Qaf_2 also includes some minor Bonneville-age and post-Bonneville fan deposits in entrenched channels above the Bonneville shoreline that are too small to show at map scale. No numerical ages have been obtained for these old fan deposits, and some of them could be pre-Quaternary in age. Thickness is undetermined, but may be great.

Qaf_2 in in the area of plate 1 is equivalent to Qaf_2 plus QTaf in the Keg Pass quadrangle directly to the west (Shubat and Christenson, 1992). QTaf has not been distinguished in the area of plate 1.

Younger alluvial-fan deposits (Qaf_1): Post-Bonneville alluvial-fan deposits are mapped as Qaf_1. Qaf_1 consists of poorly sorted, coarse- to fine-grained alluvium of ephemeral washes in channels and in fans on piedmont slopes. In many areas Qaf_1 is composed of fine-grained sediments reworked from lacustrine deposits of Lake Bonneville. Small areas of Qaf_1 are lumped with Qla if they are too small to map at a scale of 1:62,500. Thickness is variable.

Alluvium (Qal): Fine-grained alluvium on the floor of the Old River Bed and in other areas is mapped as Qal. These deposits are mostly clay, silt, and sand, and are found underlying the modern or late Holocene floodplain adjacent to modern ephemeral channels. Young alluvium is present along many other active ephemeral channels in the northern Sevier Desert, but the areas are too small to show at map scale. Qal grades into Qaf_1. The maximum thickness of Qal is unknown, but is estimated to be between 20 and 50 feet (6-15 m).

A large area of alluvium in the southeast corner of the map area consists of levee, splay, marsh, and floodplain deposits of the Sevier River. It is equivalent to the middle alluvium (Qal_2) mapped in the central Sevier Desert by Oviatt (1989). These deposits consist of sand, silt, and clay, and in places are pebbly, organic rich, and calcareous (samples 1 and 2, table 2). The unit is quite variable in color: observed colors include light reddish brown and very pale brown (2.5YR 7/4), yellowish brown (10YR 5/6), light brownish gray (10YR 6/2), brownish gray (7.5YR 5/1 and 5YR 7/1), and brownish black (2.5YR 3/1). Fossil molluscs, including the genera *Sphaerium, Anodonta, Physa, Lymnaea, Amnicola, Gyraulus, Valvata,* and *Helisoma,* are locally very abundant. Radiocarbon ages of material sampled from the Sevier River alluvium south of the study area range from 9,570 ± 430 years before present (Beta-12987) (Simms and Isgreen, 1984; Simms and Lindsay, 1989) to 1,050 ± 80 years before present (Beta-19717) (Oviatt, 1989), and therefore the range is from early to late Holocene.

Playa Deposits

Playa mud (Qpm): Areas on the lacustrine mudflats (Qld) or within late Pleistocene lacustrine fine deposits (Qlf) that contained surface water at the time of mapping appear as Qpm on plate 1. Qpm deposits consist of wet clay, silt, and sand, and are locally saline and/or calcareous. This unit represents the groundwater discharge or seepage type of playa. Qpm deposits are generally mapped as overlying lacustrine mud (Qpm/Qld). Qpm is post-Bonneville in age.

Playa silt (Qpi): Playa silt (Qpi) is mapped on Swasey Hardpan (south of Swasey Hardpan Reservoir) in the southwest corner of the map area. Water and clastic sediment from overland flow accumulate in a dry, hardpan playa in this area. Qpi consists of calcareous silt (sample 14, table 2), and develops a vesicular surface structure. It is of Holocene age.

Eolian Deposits

Eolian dune deposits (Qed): Eolian deposits having distinct dune form are mapped as Qed on plate 1. The eolian sediments are gradational in composition, texture, and geomorphic expression. Well-sorted quartz sand forms active and vegetated transverse and parabolic dunes adjacent to the Old River Bed in the northern part of the study area. Lacustrine sand of the South Pine Wash cuspate foreland has been reworked by the wind into partially vegetated transverse dunes, including parabolic dunes. Samples of dune deposits from the cuspate foreland locality consist of strongly fine-skewed, poorly sorted, medium sand (sample 3, tables 2 and 3) and nearly symmetrical, moderately sorted, fine sand (sample 4, tables 2 and 3). Most dunes are less than 10 feet (3 m) tall.

In the southeast part of plate 1, lunettes and shrub-coppice dunes predominate in the numerous areas mapped as Qed. A lunette is a playa-bordering dune that contains sufficient clay to influence dune form and structure (Hills, 1940; Stephens and Crocker, 1946; Bowler, 1973), and consists of a low, rounded mound of fine-grained eolian sediment. Many lunettes are crescent-shaped and support desert shrubs, such as greasewood. In the northern Sevier Desert, sand-sized pellets of dried marl and gypsum grains deflated from the surface of the lacustrine mudflats (Qld or Qpm) are transported generally to the northeast where they are deposited adjacent to the source as irregular lunette ridges (figure 11). Some of the lunettes also contain sand derived from the nearby deposits of lacustrine fines (Qlf) or alluvium (Qal). Subsequent wetting and drying of the lunettes causes the pellets of calcareous fines to disaggregate and reform. As a result, the lunettes lack the loose consistency of eolian sand dunes, and may become quite stable. Shrub-coppice dunes form where the pellets of marl, gypsum grains, and/or clastic eolian sand become trapped around the branches of individual shrubs. All of the deposits mapped as Qed are Holocene in age as shown by their stratigraphic relationships with deposits of Holocene and late Pleistocene age.

Sheet-like eolian deposits (Qes): Wind-deposited sand, silt, and clay that form primarily blanket-like deposits rather than geomorphically well-developed dunes are mapped as Qes. Sheet-like eolian deposits generally overlie other map units, including younger alluvial-fan deposits (Qaf_1), mixed lacustrine and colluvial deposits (Qlc), lacustrine gravel (Qlg), and basalt (Qvb). The sources of these sediments include lacustrine sand (Qls and Qlk), fine-grained lacustrine deposits (Qlf), lacustrine mud (Qld), and alluvium (Qal). The sheet-like eolian deposits are locally calcareous or gypsiferous and are Holocene in age. They are less than 10 feet (3 m) thick.

Spring Deposits

Spring marsh deposits (Qsm): Fine-grained marsh deposits are found in saturated areas around flowing and seepage springs west of Crater Bench. These deposits typically consist of organic-rich clay, silt, and sand, and are locally calcareous or saline. They are of Holocene age. Thickness is undetermined.

Calcareous spring sinter (Qst): Travertine deposited around the orifices of Abraham (Baker, Crater) Hot Springs is mapped as Qst (figure 12). Abraham Hot Springs lies in the south-central part of the study area, just east of Crater Bench and is named Baker Hot Springs on the Baker Hot Springs quadrangle. However, following the recommendation of the Utah State Committee on Place Names (J. M. Haymond *in* Mabey and Budding, 1987, p. 28), we use the name Abraham Hot Springs. Temperatures measured at five of the individual spring pools in the summer of 1990 ranged from 104° to 151°F (40° to 66°C). Gilbert (1890, p. 333) measured temperatures ranging from 110° to 178°F (43° to 81°C), and Rush (1983) reported a maximum temperature of 189°F (87°C). Deposits mapped as Qst consist

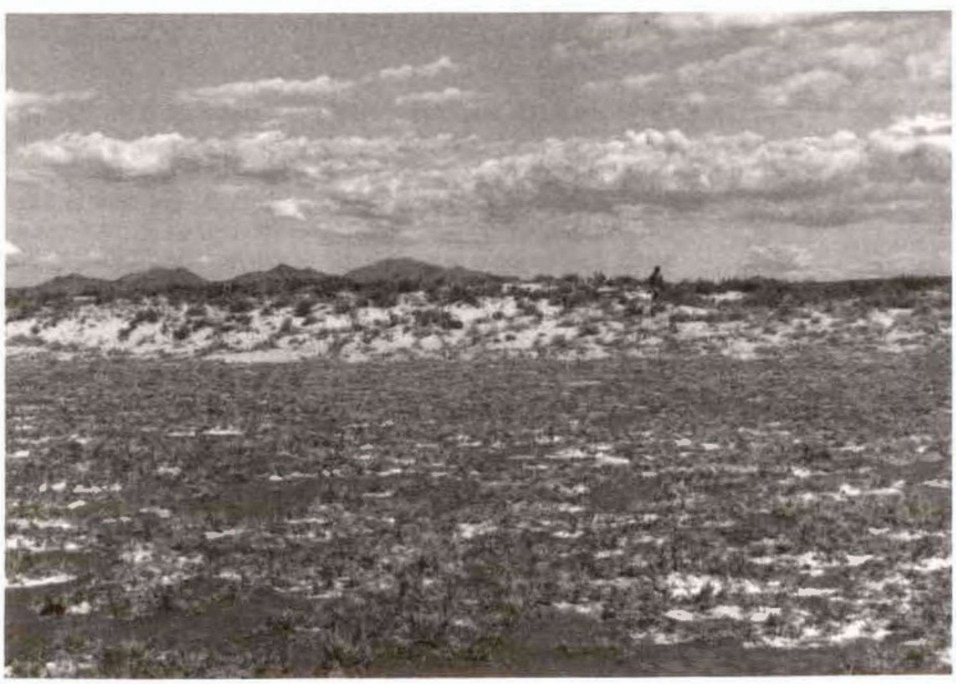

Figure 11. A lunette (Qed) formed adjacent to the flats of lacustrine mud (Qld) on the east side of Crater Bench. Pellets of dried mud and gypsum grains are entrained by the wind from the mudflats and deposited downwind (northeast) in irregular lunette ridges. View is to the northeast.

Figure 12. *Hot spring and calcareous sinter (Qst) at Abraham (Baker) Hot Springs on the east side of Crater Bench.*

of light-gray clay, silt, and sand and manganese-rich, calcareous, reddish-brown travertine (Galyardt and Rush, 1981). Deposition of this unit may have begun in latest Pleistocene time and continues through the present. Thickness is undetermined.

Volcanic Rocks

Quaternary Basalt (Qvb): Basaltic lava flows at Crater Bench are mapped as Qvb. The volcanic field has been studied by Gilbert (1890), Peterson and Nash (1980), and Galyardt and Rush (1981). Crater Bench consists of a basaltic shield volcano composed of lava flows that may range in thickness from about 500 feet (150 m) near the center at Fumarole Butte to approximately 20 feet (6 m) near the margins. Fine-grained Plio-Pleistocene lake beds (QTlf) are exposed beneath the basalt at two localities on the south and east sides of Crater Bench (plate 1; localities A and C; figure 3). As noted by Gilbert (1890, p. 334), the basalt flows were erupted onto the valley floor, and because of more rapid erosion of the less-resistant lake beds, the basalt now stands topographically high. Pillow structures at the base of the lava in an exposure at locality C indicate that the lava flowed into shallow water. Potassium-argon ages of 0.88 Ma and 0.95 ± 0.1 Ma (Peterson and Nash, 1980; Galyardt and Rush, 1981) indicate that the basalt is early Pleistocene in age. Gilbert (1890, p. 333) and later workers (Mabey and Budding, 1987) have noted that warm gas and steam issue from fractures in the vicinity of Fumarole Butte; Mabey and Budding (1987, figure 25) think that the gas and steam may be derived from the same source that heats the water that discharges at Abraham Hot Springs, and that the source may be beneath Crater Bench at a relatively shallow depth (possibly 1.5 to 1.9 miles [2.5 to 3 km]).

Pre-Quaternary Rocks

All pre-Quaternary rocks are mapped on plate 1 with the symbol "b" to indicate bedrock. This includes volcanic and intrusive igneous rocks of Tertiary age, and Paleozoic and Precambrian sedimentary rocks. See Pampeyan (1989) and the references therein, and Shubat and Christenson (1992) and Shubat and Felger (in preparation) for details on the bedrock geology of the area.

STRUCTURE

Introduction

The northern Sevier Desert occupies a complexly faulted structural basin in the eastern part of the Basin and Range Province. It is contiguous with the rest of the Sevier Desert basin to the south (Oviatt, 1989), and 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; Anderson and others, 1983), (2) a broad, low-lying basin floor underlain by a thick sedimentary fill that thins toward the basin margins, and is bounded on the east and west by mountain ranges, and (3) faults that have been active during the Quaternary Period. The Sevier Desert has been volcanically active throughout the Quaternary in contrast to many of the other basins in the Basin and Range Province.

Detachment Surface and Deep Structure

The Sevier Desert basin is bounded at a depth of about 1.2 to 2.5 miles (2-4 km) by a major detachment surface that dips gently westward at 3 to 4 degrees (Allmendinger and others, 1983; Anderson and others, 1983, p. 1065). Movement along the detachment surface may be controlled by deformation in a postulated zone of decoupling located far to the west of the Sevier Desert at a depth of 6 to 12 miles (10 - 20 km; Anderson and others, 1983, p. 1069, figure 8; see also figure 24 in Oviatt, 1989). The Sevier Desert basin is subdivided at depth into a number of smaller basins, which are separated by listric and planar faults that intersect the detachment surface, and that die out upward into the sedimentary fill of the main basin (Allmendinger and others, 1983; Anderson and others, 1983, p. 1065-1066). Some of the Holocene faults in the interior of the main basin may be connected at depth to faults in the bedrock that merge with the detachment surface (Crone and Harding, 1984). Displacement on the late Quaternary faults may therefore be controlled ultimately by deep crustal deformation many miles to the west in the zone of decoupling (Anderson and others, 1983).

Near-Surface Structures

Quaternary fault scarps in the northern Sevier Desert have been mapped by Bucknam and Anderson (1979) and Anderson and Miller (1979). Additional faults are shown on plate 1 and are discussed below.

The Drum Mountains fault zone extends northward into the southwestern part of the map area near Crater Bench. These faults cut units of late Pleistocene (Qla, Qlg) to Holocene (Qaf_1) age. In addition, the early Pleistocene basalt of Crater Bench is cut by many faults and fractures that are parallel to the Drum Mountains fault zone. The northernmost fault in the Drum Mountains fault zone cuts Qla deposits northwest of Crater Bench on the south piedmont of Keg Mountain. Figure 6 is a topographic profile of a fault scarp that cuts the Provo-phase tombolo at the northwest side of Crater Bench (locality B; plate 1). It suggests between 3 to 6 feet (1 to 2 m) of vertical displacement since the tombolo was deposited, about 14,000 years before present. South of the map area in the vicinity of the Drum Mountains the fault zone has been studied by a number of researchers, including Crone (1983) and Crone and Harding (1984) (see also Oviatt, 1989, and Hintze and Oviatt, 1993).

In the extreme southeastern corner of the study area, four fault scarps of what Oviatt (1989) called the IPP faults cross deposits mapped as lacustrine gravel overlying lacustrine fines (Qlg/Qlf). Anderson and Miller (1979) estimated these faults to be of middle to late Pleistocene age, and our mapping indicates an age as young as late Pleistocene to Holocene (post-Bonneville).

A third Quaternary fault zone, referred to here as the Old River Bed fault zone, is found in the east-central part of the study area, east of the Old River Bed channel along the lower piedmonts of Desert Mountain and the Simpson Mountains. These numerous scarps and lineaments trend approximately to the northwest and north, in some places roughly parallel to the piedmont contour. A topographic profile of one of the scarps from an area of fine-grained lacustrine deposits (Qlf) is shown in figure 13 (locality D). At that site, fine-grained lacustrine sediments have been reworked by the wind and caught on the scarp to form a small sinuous dune. No exposures are available across these faults, but assuming the difference in ground level between the two sides of the scarp is due to faulting and not to some other process, the vertical displacement is less than 3 feet (1 m) at locality D. Many vegetation lineaments visible on aerial photographs have little or no discernible vertical displacement on the ground. The scarps in the Old River Bed fault zone cut deposits of late Pleistocene and Holocene age.

GEOLOGIC HISTORY

Late Tertiary Through Middle Pleistocene

The late Pliocene through middle Pleistocene history of the northern Sevier Desert is similar to that in connected basins to the south (Oviatt, 1989, 1991a). The overflow threshold for the basin, which is in the Old River Bed area, was an important geomorphic control on sedimentation and degradation in the basin during that period. Extensional tectonism began in the Sevier Desert region between about 20 million and 7 million years ago (Lindsey, 1982), and the most recent faults are post-Lake Bonneville in age. The Sevier Desert can be characterized

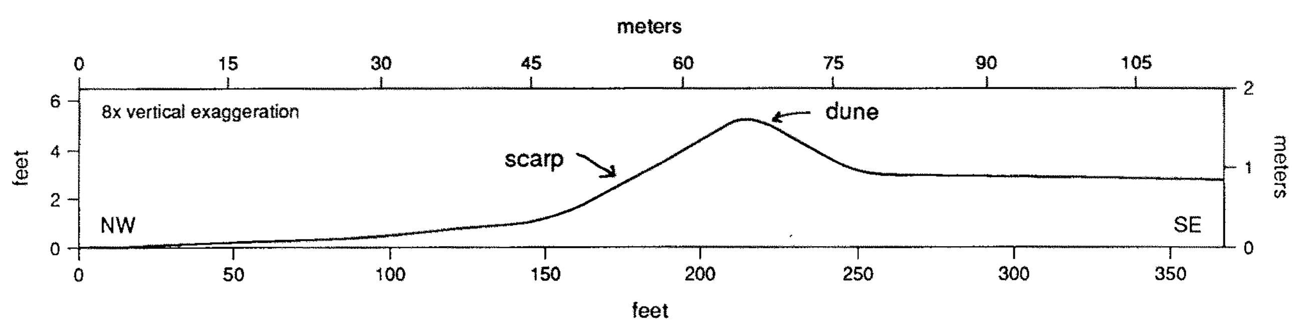

Figure 13. Topographic profile of a Quaternary fault scarp in the Old River Bed fault zone at locality D (table 1). Fine-grained lacustrine sediments reworked by eolian processes have been deposited at the top of the scarp.

as a spreading or opening basin due to the nature of movement on the low-angle Sevier Desert detachment (Allmendinger and others, 1983; Anderson and others, 1983).

During the middle and late Pleistocene, most of the Sevier Desert was subjected to denudation as shown by the following: (a) early Pleistocene basalt flows stand on pedestals of basin-fill deposits (such as at Crater Bench); and (b) widely spaced exposures of lacustrine deposits of Pliocene and Pleistocene age (QTlf) are found 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 elevations, 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 (Oviatt, 1989, 1991a). The overflow (Old River Bed) threshold has probably been lowered and has migrated southward through time primarily due to erosion by discharge from overflowing lakes (Oviatt, 1989). As the basin threshold lowered, waves would have created turbid water in shallow lakes and gradually flushed fine sediment from the basin floor. The process referred to by Currey (1990) as hydroaeolian planation, whereby wind and shallow lakes or flooded playas work together to enlarge and flatten the desert floor, is still an important contributing factor in the degradation of the basin floor. Even distal parts of the drainage basin (such as the Black Rock Desert) have been affected, although not as much as areas closer to the threshold.

The Plio-Pleistocene lake beds (QTlf) provide an excellent stratigraphic record of the early Pleistocene history of the basin, although they are not as well exposed in the northern Sevier Desert as they are farther south (Oviatt, 1989, 1991a). The widespread calcareous clays of QTlf suggest that a freshwater lake or series of lakes existed in this basin for at least the time period from 2.5 to 0.74 million years ago as shown by the ages of interbedded lava flows and volcanic ashes (Oviatt, 1989, 1991a). Steven and Morris (1984, p. 14) presented evidence that the Plio-Pleistocene lake was in existence prior to 3 million years ago. Basalt of Crater Bench, which is approximately 1 million years old (Peterson and Nash, 1980; Galyardt and Rush, 1981), flowed into the Plio-Pleistocene lake. This is evident from pillowed basalt at the base of the lava flows in contact with QTlf at sites along the southern margin of Crater Bench. At one of these sites (locality C), the pillow basalt is approximately 18 feet (5.5 m) thick.

During Bishop ash time (0.74 million years before present), the lake in the Sevier Desert was fresh, but the lake in the Great Salt Lake basin, into which it overflowed, was shallow and saline (Oviatt and Currey, 1987; Oviatt, 1988a, 1989). Therefore, the Sevier basin may have been receiving precipitation from a southerly moisture source that was not affecting the Great Salt Lake basin. This scenario is similar to the situation between about 12,000 and 10,000 years before present when Lake Gunnison overflowed into the northern basin along the Old River Bed and there may have been a dominantly southern moisture source (Oviatt, 1988a, 1988b). During this period, the Great Salt Lake reached very low levels while the Sevier Desert was wet, and Lake Gunnison was overflowing.

A fluctuation in the level of the Plio-Pleistocene lake may be inferred from stratigraphic evidence at locality A (table 1). At this stream-cut exposure, two units of QTlf are separated by a sand and gravel bed, which we interpret as lacustrine (figures 3 and 14). Therefore, we interpret the sequence as representing two relatively deep-water episodes separated by a probable regressive-transgressive event, although the timing and amplitude of the fluctuation are unknown.

Mapping in the Sevier Desert region (Oviatt, 1989, 1991a) indicates that the Plio-Pleistocene lake beds (QTlf) are found at elevations as high as about 4,800 feet (1,460 m). This elevation is presumably that of the overflow threshold during the middle Pleistocene. A comparison of the middle Pleistocene threshold elevation with the modern elevation of the Old River Bed threshold (about 4,600 feet [1,400 m]) suggests that the threshold must have been lowered by about 200 feet (60 m) during late Pleistocene time. The most likely location of the middle Pleistocene threshold is north of the present threshold in the vicinity of Warehouse Rock and Cup Butte (figure 15; plate 1). In this area the Slow Elk Hills on the west side of the Old River Bed are only about 2.5 miles (4 km) from the western limit of the dissected pre-Bonneville alluvial fans (Qaf_2) on the west flank of the Simpson Mountains. A topographic profile drawn through this

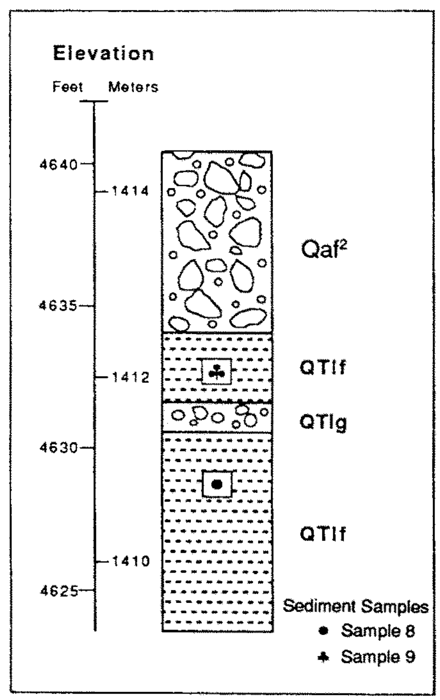

Figure 14. Columnar section measured along the north wall of the stream cut at locality A (table 1). The section shows lower and upper QTlf units that are separated by a sandy gravel bed. Because the sandy gravel unit (QTlg) is interpreted as a transgressive lacustrine shorezone deposit, a fluctuation in the Plio-Pleistocene lake is inferred. The uppermost unit consists largely of pre-Bonneville alluvial-fan deposits, which were surficially reworked by Lake Bonneville. Although the uppermost unit is well below the Bonneville shoreline, it is labelled Qaf_2 here because that designation most adequately characterizes its appearance in the exposure. On plate 1, the uppermost unit is included within an area mapped as mixed lacustrine and alluvial-fan deposits (Qla). Figure 3 is a photograph of this site.

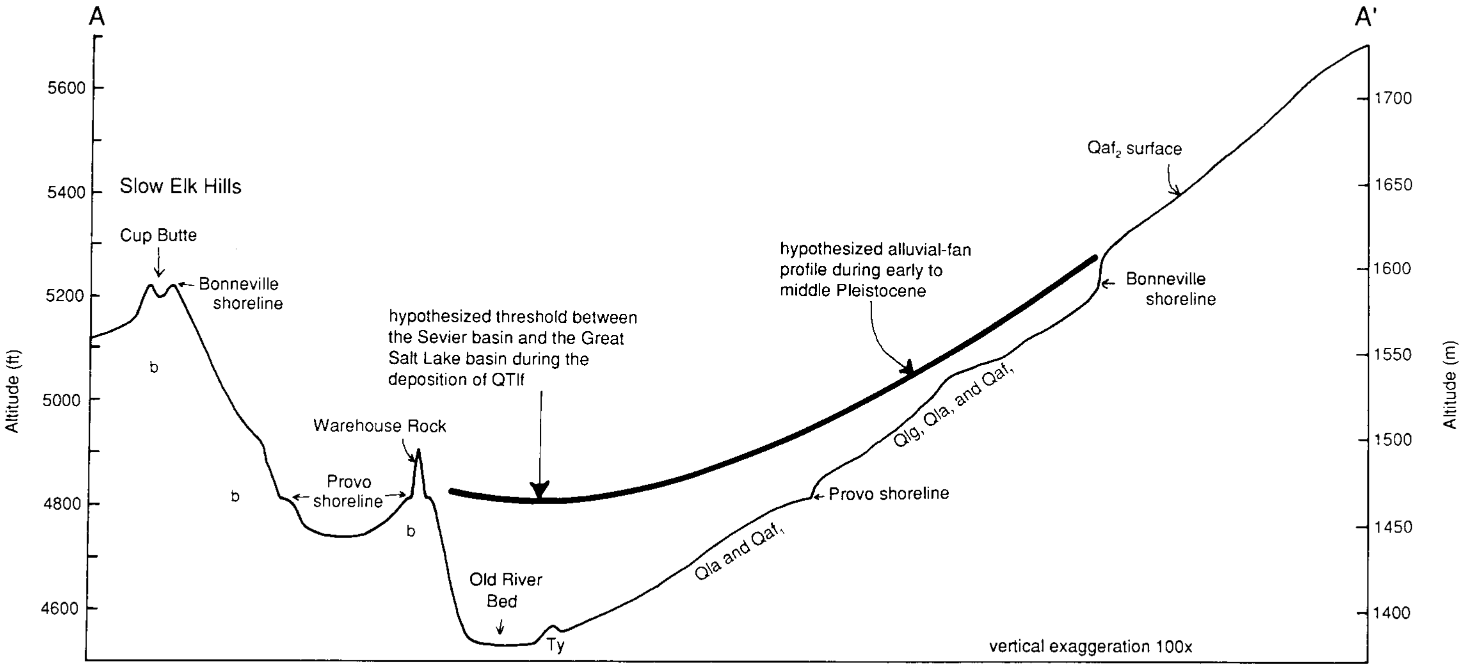

Figure 15. Topographic profile across the Old River Bed along line A-A' from Cup Butte to the west flank of the Simpson Mountains (plate 1).

area (figure 15) shows that it would not be unreasonable for the pre-Bonneville alluvial-fan surface (Qaf_2) to have intersected the Slow Elk Hills at about 4,800 feet (1,460 m) or higher prior to dissection by the ancestral Sevier River along what is now the Old River Bed. The present Old River Bed threshold is near the mouth of South Pine Wash (see Oviatt, 1989, figure 27).

The Pleistocene history of the Sevier Desert, from Bishop ash time (0.74 million years ago) until the deposition of the Little Valley Alloformation (about 0.14 million years ago), is poorly known. It is likely that during this interval a number of lakes existed in the basin, but no lacustrine deposits of intermediate age have been identified in the Sevier Desert (however, it is possible that the upper QTlf unit shown in figure 14 is middle Pleistocene rather than early Pleistocene in age). The lack of surficial preservation of middle Pleistocene deposits may be due to the dominantly erosional environment that has prevailed throughout most of the map area. The Little Valley Alloformation (about 140,000 years before present) is exposed south of the map area in the Sevier River delta (Oviatt, 1989).

Late Pleistocene

Lake Bonneville: The late Pleistocene history of the Sevier Desert is dominated by Lake Bonneville, the history of which is relatively well known (figure 2). See Scott and others (1983), Spencer and others (1984), Currey and Oviatt (1985), McCoy (1987), Oviatt (1987), and Oviatt and others (1992) for discussions of recent refinements in the chronology and stratigraphy of Lake Bonneville. Discussed below are additions to the information on Lake Bonneville derived from this COGEOMAP project.

Old River Bed stratigraphic sections: The Lake Bonneville deposits exposed in the bluffs of the Old River Bed were first studied by Gilbert (1890), and his interpretations of these sections were important in his reconstruction of lake history (Gilbert, 1890, figure 30). Since Gilbert's work, a number of researchers have studied the exposures in the Old River Bed area (figure 10; Antevs, 1948; Ives, 1951; Varnes and Van Horn, 1961; Morrison, 1966; Oviatt, 1984, 1987; Oviatt and McCoy, 1988). The interpretations below are summarized from Oviatt (1987) and Oviatt and McCoy (1988), and from ongoing work in the Bonneville basin.

Figure 16 shows a measured section of the Bonneville beds on the east bluff of the Old River Bed at the point where the Pony Express Road crosses the bluff (locality E, table 1). The section shows many features typical of the Bonneville beds in the Old River Bed area and throughout the Bonneville basin. These include the following. (1) At the base of the section is a transgressive-phase sequence, which in this area consists of fine-grained and coarser grained deltaic units (Qdf_2, Qds_2, Qdf_1) deposited prior to and during the Stansbury oscillation. (2) Overlying the basal deltaic units is a transgressive sand bed (S) at the base of the deep-water marl. (3) A relatively thin marl section below the Bonneville flood contact (BFC), consists of laminated marl in the lower part grading upward into more massive gray marl directly below the contact. The BFC has now been identified basinwide as the boundary between marl deposited during the highest stage of the lake and marl or other sediments deposited during the Provo stillstand. In this section and at many other sections in the Sevier and Black Rock Deserts, the BFC is found a short vertical distance above the Pahvant Butte basaltic ash (PB), which in this section is about 0.8 inches (2 cm) below the contact. (4) A coarsening-upward sequence in the upper part of the white marl (Qlm) represents deposition during the Provo stillstand and the subsequent rapid regression (figure 2). (5) In the Old River Bed area, eolian dunes (Qed) are common at the top of the section. Some of the units listed above are shown in figure 17.

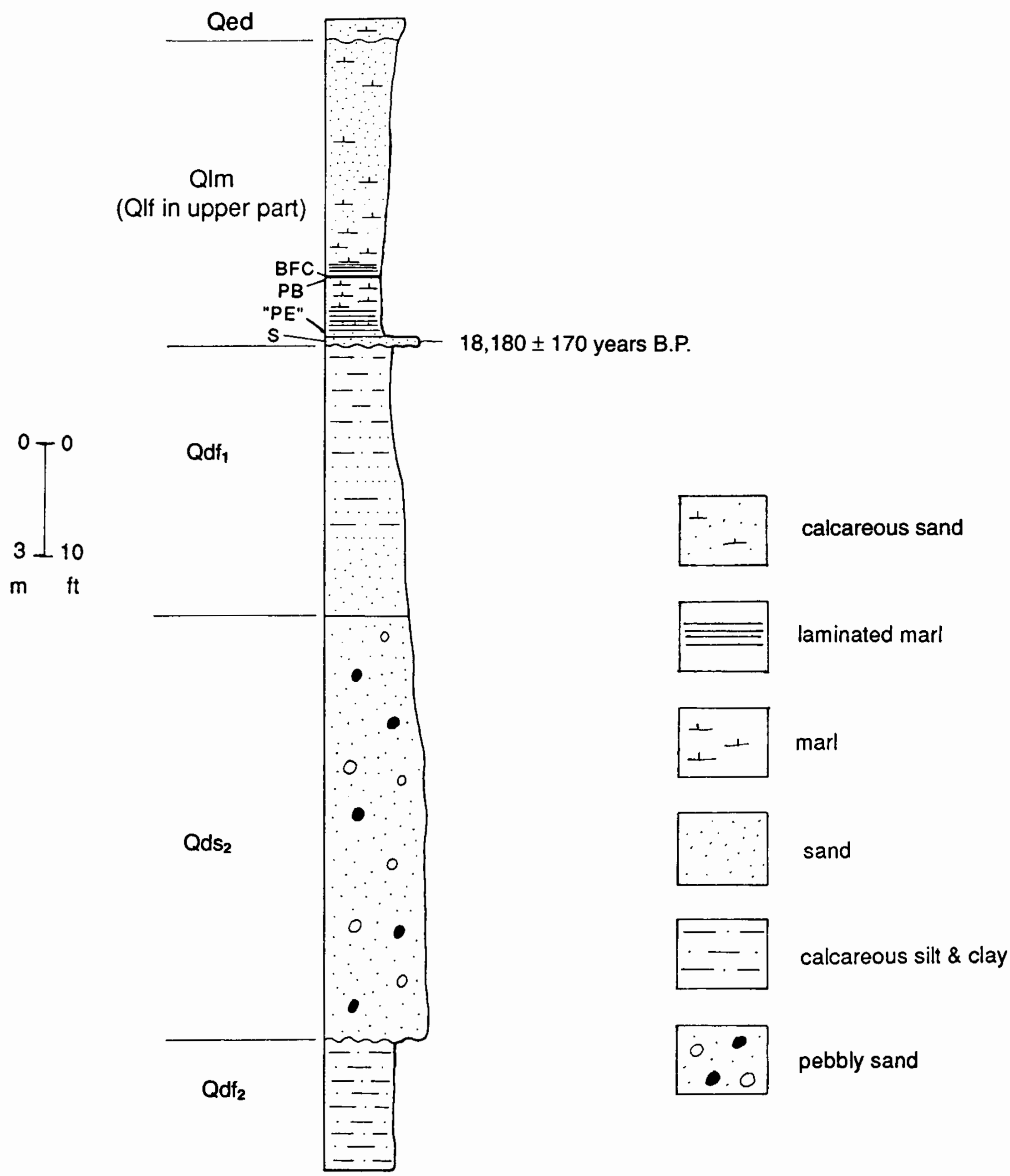

*Figure 16. Measured stratigraphic section of the Bonneville beds 500 feet (150 m) south of the point where the Pony Express Road crosses the east bluff of the Old River Bed (locality E, table 1). Map units in plate 1 are shown. S = beach sand at the base of the white marl (Qlm) from which gastropod shells (**Amnicola**) were collected for radiocarbon analysis (see text); BFC = abrupt contact between massive gray marl (below) and laminated sandy marl (above) interpreted as representing a sharp change in sedimentation caused by the catastrophic Bonneville flood; PB = the Pahvant Butte ash (0.5 to 1 inch [1 to 2 cm] below the BFC); "PE" = informally named "Pony Express" basaltic ash.*

Gastropod shells *(Amnicola)* collected at locality E from the base of the white marl (from the transgressive sand labelled "S") were analyzed for radiocarbon. The determined age, unadjusted for C-13 content, was 17,800 ± 60 years before present (Beta-39295). With a ratio of $^{13}C/^{12}C$ of -1.24 per mil, the adjusted age is 18,180 ± 170 years before present X-ray diffraction analysis indicates that the sample was 100 percent aragonite. An age of 18,000 years is slightly younger than expected for this stratigraphic position at this altitude (figure 2), and is younger than the age obtained by Broecker and Kaufman (1965; 19,800 years before present) for a similar sample from the same strati-graphic position, but from a higher elevation at the Old River Bed (Oviatt, 1987). The age determined by Broecker and Kaufman (1965) is more consistent with the basin-wide sequence, and no satisfactory explanation is yet available for why the age determined in this study is slightly young.

A second basaltic ash, in addition to the Pahvant Butte ash, was discovered at locality E. The ash, which included small pumice lumps, was found in a single thin lens 3.5 inches (9 cm) above the top of the "S" sand bed (figure 16) in the white marl.

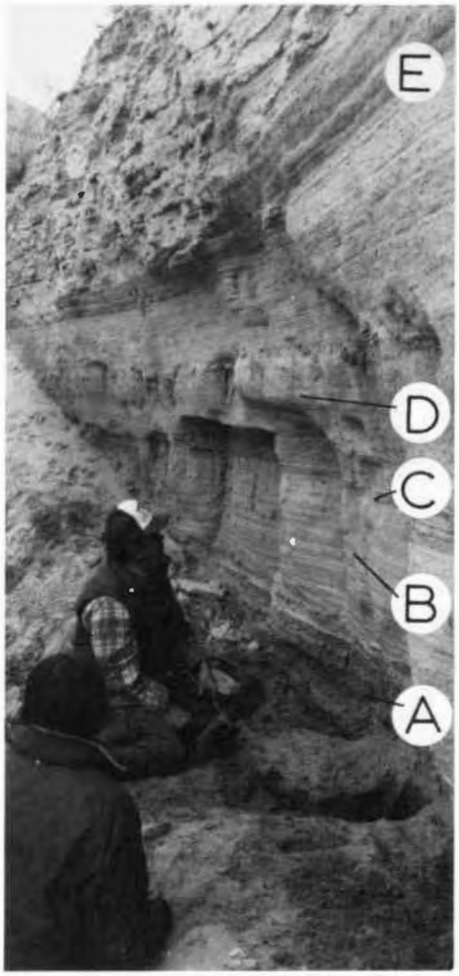

Figure 17. Photograph of an exposure of the white marl (Qlm) on the east side of the Old River Bed at locality I (table 1). Transgressive gravel and sand (A) overlies the lower yellow clay (Qdf_2), and is overlain by the deep-water marl (B), the Bonneville flood contact (C), the Provo marl (D), and upward-coarsening regressive-phase marl (E). This section is shown schematically in figure 4 of Oviatt (1987).

The lens could not be traced laterally more than about 1 foot (30 cm). Microprobe analyses of the basaltic glass are summarized in table 4 (W. P. Nash, written communication, 1991). The glass is chemically similar to basaltic ashes and lavas from the Sevier Desert, but the source volcano has not been identified. At present, no eruption of this age (about 20,000 years before present) is known in the Sevier Desert. The ash bed is informally referred to here as the "Pony Express" basaltic ash (figure 16).

Figure 18 shows a stratigraphic sequence similar to that at the Pony Express Road, but in a geomorphic position above the level of influence of the Sevier River and its deltaic input (locality F, table 1). In this case the transgressive deposits consist of lacustrine gravel and sand, and the regressive deposits are dominated by carbonate-rich sand (Qlk) of Provo and post-Provo age. The details of the white marl stratigraphy in this sequence are similar to those of the Pony Express section (massive, gray deep-water marl containing Pahvant Butte ash is overlain by an abrupt Bonneville flood contact). In addition, it indicates one major transgressive-regressive cycle.

Table 4. Microprobe analysis[a] of basaltic glass from an ash sample collected at locality E (figure 16)

SiO_2	48.1
TiO_2	1.75
Al_2O_3	15.5
FeO[b]	10.2
MnO	0.21
MgO	6.45
CaO	10.3
Na_2O	3.23
K_2O	0.70
P_2O_5	0.34
Cl	0.03
F	0.1
H_2O	3.2
TOTAL	100.11

[a]averages of five analyses of basaltic glass by W. P. Nash, University of Utah (1991, personal communication)
[b]total iron

Keg Mountain oscillation: An exposure on the west flank of the Simpson Mountains lacks evidence for the Keg Mountain oscillation, a hypothesized drop in lake level of about 130 feet (40 m) from the Bonneville shoreline just prior to the Bonneville flood.

The hypothesis of a non-catastrophic drop in lake level from an overflowing lake at the Bonneville shoreline, and the subsequent rise to overflow again just prior to the catastrophic Bonneville flood (figure 19B), was first proposed by Currey (1980, p. 72). The hypothesis helped explain certain aspects of the observed isostatic deformation of the Bonneville and Provo shorelines (they are not parallel; Currey, 1982, 1990) and has been used to explain certain geomorphic features in the Bonneville shoreline zone (Burr and Currey, 1988). Currey and others (1983) named the fluctuation in water level the Keg Mountain oscillation after Keg Mountain (plate 1), where exposures on its east flank (locality G; table 1) were interpreted as representing the oscillation. Since its definition, evidence in other parts of the basin has been interpreted as indicative of the Keg Mountain oscillation (Oviatt, 1984; Machette, 1988).

The Keg Mountain oscillation was originally hypothesized to have been a drop in lake level of about 150 feet (45 m) from the Bonneville shoreline, with the low point of the oscillation being reached just prior to the eruption of the Pahvant Butte basaltic ash (figure 19B; Oviatt, 1984; Currey and Oviatt, 1985).

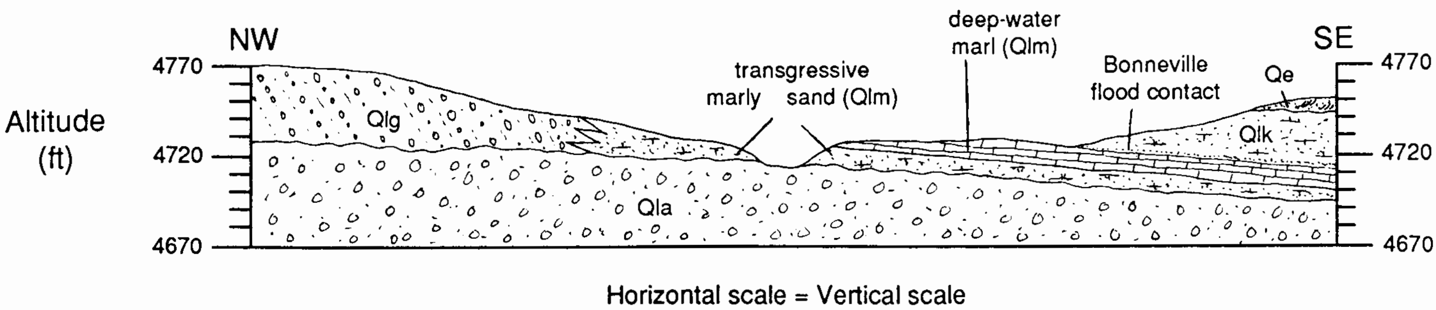

Figure 18. Measured cross section through Lake Bonneville deposits at locality F (table 1). The section shows typical stratigraphic relationships between lacustrine map units. A pre-Bonneville alluvial fan (Qla) is overlain by transgressive-phase calcareous sand and barrier-spit gravel (Qlg), which are both overlain by the southwesterly dipping white marl (Qlm). The Bonneville flood contact separates the deep-water marl from marl and calcareous sand (Qlk) of Provo and immediate post-Provo age. The Pahvant Butte basaltic ash is present about 1 inch (2 cm) below the Bonneville flood contact at the top of the deep-water marl.

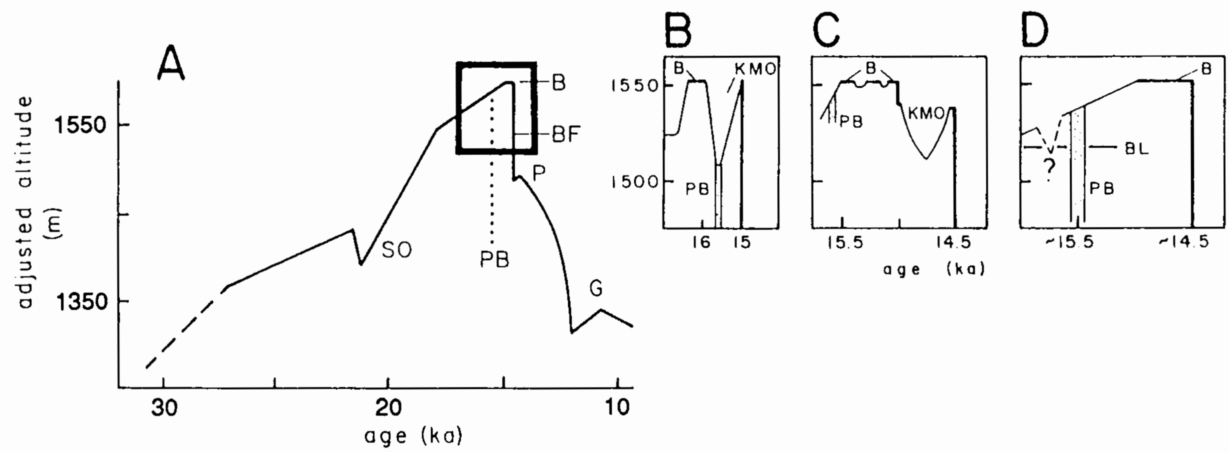

*Figure 19. Diagrams showing interpretations of the Keg Mountain oscillation. **19A** – Time-altitude diagram of Lake Bonneville modified from Oviatt (1992, figure 2). Altitude of water level is adjusted for the effects of isostatic rebound. SO = Stansbury oscillation; B = Bonneville shoreline; BF = Bonneville flood; P = Provo shoreline; G = Gilbert shoreline; PB = Pahvant Butte basaltic ash. The heavy rectangle represents the approximate area enlarged in figures 19B, 19C, and 19D. **19B** – Interpretation of water-level fluctuations near the Bonneville shoreline by Currey and Oviatt (1985). KMO = Keg Mountain oscillation. **19C** – Interpretation of lake level changes near the Bonneville shoreline by Currey and Burr (1988). **19D** – Interpretation based on the Simpson Mountains locality. ? = unnamed transgressive-phase oscillation; other oscillations having this form and magnitude likely occurred during the transgressive phase of the lake. BL = elevation of the boulder line shown in figure 21. The sequence at the type locality of the Keg Mountain oscillation may represent one of these oscillations. The Pahvant Butte ash is not seen at the Simpson Mountains locality; the age of the oscillation is inferred. In figures 19B, 19C, and 19D the heavy line represents periods of overflow; the vertical heavy line is the Bonneville flood. The vertical scale is adjusted altitude (to take into account differential isostatic rebound in the basin); note differences in time scales between the three figures.*

Subsequently, Pahvant Butte was found to have erupted during the transgressive phase of the lake (Oviatt and Nash, 1989; Oviatt, 1991a), and some of the stratigraphic evidence previously thought to represent the oscillation has had to be reinterpreted, as discussed below. Currey and Burr (1988) revised the magnitude and shape of the oscillation based primarily on geomorphic evidence at the Stockton Bar (figures 1 and 19C). Re-evaluation of the evidence at the type locality at Keg Mountain during mapping for the present study indicates that the exposures there are not adequate to demonstrate that the lake dropped from an altitude at or near the Bonneville shoreline to a point approximately 130 feet (40 m) lower (after Currey and Burr, 1988) and then returned to an altitude close to its previous high level. Instead, a hypothesis that calls for a transgressive-phase oscillation of lesser magnitude could also explain the sequence at Keg Mountain and, because it is simpler, may be more likely (figure 19D).

A schematic cross section of the sequence at Keg Mountain is shown in figure 20 reproduced from Currey and others (1983, figure 11). Currey and others (1983) show "deep-lake calcareous silts and clays" of the "White Marl" extending to an elevation close to 5,050 feet (1,540 m) beneath sand and gravel interpreted as representing the Keg Mountain oscillation (their unit 3). At the elevation of unit 3, however, the fine-grained deposits actually consist of calcareous sand, and thus they probably represent deposition relatively close to the shoreline. Downslope from unit 3, below the Provo shoreline, the "White Marl" does consist of "deep-lake calcareous silts and clays," as shown by Currey and others (1983, figure 11). The calcareous sand beneath unit 3 was interpreted by Currey and others (1983) as representing deposition during a high stand at the Bonneville shoreline (5,200 feet; 1,585 m), and the unit 3 lacustrine gravel was interpreted as representing deposition during a drop in lake level from the Bonneville shoreline prior to the Bonneville flood (figure 19B). In this interpretation the lake was inferred to have transgressed again almost to the Bonneville shoreline, and then almost immediately to have dropped catastrophically due to the flood.

The gravel of unit 3 can be traced laterally to the south into a spit that seems to have formed at a water-level elevation of about 5,055 feet (1,540 m) (hand-level measurement of 145 feet [44 m] below the Bonneville shoreline at 5,200 feet [1,585 m]). The calcareous sand that underlies the Keg Mountain gravel does not extend below the lower elevational limit of unit 3 (4,955 feet; 1,510 m), and cannot be traced higher than 5,055 feet (1,540 m) on the mountain side. Likewise, the lacustrine gravel that underlies the calcareous sand (labelled number 2 in figure 20) cannot be traced higher than 5,055 feet (1,540 m). Therefore, at this locality it is not possible to determine the maximum elevation of the lake surface during the deposition of the calcareous sand, and a hypothesis involving a lake-level fluctuation during the transgressive phase, such as that shown in figure 19D, could explain the evidence.

In order to test the two hypotheses (figures 19C and 19D), it is necessary to examine the stratigraphic sequences at other localities. At Leamington, Utah, a gravel wedge that was interpreted at one time as evidence for the Keg Mountain oscillation (Oviatt, 1984), has been restudied, and is now interpreted as having been deposited during a transgressive-phase fluctuation of unknown amplitude. The gravel is nearshore lacustrine gravel that is both underlain and overlain by fine-grained nearshore and deltaic deposits. A reinterpretation of the gravel is necessary because it is directly overlain by the Pahvant Butte basaltic ash, which was erupted about 15,500 years before present after Lake Bonneville had transgressed to within about 50 feet (15 m) of the Bonneville shoreline (Oviatt and Nash, 1989; Oviatt 1991a). Therefore the Keg Mountain oscillation hypothesis must be rejected as an explanation for the Leamington gravel wedge, and the hypothesis of a transgressive-phase fluctuation should be adopted in its place. An older lacustrine gravel wedge at Leamington (Varnes and Van Horn, 1961; McCoy, 1981; Oviatt, 1984), which is stratigraphically between fine-grained units, must also represent deposition during a fluctuation on the transgressive phase. Either of these fluctuations could be correlative with the fluctuation that deposited unit 3 at Keg Mountain. No known deposits at Leamington are reasonable candidates for representing the Keg Mountain oscillation.

We describe below an exposure in the map area (locality H; table 1) that also lacks evidence for the Keg Mountain oscillation. On the west flank of the Simpson Mountains (plate 1) the Bonneville shoreline and many large cuspate barriers (V-bars of Gilbert, 1890, plate VII), and other massive gravel embankments referred to as "Intermediate Shore-Lines" by Gilbert (1890) are well preserved. At locality H, a stream cut exposes a sequence of lacustrine sediments that contains evidence for a transgressive-phase oscillation and subsequent development of the Bonneville-shoreline gravel-barrier complex, but no evidence for the Keg Mountain oscillation.

Figure 21 shows the stratigraphic relationships at the Simpson Mountains locality. Foreset beds in lacustrine gravel (1 in figure 21) at the base of the sequence dip lakeward, and are truncated and overlain by a boulder line (2) consisting of rounded quartzite boulders that locally bear a tufa coating. The horizontal and vertical extent of the boulder line cannot be determined completely, but within the limits of the exposure the line of boulders is uniform, dips gently lakeward, and lies at an elevation of about 5,110 feet (1,558 m). Exposures to the east of figure 21 suggest that the boulder line does not rise in elevation to the Bonneville shoreline. Calcareous fine to medium sand (3) overlying the boulder line contains abundant gastropod shells of the genera *Lymnaea* and *Amnicola*, which are common taxa in the Bonneville Alloformation throughout the basin. The sand has been protected from erosion by a small post-Bonneville alluvial fan (6) composed of reworked lacustrine gravel derived from a gully on the face of a large gravel cuspate barrier to the east (4). At the eastern end of the exposure, a wedge of gravel (4) at the edge of this barrier divides the calcareous sand into upper (5) and lower (3) parts. The gravel can be traced to the Bonneville shoreline about 110 feet (34 m) vertically above the base of the gravel wedge (figure 21).

Lymnaea shells collected from the lacustrine sand (3) have a radiocarbon age of 14,830 ± 160 years before present (Beta-39294; C-13/C-12 content -1.48 per mil; unadjusted age 14,440 ± 150 years before present). X-ray analysis indicates that the shells are composed of 100 percent aragonite, and therefore contamination by secondary calcite precipitation is insignificant (or undetectable). An age of 14,800 years before present is essentially identical to the postulated age of the Bonneville shoreline at 15,000 years (Oviatt, 1991a) when all possible sources of error are considered.

We interpret the sequence at locality H as follows. The lowermost foreset gravel (1 in figure 21) represents wave-zone deposition during the transgressive phase of the lake. The lake level then dropped and waves washed over the flat top of this gravel embankment and formed a boulder beach (boulder line; 2); the amplitude of this oscillation in lake level is unknown. The initial working hypothesis evaluated in the field was that the boulder line represents the Keg Mountain oscillation. This hypothesis was rejected when it was discovered that the thick foreset gravel (unit 4) that overlies the boulder line could be traced to the Bonneville shoreline; the boulder line therefore is older than the Bonneville shoreline, and cannot be related to the Keg Mountain oscillation (see figures 19B and 19C).

Following the fluctuation that produced the boulder line, the lake continued to transgress toward its highest level, the Bonneville shoreline. As the lake deepened at this locality the first facies to be deposited was offshore sand (3), but eventually foreset gravel (4) was deposited above the sand as the cuspate

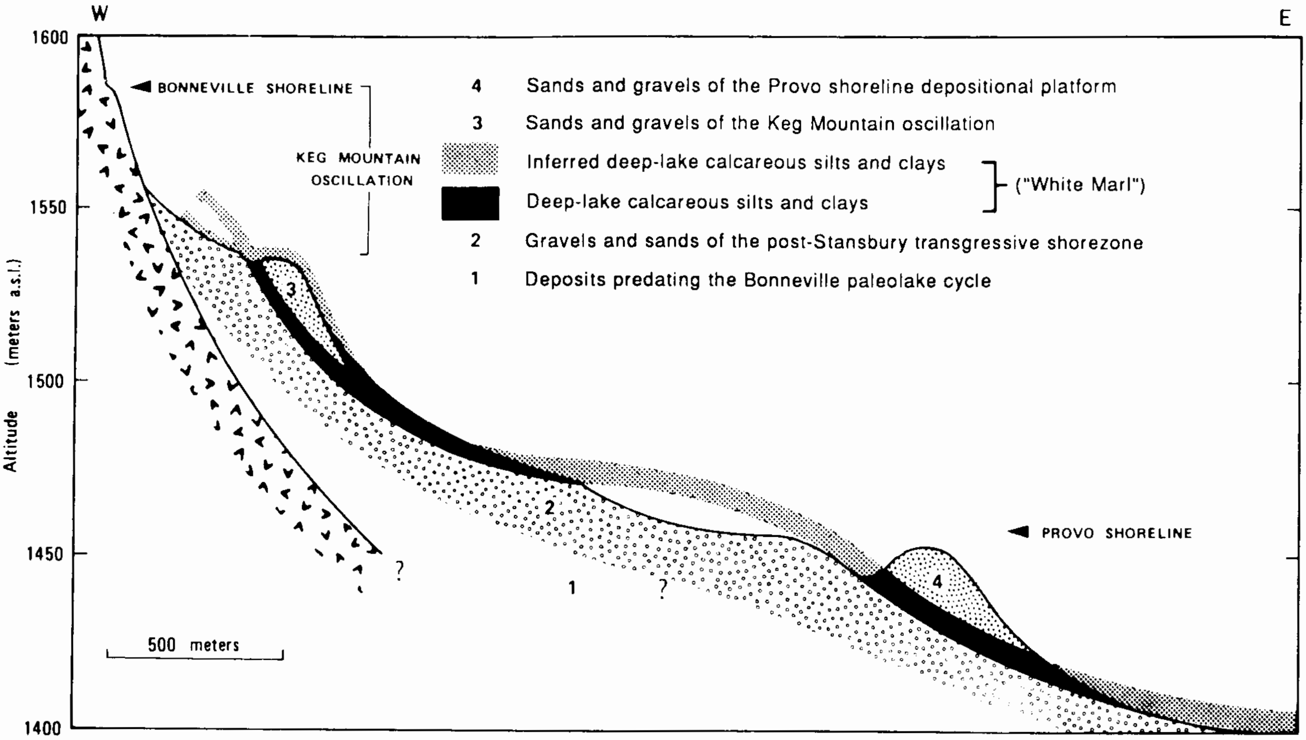

Figure 20. *Schematic cross section showing stratigraphic relationships on the east flank of Keg Mountain (locality G, table 1) (from Currey and others, 1983, figure 11).*

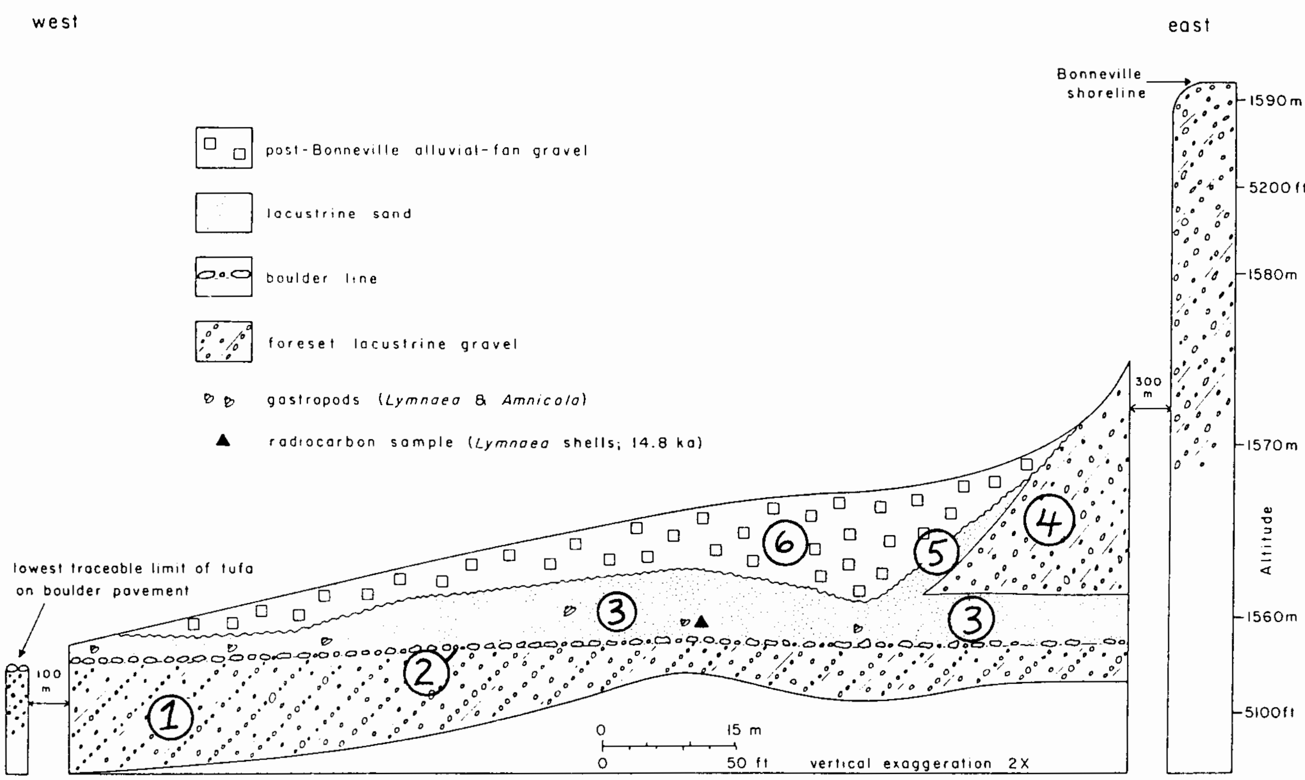

Figure 21. *Cross section through Lake Bonneville deposits at the Simpson Mountains locality (locality H, table 1). See text for an explanation of the numbered stratigraphic units.*

barrier prograded lakeward. This barrier forms the foundation for the final Bonneville-level cuspate barrier. At the lake's highest levels more offshore sand (5) was deposited on the sublacustrine flanks of the barrier, the crest of which was at or near the Bonneville shoreline approximately 100 feet (30 m) higher. In this interpretation, the 14,800 years before present *Lymnaea* shells were deposited offshore, but the snails were probably living in or near the Bonneville shorezone.

Following the catastrophic drop in lake level caused by the Bonneville flood, the cuspate barrier (unit 4) was exposed to gullying, and fan gravel (6) was deposited over the lacustrine sand (5). The gravel thus protected the lacustrine sand from erosion during the Holocene. Evidence for the Keg Mountain oscillation, in the form of another regressive/transgressive cycle, should be at the top of the lacustrine sand, and should consist of evidence for erosion of the sand and/or of deposition of a coarse facies. Considering the local geomorphic setting at this locality (an open coastline exposed to over 100 miles [160 km] of fetch and abundant sediment supply), the probability is low that the lake could have regressed and transgressed across the sand at this locality without eroding the sand, depositing gravel, or forming a boulder beach similar to the number 2 (figure 2) boulder line.

In conclusion, if the interpretations outlined above are correct, there is no positive evidence for the Keg Mountain oscillation at locality H. Three hypotheses can then be proposed: (1) The Keg Mountain oscillation did occur, but evidence for it was eroded prior to the alluvial-fan deposition. (2) The Keg Mountain oscillation did occur, but the lower limit of the oscillation was above the exposure described here. (3) There was no Keg Mountain oscillation. None of these hypotheses can be tested at the Simpson Mountains locality. Hypothesis number 2 would require revision of Currey and Burr's (1988) model to show the low point of the oscillation at least 60 feet (20 m) higher, and may not be consistent with other interpretations of lake history.

If the stratigraphy at Keg Mountain, Leamington, and the Simpson Mountains localities had been studied independently of any knowledge of the Keg Mountain hypothesis, such a hypothesis might not have been considered. That is, there is no empirical evidence at these three localities that would lead directly to the Keg Mountain oscillation hypothesis. This lack of evidence, of course, does not demonstrate that the Keg Mountain hypothesis is not viable, but it does reveal that a great deal of hypothesis testing is in order. For instance, there are unpublished suggestions for the Keg Mountain oscillation in the stratigraphic records at a few localities in the basin for which alternative hypotheses have not been tested (Black Rock Canyon in the Oquirrh Mountains, D. R. Currey, oral communication, 1985; near Kanosh, Utah, Oviatt, 1987, unpublished data). In addition, an alternative explanation for the isostatic relationship between the Bonneville and Provo shorelines has not been proposed. Therefore, more work is necessary before the question can be answered with satisfaction. Until that work has been accomplished, inferences about paleoclimate based on the Keg Mountain oscillation, and correlations with other lake basins, should be made with caution. In addition, it can be stated that the Keg Mountain locality is not an appropriate type area for the oscillation, and that if after further testing the oscillation is shown to have been real, the type locality should be changed to a more appropriate locality where unequivocal evidence exists.

Following development of the Provo shoreline, Lake Bonneville regressed rapidly until it reached the elevation of the Old River Bed threshold, where it split into separate lakes, Great Salt Lake in the northern basin, and Lake Gunnison in the Sevier basin (Oviatt, 1988b; Oviatt and others, 1992). Water flowed along the Old River Bed from the Sevier basin from about 12,000 to 10,000 years before present (Oviatt, 1988b), after which Lake Gunnison dessicated. The Sevier River, which during the transgressive phase of Lake Bonneville had flowed into the Great Salt Lake basin without terminating in the Sevier basin, has terminated in Sevier Lake since, and including, Lake Gunnison time. The relocation of the Sevier River was partly caused by a change in the course of the river in the area of its delta northeast of the town of Delta, Utah. During the transgressive phase of Lake Bonneville the Sevier River flowed almost due west from Leamington Canyon, where it enters the Sevier Desert, but during the regression of Lake Bonneville the river shifted to a more southerly course (Oviatt and others, 1994).

Holocene

During the Holocene, the Sevier Desert has been dominated by degradation caused largely by base-level lowering following the regression of Lake Bonneville. However, sediments have been deposited in local areas such as in alluvial fans, mudflats, and floodplains of ephemeral streams and the Sevier River. Eolian deposits of Holocene age are especially widespread.

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