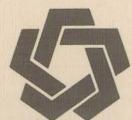


QUATERNARY GEOLOGY OF FISH SPRINGS FLAT, JUAB COUNTY, UTAH

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A COGEOMAP project in cooperation with the U.S. Geological Survey



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ABSTRACT

Fish Springs Flat is a sediment-filled valley between two tilted mountain blocks, the Thomas Range and the Fish Springs Range, in the Basin and Range physiographic province of western Utah. The valley is bordered on the north by the Great Salt Lake Desert and on the south by Whirlwind Valley. This report describes the surficial deposits of Quaternary age on the floor of Fish Springs Flat and along its peripheral piedmont slopes, an area of about 330 miles² (840 km²), which was mapped at a scale of 1:50,000.

Surficial deposits in the map area consist of late-Pleistocene and Holocene alluvial fans and alluvium of ephemeral streams that drain the surrounding mountains, and lacustrine deposits of late-Pleistocene Lake Bonneville. Eolian sand dunes are locally important, and alluvial or playa mud covers the low parts of the valley at the north end. A prominent late-Holocene fault scarp parallels the front of the Fish Springs Range on the west side of the valley, and older pediments have developed along the flank of the Thomas Range on the east.

Deposits and landforms of Lake Bonneville, especially of the Stansbury, Bonneville, and Provo shorelines, are well preserved in the Fish Springs Flat area and provide an excellent stratigraphic record of the lake.

INTRODUCTION

Fish Springs Flat is located in west-central Utah, between the Fish Springs Range and the Thomas Range, at the southern margin of the Great Salt Lake Desert (figure 1). It is a down-faulted sediment-filled basin in the eastern Basin and Range province. Fish Springs Flat is a gently sloping valley that opens out into the Great Salt Lake Desert on the north and rises to the south to a low divide between it and Whirlwind Valley. The lowest altitude at the north end of Fish Springs Flat is about 4290 feet (1310 m); the highest altitudes in the map area are in the Fish Springs Range (7660 ft; 2330 m), and the Thomas Range (7100 ft; 2160 m). The valley floor has little relief except for a few small hills of Tertiary volcanic rocks and Paleozoic sedimentary rocks along the eastern and southern margins.

The purpose of this report is to describe the surficial deposits of Quaternary age on the floor of Fish Springs Flat and along its peripheral piedmont slopes. The map area (plate 1) is irregular and includes about 330 miles² (840 km²), or the equivalent of about six 7.5-minute topographic quadrangles. Surficial deposits were

mapped on 1:40,000-scale aerial photographs in the field during the months of June and July, 1988. The field data were later transferred to 1:24,000-scale orthophotoquads which were reduced to 1:50,000 and compiled to produce the map (plate 1).

Surficial deposits that dominate the map area consist of alluvial fans and alluvium of ephemeral streams that drain the surrounding mountains, and lacustrine deposits of Lake Bonneville. Eolian sand dunes are locally important, and alluvial or playa mud covers the low parts of the valley at the north end. A prominent late-Holocene fault scarp parallels the front of the Fish Springs Range on the west side of the valley, and older pediments have developed along the flank of the Thomas Range on the east.

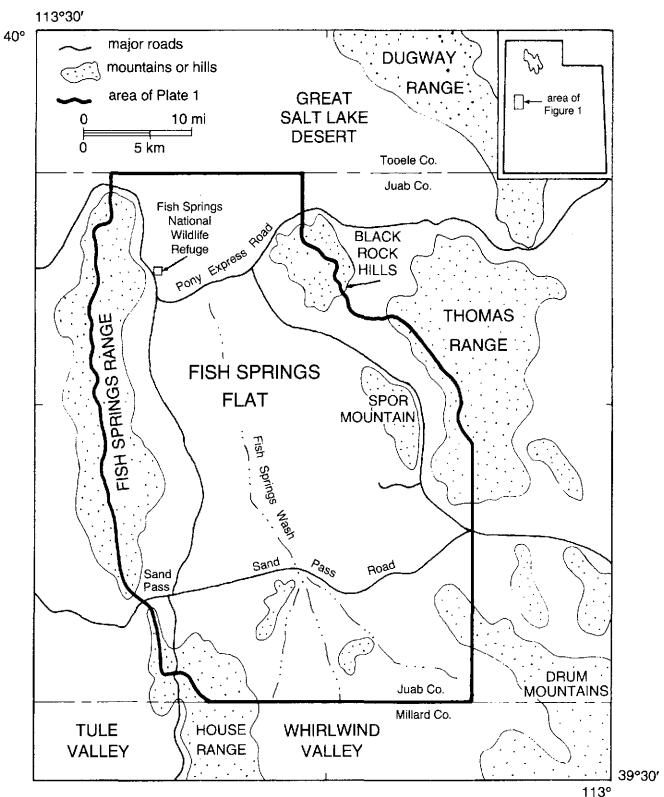


Figure 1. Location of Fish Springs Flat in western Utah. The area encompassed by plate 1 is shown with a heavy line.

The climate of Fish Springs Flat is warm and arid. Mean annual temperature at Deseret, Utah, 50 miles (80 km) southeast of Fish Springs Flat, is 49°F (9.4°C), and mean annual precipitation is 7.06 inches (179 mm) for the period 1951 to 1974 (NOAA, 1980). The only permanent human inhabitants of the area are the employees at the Fish Springs National Wildlife Refuge and the Brush-Wellman beryllium mine. Water from a number of large springs maintains a series of shallow diked pools at the wildlife refuge.

Previous geologic studies in the area have focused mainly on the Paleozoic and Tertiary bedrock (Staatz and Carr, 1964; Hogg, 1972; Hintze, 1978, 1980a-e; Morris, 1978; Lindsey, 1978, 1979, 1982; Dommer, 1980). Bucknam and Anderson (1979a, b), Piekarzki (1980), and Bucknam and others (1989) have studied the Holocene fault scarps along the eastern base of the Fish Springs Range. Sack (1988) mapped the Quaternary geology of Tule Valley, southwest of Fish Springs Flat, while Davis (Hintze and Davis, 1988) has mapped the Quaternary deposits in Whirlwind Valley, south of Fish Springs Flat. Davis (1984) reviewed the development of beryllium mining in the Spur Mountain area. Gates and Kruer (1981) and Gates (1984, 1987) reviewed the ground-water geology of the eastern Great Basin, including that of Fish Springs Flat. In the 1940s, Ives (1946a, b, 1948) wrote several short articles on the Fish Springs area. Gilbert (1890) and Currey (1982) have mapped Lake Bonneville shorelines in Fish Springs Flat.

DESCRIPTION OF MAP UNITS

For mapping purposes (plate 1) the Quaternary deposits in Fish Springs Flat are classified primarily on the basis of their environments of deposition. The unconsolidated Quaternary sediments were deposited in lacustrine, alluvial, mass-wasting, and eolian environments as indicated by the first lower-case letter in the map-unit symbols. Other distinguishing characteristics, such as texture, lithology, or geomorphic expression, are used to subdivide the deposits into mappable units and are indicated by the second lower-case letter in the symbol. Some deposits can be grouped into map units having distinctly different relative ages. In these cases, number subscripts are used, such as in the map units Qal₁, Qal₂, and Qal₃, where the subscript 1 indicates a younger relative age than the subscripts 2 or 3. 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. The only example of this in the area of plate 1 is where thin or discontinuous lacustrine tufa overlies lacustrine and alluvial gravels, which are mapped together as Qlt/Qla.

The ages of the map units discussed below are primarily based on the stratigraphic relationships of the deposits with deposits or landforms of Lake Bonneville, the ages of which are well known (figure 2). In addition, three radiocarbon-age determinations were obtained for this study (table 1; see discussions of these ages in the text below).

The map units are described below under their major genetic categories but not necessarily in stratigraphic order.

Pre-Quaternary Rocks

Paleozoic sedimentary rocks (Ps) — All Paleozoic sedimentary rocks, which are mostly marine carbonate rocks, but which also include some marine clastic units, are mapped as Ps. See the following references for more information on the Paleozoic rocks (Staatz and Carr, 1964; Dommer, 1980; Hintze, 1980a-e). Undiffer-

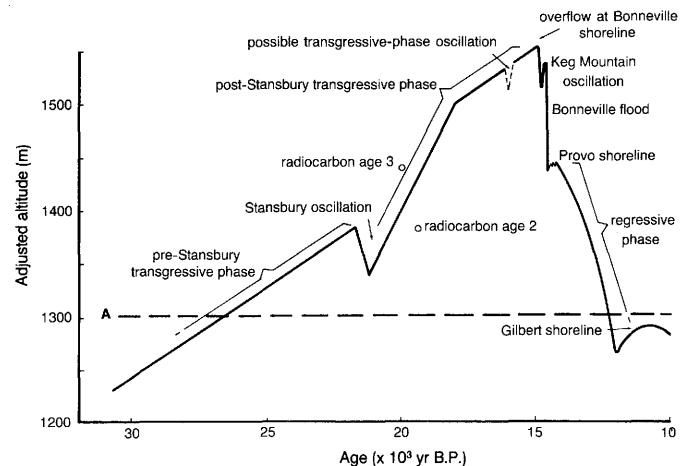


Figure 2. Schematic time-altitude curve for Lake Bonneville (modified from Currey and Oviatt, 1985; Currey and Burr, 1988; and Oviatt and others, 1990). Altitudes are adjusted for the effects of isostatic rebound, and therefore do not necessarily reflect modern altitudes. A = approximate level of lowest part of floor of Fish Springs Flat; the white marl (Qlm) and other lacustrine deposits can be found at altitudes above this level in Fish Springs Flat.

entiated thin colluvium and talus are present throughout the area mapped as Ps.

Tertiary sedimentary rocks (Ts) — Coarse-grained sediments of Tertiary age are mapped at several localities in Fish Springs Flat. Three small patches of Ts, composed of large boulders of quartzite, are present near the Sand Pass Road in the southeast corner of the map area. L.F. Hintze regards these as outcrops of the Skull Rock Pass Conglomerate of Oligocene age (L.F. Hintze, oral communication, 1988). In addition, Hintze (1980d) has mapped several exposures of the Skull Rock Pass Conglomerate (Ts in plate 1) along the eastern base of the Fish Springs Range.

Tertiary volcanic rocks (Tv) — All Tertiary volcanic rocks, and some minor exposures of Tertiary intrusive rocks, are mapped as Tv. These rocks have been mapped by previous authors (Staatz and Carr, 1964; Lindsey, 1978, 1979, 1982; Dommer, 1980; Hogg, 1972; Hintze, 1980a-e), and they have not been subdivided in plate 1.

Lacustrine Deposits

Lacustrine and alluvial deposits, undivided (Qla) — In piedmont areas, thin lacustrine gravel deposits overlying pre-Bonneville alluvial fans are mapped as Qla. The thin lacustrine gravel was derived from coarse-grained alluvium that was reworked by waves during the transgressive and regressive phases of Lake Bonneville. The gravel is moderately well rounded and sorted, and locally contains gastropods. In some areas, the lacustrine-gravel component of Qla is so thin it cannot be easily distinguished from the pre-Bonneville alluvial-fan gravel on which it lies. In such cases, however, Lake Bonneville shorelines, which are visible on aerial photographs, are etched across the pre-Bonneville alluvial fans, indicating that waves in Lake Bonneville modified the alluvial-fan surfaces, and that post-Bonneville fluvial activity has been negligible in these areas. In addition, areas of alluvial and lacustrine deposits in patches too small to differentiate at a scale of 1:50,000 are mapped as Qla. The lacustrine gravel in Qla is probably less than 20 feet (6 m) thick in most areas, but the underlying pre-Bonneville alluvial-fan gravel mapped as Qla could be hundreds of feet thick.

Table 1.
Radiocarbon ages of shell samples from Fish Springs Flat

No.	Anticipated Significance ^a	Lab Number	Dated Materials	Altitude ^b	Locality ^c	Depositional Setting	¹⁴ C Age ^d
1	Lake Bonneville transgression at the beginning of the Stansbury oscillation.	Beta-27461	<i>Valvata</i> and <i>Gyraulus</i> shells ^f	4550 1387	M	lagoon marl deposited behind transgressive-phase Bonneville barrier-beach	>38,160 >38,510 ^e (-3.6)
2	Lake Bonneville transgression at the end of the Stansbury.	Beta-27462	<i>Amnicola</i> shells	4550 1387	M	base of white marl above transgressive-phase barrier-beach — shallow water, offshore	18,920 19,320 ^e (-0.9)
3	Lake Bonneville transgression following the Stansbury oscillation.	Beta-27463	<i>Lymnaea</i> shells ^f	4787 1460	N	base of white marl at an altitude 18 feet (5.5 m) below the Provo shoreline — transgressive-phase, shallow water, offshore.	19,500 19,920 ^e (+0.6)

^aList of stratigraphic interpretations based on field observations made prior to submitting the samples for analysis. Note that only one of the age determinations is consistent with other radiocarbon-age determinations from the Bonneville basin (see footnote f and discussion in text.)

^bPresent altitudes in feet and meters; uncorrected for the effects of isostatic rebound of the basin caused by the removal of the Lake Bonneville water load.

^cRefer to table 2 for locality descriptions.

^dRadiocarbon ages in yr B.P. (years before present, considered as 1950).

^e¹³C-adjusted age; ¹³C/¹²C ratio (o/o; PDB) in parentheses.

^fReported age considered unreliable; see text for explanation.

In places between the Provo (elevation range: 4826-4843 ft or 1471-1476 m) and Bonneville (elevation range 5194-5220 ft or 1583-1591 m) shorelines, Qla represents the basal transgressive boulder-beach deposits of Lake Bonneville resting on the older alluvial fans. Below the Provo shoreline, Qla represents both the basal transgressive shorezone deposits and the regressive shorezone deposits of Lake Bonneville. Fine-grained lacustrine deposits (Qlf or Qlm) are locally preserved on Qla, but these fine-grained deposits were stripped off in most areas by waves during the regressive phase of Lake Bonneville and by post-Bonneville stream erosion or sheet wash. In some places significant accumulations of lacustrine gravel (Qlg) in spits or barrier beaches are mapped with Qla if they are too small to show at a scale of 1:50,000.

Lacustrine gravel (Qlg) — Beach or spit gravel deposited in Lake Bonneville is mapped as Qlg. Only the thickest and most extensive accumulations of lacustrine gravel are shown as Qlg in plate 1. Less extensive accumulations of lacustrine gravel, some of which include well-formed, but small, gravel barrier beaches or spits, are mapped with Qla. The best developed barrier beaches are found at the Bonneville and Provo shorelines (figure 3), but well-preserved beaches can be found at almost any level on the piedmont slopes in favorable geomorphic settings, including the Stansbury shoreline zone. In plate 1 the Bonneville and Provo shorelines are depicted as dashed or dotted lines. Depositional and erosional segments of the shorelines are not distinguished except where gravel embankments are large enough to be mapped as Qlg. Lacustrine gravel is generally less than 20 feet (6 m) thick but may be thicker in some large spits or barrier beaches.

Three large barrier beaches are mapped in the southern part of Fish Springs Flat (plate 1; localities A, B, and C, table 2). The highest and best developed of these is at the Provo shoreline (A), and the lower two are transgressive-phase beaches formed just prior to the Stansbury oscillation (figure 2). All three barriers are composed of gravel and sand having source areas on the east side of the valley. Most notable are well-rounded clasts of obsidian, the closest source of which is one of the major washes draining the western slope of the Thomas Range (labeled D in plate 1; table 2). The source of the obsidian is rhyolite flows and breccia near the

base of the Topaz Mountain Rhyolite (unit Ttm₃ of Lindsey, 1979) in the vicinity of locality E (plate 1; table 2). Clasts of other easily identified rock types derived from the east side of the valley include Topaz Mountain Rhyolite, Needles Range Formation (?), and Drum Mountains Rhyodacite (see Lindsey, 1979, 1982 for descriptions and distributions of these rocks).

Because the source area for the gravel in these three barriers is known precisely (there is only one known source: locality E, plate 1, table 2 for most of the abundant obsidian clasts), it is possible to show that the barriers had to have been produced as spits that grew across the valley by longshore transport from east to west. At the western termini of the three barriers, only a minor percentage of the total volume of gravel has a potential source in the immediately adjacent alluvial fans or bedrock hills. Therefore, most or all of the gravel in each of the barriers was transported from the east side of the valley. The maximum longshore transport distance for the three spits was 7 miles (11 km) for barrier C, 8 miles (13 km) for barrier B, and 9.5 miles (15 km) for barrier A. The Provo barrier (A) was formed during a relatively long period when the lake was overflowing, and thus the lake's level maintained a relatively constant altitude (with some changes due to isostatic adjustments and landsliding at the overflow threshold; Burr and Currey, 1988; Currey and Burr, 1988). Barriers B and C, however, were formed while the lake had no outlet, so the level was free to shift with minor changes in climate, just as the modern Great Salt Lake does. Therefore, barriers B and C, which have flat crests in a longitudinal direction and show no other evidence of having been formed during multiple phases, must have been deposited very quickly, possibly as fast as a few decades.

Ice rafting is another transporting mechanism for lacustrine gravel in Lake Bonneville in the Fish Springs area. Although an insignificant volume of gravel was transported by ice rafting, the mechanism can explain the anomalous occurrences of certain clasts whose source areas are known precisely. Clasts of distinctive rock types that can be traced to their sources suggest ice rafting as the most probable transporting mechanism. Specifically, pebble- to boulder-size clasts of mafic volcanic rocks (banakite; Hogg, 1972) derived from low hills at the south end of Fish Springs Flat (locality



Figure 3. Gravel barrier beach at the Bonneville shoreline south of Sand Pass. View is to the northwest. White sediments on the left side of the photo are lagoon sediments (QII), and the barrier beach has a few short juniper trees growing on its flanks.

Table 2.
Localities discussed in text and indicated on plate 1.

Locality	Description	Significance	Latitude/Longitude	
A	south end of Fish Springs Flat	well-developed gravel barrier beach at Provo shoreline	39°	36.5'
B	south end of Fish Springs Flat	gravel barrier beach deposited during the transgressive phase	113°	17.2'
C	south end of Fish Springs Flat	gravel barrier beach deposited during the transgressive phase	39°	38.1'
D	wash that drains the west slope of Thomas Range	primary source of obsidian pebbles in barrier beaches	113°	22.2'
E	west slope of Thomas Range	source area for obsidian pebbles	39°	41.7'
F	hills of volcanic rocks north of Sand Pass Road	location of Provo wave-cut platform (figure 7)	113°	38.9'
G	near center of map area on floor of Fish Springs Flat	coppice dunes having plan-view form similar to barrier beach	113°	21.7'
H	at base of southern Fish Springs Range	Tertiary volcanic ash exposure	39°	42.2'
I	pediment west of Spor Mountain	westward tilted (?) Quaternary alluvial gravel	113°	9.7'
J	east base of Fish Springs Range north of the Fish Springs National Wildlife Refuge	wedge of Stansbury gravel between two marl units (figure 16)	39°	39.6'
K	north end of Black Rock Hills	wedge of Stansbury carbonate-coated sand between two marl units	113°	15.6'
L	west side of Black Rock Hills	extensive badland exposures in Stansbury deposits (figure 15)	39°	20.8'
M	gravel pit at south end of Fish Springs Flat	collection site for radiocarbon samples 1 and 2 (table 1; figure 17)	113°	43.75'
N	exposure of white marl at south end of Fish Springs Flat	collection site for radiocarbon sample 3 (table 1; figure 18)	39°	14.70'
O	exposure in gravel pit near Sand Pass Road, near east edge of map area	location of figure 19 — gravel possibly representing the Keg Mountain oscillation	113°	37.88'
P	on piedmont of Fish Springs Range north of Sand Pass	location of Provo wave-cut platform, and figure 20	39°	19.08'
Q	east side of Fish Springs Flat	location of figure 5 — Stansbury stratigraphic relationships	113°	36.71'
R	south of Fish Springs National Wildlife Refuge, piedmont of Fish Springs Range	location of figure 10 — schematic profile through Stansbury deposits	39°	17.60'
S	hills at the south end of Fish Springs Flat	outcrops of Tertiary mafic volcanic rocks (banakite; Hogg, 1972); source of ice rafted clasts	113°	48.0'

S, table 2) can be found on the sides and tops of nearby hills of Paleozoic rocks. The transported banakite clasts were found on hills south (downcurrent) of the banakite outcrops and are separated from the outcrops by a valley 100 feet (30 m) deep. These clasts were probably frozen into shore ice at the banakite outcrops, then floated across the valley to the adjacent hills and dropped when the ice melted. The banakite fractures easily under wave attack, and some huge gravel embankments and spits were produced at locality S between the Provo and Bonneville shorelines.

As another example of probable ice rafting, obsidian pebbles can be found on the lacustrine gravel embankments on the west side of Fish Springs Flat above levels at which they could have been transported from their source by longshore currents.

The ages of barrier beaches and spits that were deposited at the shore of Lake Bonneville at different stages can be inferred from the time-altitude diagram of Lake Bonneville (figure 2). In addition, two radiocarbon-age determinations on shells collected in Fish Springs Flat provide minimum-limiting ages for the transgression of the lake above the Stansbury shoreline zone (table 1). Only age 2 (table 1) is considered to be an accurate estimate of the age of the transgression; the other two ages are considered unreliable for the reasons outlined in table 1 and under the Quaternary history discussion.

Lacustrine gravel from Fish Springs Valley has been used for road construction, and any of the Qlg deposits mapped in plate 1 would be suitable for such a purpose.

Lacustrine marl (Qlm) — The open-water or deep-water deposits of Lake Bonneville are mapped in plate 1 as lacustrine marl. 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 authigenic calcium carbonate, and variable amounts of detrital sediments, which were deposited in open-water environments of Lake Bonneville. The white marl is finely bedded to indistinctly laminated and contains abundant ostracodes throughout. Gastropods are locally abundant near the base and top of the unit, and some exposures of Qlm contain abundant diatoms. Thickness ranges from 6 to 30 feet

(2-10 m; figure 4), depending on the local depositional setting. Qlm also includes clastic-rich marl at the base and top of the unit, and local thick deposits of sand- to gravel-size charophyte debris associated with the Stansbury shoreline.

Lacustrine marl (Qlm) differs from fine-grained lacustrine deposits (Qlf) in that the white marl (Qlm) is mapped in places where it is well preserved, well exposed, and its stratigraphic relationships can be determined. Qlm has not been modified significantly by post-Bonneville fluvial activity, whereas Qlf may be overlain by thin alluvium consisting of reworked Qlm and other fine-grained deposits.

The white marl is best preserved and thickest in localities within about 150 feet (45 m) below the Provo shoreline, and directly below the lower limit of the Stansbury shoreline. The Provo shoreline was formed during a period of relatively prolonged still stand, during which thick tufa and other carbonate-rich sediments were deposited in the shorezone. In addition, most of the white marl that had been deposited on the piedmont slopes between the Provo and Bonneville shorelines during the highest stages of the lake was washed off those slopes and into the lake during the development of the Provo shoreline. Therefore, the marl deposits just offshore from the Provo shoreline are relatively thick.

The Stansbury shoreline was formed during a period in which the water level declined about 150 feet (45 m) from a previous high (figure 2; see discussion below). Therefore, fine-grained deposits that had been laid down in relatively deep water were reworked and swept a short distance offshore. In addition, the water became more concentrated in dissolved solids causing thick deposits of tufa, carbonate-coated sand, and charophyte debris to be deposited in the shorezone (figure 5). In many places, these deposits are mapped as Qlm because they interfinger with the marl.

In Fish Springs Flat the white marl ranges in age from about 25,000 yr B.P. to about 12,000 yr B.P. (figure 2). Therefore, marl was deposited for roughly 13,000 years in the lowest parts of Fish Springs Flat but was deposited during much shorter time periods at localities approaching the Bonneville shoreline (figure 2). The base of the white marl is diachronous. However, at all altitudes between



Figure 4. Exposure of the white marl (Qlm) near locality A (table 2). Dark sediments at the base of the exposure are transgressive-phase lacustrine gravel. The white marl is about 6 feet (2 m) thick at this locality and is overlain by reworked sandy marl, then by sand deposited as the lake dropped rapidly to the Provo shoreline during the Bonneville flood. The sand forms the resistant caprock in the photo and is overlain by Provo barrier-beach gravel (not shown in photo). The measuring stick is 6 feet (2 m) long.

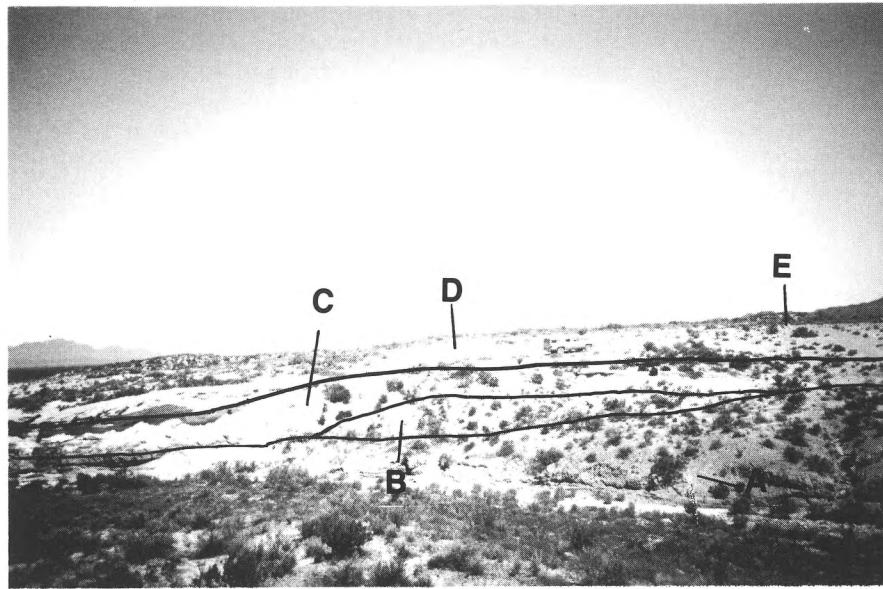


Figure 5. View north of a stream cut in Stansbury deposits at locality Q (table 2) on the east side of Fish Springs Flat. A = pre-Bonneville alluvium; B = transgressive-phase beach gravel; C = the lower white marl (pre-Stansbury); D = wedge of offlapping carbonate-coated sand deposited during the Stansbury oscillation; E = erosional remnant of the upper post-Stansbury white marl overlain by sand dunes.

the Bonneville and Provo shorelines the stratigraphic top of the white marl is essentially isochronous because deposition ceased abruptly due to the Bonneville flood (Gilbert, 1890; Malde, 1968; Jarrett and Malde, 1987), a geologically instantaneous event.

Fine-grained lacustrine deposits (Qlf) — Fine-grained lacustrine sediments deposited in Lake Bonneville are widespread in Fish Springs Flat and are represented in part by the map unit Qlf. These deposits include silt, sand, marl, and calcareous clay. Qlf locally includes the white marl (Qlm), but it also includes reworked white marl and other lacustrine sediments that had been eroded and washed towards the basin during the regressive phase of Lake Bonneville. Qlm (the white marl) is distinguished as a map unit only where it is well exposed, and where its stratigraphic relationships are clearly displayed. At a number of localities on the floor of Fish Springs Flat, Qlf is capped by a thin layer of tufa that weathers into tiny fragments. The tufa was probably deposited rapidly as the lake regressed across the valley floor.

Locally Qlf includes thin alluvium of post-Lake Bonneville age composed mostly of reworked fine-grained lacustrine deposits; Qlf grades downslope on the floor of Fish Springs Flat into alluvial mud (Qam). Qlf is Bonneville and post-Bonneville in age. Qlf is 10 feet (3 m) or less in thickness.

Lacustrine lagoon deposits (Qll) — Poorly bedded deposits of silt, sand, and clay filling lagoons behind Lake Bonneville barrier beaches are mapped as Qll (figure 3). Some of the fine-grained sediment in these settings was probably deposited by waves that washed over the crests of the barrier beaches during storms, and some was deposited in post-Bonneville time as slope-wash from the surrounding hillslopes. Qll therefore is Bonneville and post-Bonneville in age. Only the largest lagoons are shown on plate 1; other lagoons in the map area are too small to map at a scale of 1:50,000. Deposits may be up to 50 feet (15 m) thick in some lagoons.

Lacustrine tufa (Qlt) — Tufa associated with the Provo and Stansbury shorelines is mapped as Qlt. Tufa is calcium carbonate deposited in the wave zone, or in relatively shallow water offshore, by direct precipitation from the water or through the action of algae

(by removal of CO₂ from the water for photosynthesis). In Fish Springs Flat the tufa encrusts bedrock or cements coarse gravel.

Tufa is associated with the Provo shoreline where it encrusts bedrock or cements coarse gravel as much as 70 feet (20 m) below the estimated mean Provo water level (figure 6). Some of the tufa near the lower limit of this range may have been deposited as the lake began its regression from the Provo shoreline, but most of the tufa was probably deposited while the lake maintained a relatively constant level at the Provo shoreline. A topographic profile (figure 7) of the Provo wave-cut platform at locality F (plate 1; table 2) shows tufa preserved up to about 6 feet (2 m) vertically below the Provo wave-cut notch. The tufa is as much as about 3 feet (1 m) thick on the outer edges of the wave-cut platform, where it forms large bulbous mounds encrusted on the bedrock. Other well-formed wave-cut platforms and tufa draperies are found at the north end of the Fish Springs Range (figures 6 and 8), and at the north end of the Black Rock Hills and other places where wave energy was high and the bedrock was suitable. Tufa is mapped overlying (and cementing) lacustrine and alluvial deposits (Qla) below the Provo bluff on the east side of the valley.

Tufa is not as thick or voluminous at the Stansbury shoreline, but it is mappable in some localities. The Stansbury tufa is found in a broad altitudinal zone because it was deposited while the lake fluctuated in its closed basin. Stansbury tufa cements gravel which creates a sloping caprock that overlies marl, charophyte debris, or unconsolidated gravel deposited early in the Stansbury oscillation (figures 9 and 10). Some Stansbury tufa is encrusted on bedrock (figure 11).

Alluvial Deposits

Alluvial deposits (Qal₁, Qal₂, Qal₃) — Quaternary alluvial deposits are mapped as Qal, with subscript numbers indicating their relative ages. The alluvial units, especially Qal₁, are the most widespread deposits in the map area and include alluvial-fan deposits, and more restricted deposits along ephemeral stream channels. Alluvial-fan deposits and ephemeral-stream deposits were not separated in plate 1 because in many areas the two grade into one



Figure 6. Bulbous mound of tufa covering a bedrock outcrop at the Provo shoreline at the north end of the Fish Springs Range. View is to the northeast; Dugway Range is in the background. This tufa mound is on the outer edge of the Provo wave-cut platform and is about 9 feet (3 m) high.

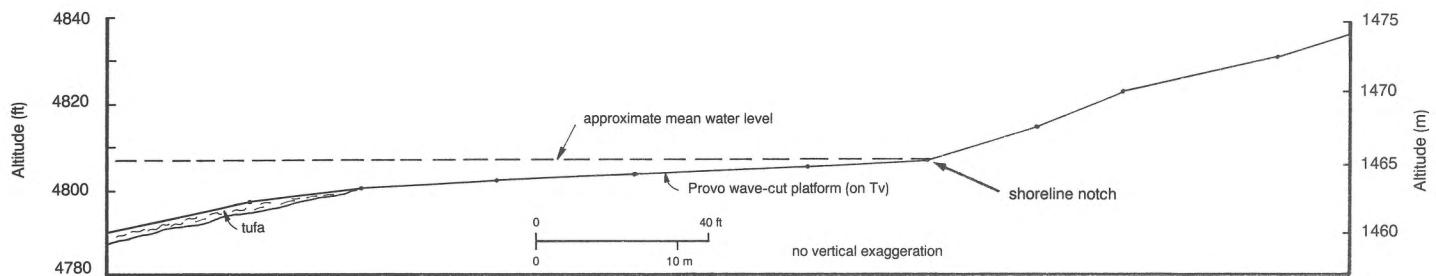


Figure 7. Topographic profile across a wave-cut platform at the Provo shoreline at locality F (table 2). The profile was constructed from hand-level survey data and shows tufa on the margin of the platform, the shoreline notch, and the steep slope above the notch cut in Tertiary volcanic rocks.



Figure 8. Wave-cut platform at Provo shoreline at north end of Fish Springs Range. Note cliff in Paleozoic carbonate rocks at left, large blocks that have fallen from cliff and that bury the shoreline notch, and offlapping tufa-cemented gravel on the outer margin of the platform. The platform is largely erosional, but approximately the outer one-fourth is constructional. The platform is about 50 to 60 feet (15-18 m) wide.



Figure 9. View north of Stansbury tufa caprock at the base of the Fish Springs Range. At this locality the caprock consists of tufa-cemented gravel overlying uncemented gravel. Fish Springs National Wildlife Refuge in middle ground; Granite Peak in background.

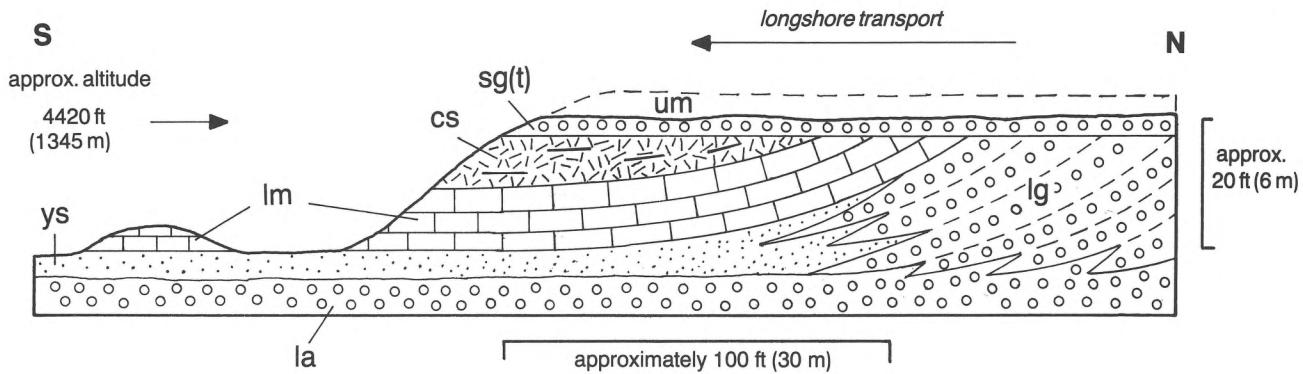


Figure 10. Schematic cross section through Stansbury deposits, including the tufa caprock and lower marl south of Fish Springs National Wildlife Refuge (locality R, table 2). *la* = thin transgressive lacustrine gravel overlying pre-Bonneville alluvial-fan surface; *ys* = yellow, poorly sorted calcareous sand, deposited as offshore facies during deposition of *lg*; *lg* = lacustrine gravel deposited during the transgressive phase prior to the Stansbury oscillation; *lm* = lower marl, deposited during the transgressive phase prior to the Stansbury oscillation; *cs* = charophyte sand — offlapping (cross-bedded) deposit of sand- to granule-size fragments of charophyte stem encrustations which, with the overlying caprock, represent deposition during the low point of the Stansbury oscillation; *sg(t)* = tufa-cemented Stansbury gravel caprock; *um* = upper marl, inferred at this locality.



Figure 11. Stansbury tufa-cemented gravel cemented to Paleozoic carbonate bedrock at locality J (table 2) near the north end of the Fish Springs Range. The tufa-cemented gravel is about 10 feet (3 m) thick.

another, and it was not possible to differentiate them. In general, however, the fans are found in relatively steep piedmont settings and the ephemeral-stream deposits in valley-bottom settings. In texture, the alluvium ranges from very coarse-grained fan gravels near the mountain fronts to poorly sorted sandy and pebbly mud where it has been spread out onto the valley floor by major washes. The composition of the alluvium depends on local sources.

The oldest Quaternary alluvial unit (Qal_3) consists of coarse-grained alluvial-fan and ephemeral stream deposits above and older than the Bonneville shoreline. The most extensive pre-Bonneville alluvial deposits are near the southeast corner of the map area where they form benches that stand 20 to 40 feet (6-12 m) higher than the younger (Qal_1) alluvial deposits along active stream channels. Many of the areas mapped as Qla are underlain at a shallow depth by pre-Bonneville alluvium having a relative age that is probably similar to Qal_3 . Maximum thickness is unknown, but it is over 50 feet (15 m). At locality H (plate 1; table 2) two silicic volcanic ashes are exposed in the fault zone between the Paleozoic bedrock of the Fish Springs Range and the coarse alluvium of Qal_3 . The ashes are white to gray, of coarse to medium sand size, and highly deformed in the fault zone. Microprobe analyses by W.P. Nash suggest that more than one population of shards may be present in each ash sample. Therefore, definitive identifications have not yet been made.

Deposits mapped as Qal_2 have a limited distribution behind the large barrier beach at the Provo shoreline at the south end of Fish Springs Flat (locality A, plate 1; table 2). The Qal_2 deposits are largely of Provo age and represent stream deposition in the lagoon behind the Provo barrier beach. Qal_2 consists of horizontally bedded sand and gravel up to about 30 feet (9 m) thick overlying the white marl (Qlm) with an abrupt contact (figure 12). Contorted bedding and soft-sediment deformation structures in the white marl (figure 12) may suggest rapid loading of the water-saturated marl by the coarse-grained alluvium, although only the lower part of the gravel is deformed.

The youngest alluvial deposits (Qal_1) consist of post-Bonneville alluvial fans along pediments of the Fish Springs Range and the

Thomas Range, and lower gradient deposits along major washes. These two kinds of deposits are closely related and grade into one another. Therefore, because of the difficulty of separating them, they are mapped together as a single unit. Qal_1 includes thin, but widespread, fine-grained alluvium on the floor of Fish Springs Flat at the mouth of Fish Springs Wash. Small areas of colluvial deposits on or adjacent to steep slopes are also mapped with Qal_1 . The maximum thickness of Qal_1 is probably less than 100 feet (30 m), but the base is not exposed in the map area.

Alluvial sand (Qas) — Poorly sorted fine-grained sandy alluvium at the margins of mud flats is mapped as Qas. Sandy alluvium is a distal facies of the alluvial fans (Qal_1) along the flanks of the Fish Springs and Thomas Ranges. There is an abrupt change in gradient and in grain size from the steep fan gravels onto the more gently sloping sandy alluvium. Qas is locally reworked into dunes and is less than 20 feet (6 m) thick. It is Holocene in age.

Alluvial mud (Qam) — Mud deposited on the valley floor by sheet-flow from surrounding slopes is mapped as Qam. The mud includes poorly sorted silt and clay, and fine-grained gypsumiferous deposits at the southern margin of the Great Salt Lake Desert (extreme northern margin of the map area). Qam also includes organic-rich mud associated with springs in the vicinity of Fish Springs National Wildlife Refuge. The maximum thickness of Qam is unknown. Qam is Holocene in age.

Eolian Deposits

Eolian dunes (Qed) — Eolian deposits are mapped as Qed in plate 1. Eolian deposits are gradational in composition and texture from moderately sorted quartz sand to silt and clay. The clay quartz sand dunes are found mainly in piedmont areas and in many cases are associated with lacustrine sources of sand, such as the large barrier beach at the Provo shoreline near the south end of Fish Springs Flat. Fine-grained deposits and dunes are found on the valley floor and are associated with local sources of sandy alluvium (Qas). Many of the fine-grained dunes are coppice dunes.

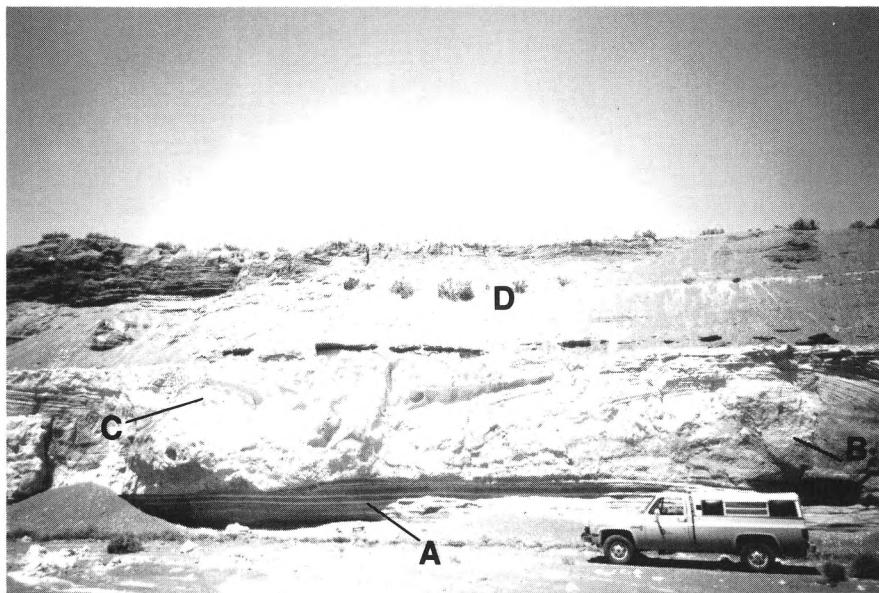


Figure 12. An exposure of the white marl (Qlm) overlain by Provo-age alluvial gravel (Qal_2) in a cut bank of Fish Springs Wash, just south of where it crosses the prominent Provo barrier-beach complex at the south end of Fish Springs Flat. The white marl can be divided into three parts: A) a lower part consisting of finely bedded, undeformed, transgressive-phase sandy marl; B) a middle part consisting of deformed massive deep-water marl; and C) an upper part consisting of reworked marl that is ripple-bedded and highly deformed. The overlying alluvial gravel (D) is horizontally bedded and was deposited behind the Provo barrier beach (out of view to the right or north).

A line of coppice dunes near the center of Fish Springs Flat (locality G, plate 1, table 2) has the form of a curved bayhead barrier similar to the Stansbury-zone bayhead barriers a few miles to the south (localities B and C; table 2). No gravel is present at the surface in the vicinity of the coppice dunes (at locality G), and the eolian deposits rest on fine-grained lacustrine sediments. The distribution of the dunes suggests that they are related to a gravel barrier at a shallow depth. Greasewood (*Sarcobatus vermiculatus*) is the dominant shrub on the dunes. The greasewood bushes, which are phreatophytes, probably colonized the flat desert floor along a buried gravel barrier because the gravel contains abundant ground water. The greasewood bushes probably then trapped deflation dust and fine sand from the mud flats and distal parts of the alluvial fans, thus producing the coppice dunes, which in plan view appear to have the form of a barrier beach. A similar association of greasewood bushes with buried alluvial gravel has been noted in the Sevier Desert, southeast of Fish Springs Flat (Oviatt, 1989).

All the deposits mapped as Qed are Holocene in age as shown by their stratigraphic relationships with deposits of Holocene and late Pleistocene age. The maximum thickness of Qed is about 10 feet (3 m) in the study area.

Mass-Wasting Deposits

Landslide deposits (Qms) — A single large mass movement or landslide is mapped in plate 1 0.5 mile (1 km) southwest of the headquarters of the Fish Springs National Wildlife Refuge (Hintze, 1980b). The slide is composed of lacustrine gravel that slid off the steep mountain face to the west. Although an earthquake, possibly produced in the Fish Springs fault zone, could have triggered the slide, there is no direct evidence for this. The most recent surface rupture along the fault zone occurred about 2000 yr B.P. (Bucknam and others, 1989), but the landslide surface appears to be well stabilized and the slide may be considerably older than 2000 years. Its maximum possible age is about 12,000 years; there are no shorelines on the landslide, indicating that it formed after the lake had dropped below the lower altitudinal limit of the landslide (4360 ft or 1330 m; figure 2). The landslide source includes gravel from the Provo shoreline and from levels down to and including the Stansbury. Landslide gravel is up to about 50 feet (15 m) thick.

Artificial Fill

Mine dump and strip mine (Qfm) — A single large area at the Brush-Wellman beryllium strip mine in the east-central part of the

valley is mapped as Qfm. The mapped area includes the strip mine itself and the associated spoils pile. Other mine dumps are present in the area but are not mapped in plate 1.

STRUCTURE

Fish Springs Flat is a down-faulted basin similar to many of the faulted basins in the eastern Basin and Range province. The surrounding mountain ranges have experienced a long and complex structural history beginning in the Cretaceous and extending into the late Tertiary (Staatz and Carr, 1964; Hintze, 1978; Lindsey, 1982). Basin and Range extensional tectonism began sometime between 21 and 7 million years ago (Lindsey, 1982), and faulting has continued into the Quaternary, with Holocene displacement along the Fish Springs fault (Piekarski, 1980). Based on fault-scarp profile studies and a radiocarbon age, Bucknam and others (1989) report that the most recent surface rupture along the Fish Springs fault was about 2000 yr B.P.

The Fish Springs basin appears to be formed between two tilted blocks — a large structurally complex block on the east consisting of the Drum Mountains and the Thomas and Dugway Ranges, and a block on the west consisting of the Fish Springs Range (figure 13). Paleozoic strata in both mountain blocks dip generally to the west or northwest (Staatz and Carr, 1964; Hintze, 1980a-d). The piedmont west of Spor Mountain (figure 1) is a pediment cut on Paleozoic sedimentary rocks and Tertiary volcanic rocks. The alluvial/lacustrine cover is thin in this area and has permitted shallow prospecting for beryllium and fluorspar.

Although most of the tilting and faulting that produced Fish Springs Flat must be Tertiary in age, some of the deformation is Quaternary in age. The Fish Springs fault zone is strong evidence for this, and limited evidence suggests that the Spor Mountain block has continued tilting during Quaternary time. A shallow bulldozer cut at locality I (plate 1; table 2) exposes about 5.5 feet (1.5 m) of Holocene alluvium overlying an angular unconformity with older alluvial deposits that dip about 8° to the west. The older alluvium consists of poorly sorted sand and fine gravel, similar in texture and composition to the overlying Holocene alluvium. Some of the older alluvial sandy beds contain pedogenic (soil) carbonate. The modern alluvial surface at this locality (Qal₁) slopes about 1.5° to the west, and this seems to be about the average slope on the piedmont in this area. Therefore, a possible interpretation of these observations is that the older Quaternary alluvial deposits in this exposure have been tilted about 6.5° to the west following their deposition. This hypothesis has not been tested, however, and it is not known at present whether the relationships in

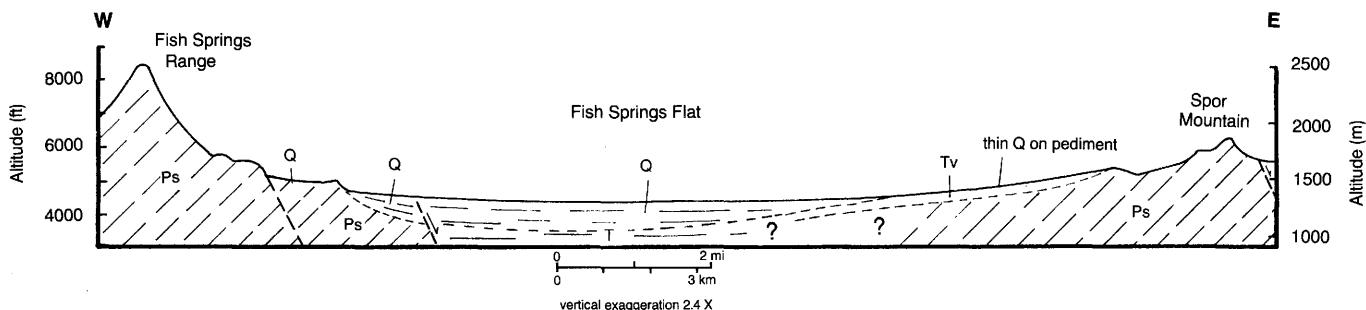


Figure 13. Schematic structural cross section across the center of Fish Springs Flat, from the Fish Springs Range on the west to Spor Mountain on the east, showing the generally westward-tilting Paleozoic rocks in the mountain blocks, the fault zone at the base of the Fish Springs Range, and the pediment at the western base of Spor Mountain. Structural complexities within the mountain blocks are not shown (see Staatz and Carr, 1964; Hintze, 1980b, 1980c). Ps = Paleozoic sedimentary rocks; Q = Quaternary sediments; T = Tertiary sediments; Tv = Tertiary volcanic rocks.

this exposure have regional or merely local significance. The tilted alluvium at this locality has not been dated but, judging from the amount of pedogenic carbonate in some of the sandy layers, it is pre-Bonneville in age.

QUATERNARY HISTORY

Early and Middle Pleistocene

Little is known of the early and middle Pleistocene history of Fish Springs Flat. The only known deposits of possible early or middle Pleistocene age are the pre-Bonneville alluvial deposits mapped as Qal₃. No numerical ages, however, are available for these deposits. Pre-Bonneville lacustrine deposits, which are known from other localities in the Bonneville basin (Oviatt and Currey, 1987), are likely buried beneath the floor of Fish Springs Flat.

Late Pleistocene

The stratigraphic record of Lake Bonneville is locally well preserved in Fish Springs Flat, where geomorphic and/or stratigraphic evidence of the lake is present throughout almost its entire altitudinal range. Landforms and stratigraphic sequences at the Provo and Stansbury shorelines are particularly well preserved and exposed, and they are discussed below.

Stansbury shoreline zone — The Stansbury shoreline should be thought of as a shoreline zone because a number of different geomorphic features which are found in different positions in the valley and, at different altitudes, can be considered to represent the

Stansbury shoreline (figure 14). The Stansbury shoreline zone spans a vertical altitudinal range of about 150 feet or 45 m (Oviatt and others, 1990) and represents coastal deposition and, in some areas, erosion during a period of fluctuating lake level. This period, referred to as the Stansbury oscillation, occurred during the transgressive phase of the lake (figure 2; Currey and others, 1983; Oviatt, 1987; Oviatt and others, 1990). In Fish Springs Flat, the Stansbury shoreline zone is represented by gravel barrier beaches, tufa-cemented gravel caprock, tufa-cemented gravel plastered onto bedrock, and wedges of carbonate-coated sand, charophyte debris, or coarse gravel interbedded with marl units (figures 5, 9, 10, 11, 14, 15, 16).

The lower altitudinal limit (4396 ft or 1340 m) of the Stansbury oscillation is well constrained by exposures in Fish Springs Flat. The lowest of these exposures are shown schematically in figure 14 (1 and 2; localities J and K, plate 1; table 2). At locality J (figure 16; figure 14, #1) a coarse-gravel wedge intertongues with two marl units; the gravel grades downslope into two marly sand beds between the lower and upper marls. The gravel wedge thickens in a short distance away from the marl-sand-marl sequence, but it is not connected to the tufa-cemented gravel of the Stansbury shoreline at this locality (figure 11, figure 14, #5). Ostracode faunas in samples from near the top of the lower marl and from near the bottom of the upper marl are similar; both are dominated by *Limnocythere stiplini* and *Candona* aff. *C. caudata*, both of which are typical of Stansbury-age deposits elsewhere in the Bonneville basin (R.M. Forester, personal communication, 1989). A sample of sandy marl from the intervening marly sand unit contains a similar ostracode fauna to those above and below it. Therefore, the ostracode faunas support the hypothesis that the lower-marl/gravel-and-sand-wedge/upper-marl sequence represents the Stansbury oscillation.

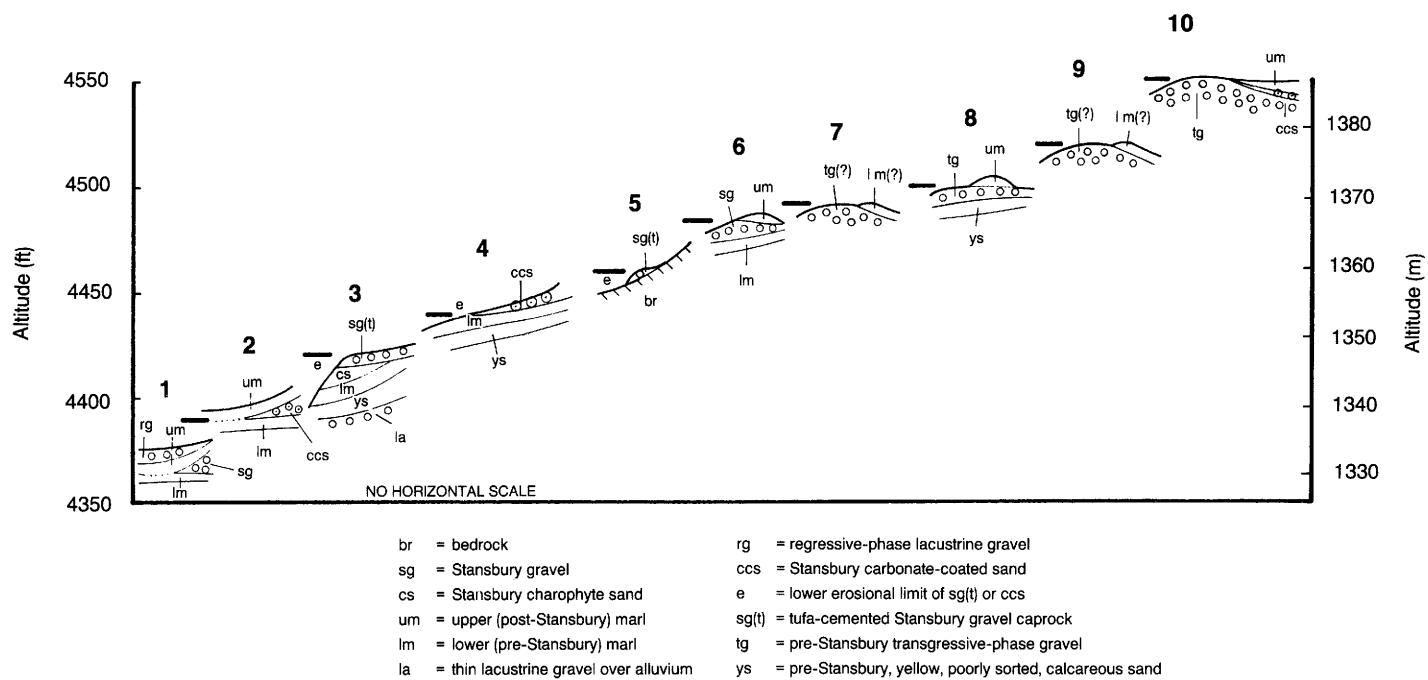


Figure 14. Schematic diagram of stratigraphic and geomorphic relationships within the Stansbury shoreline zone in Fish Springs Flat. Each numbered cross section (representational only; vertical scales vary) is plotted at its approximate altitude as keyed to the short, heavy line segments (altitudes determined by hand level from some known point or from the topographic map). See table 2 for locality information: 1 = locality J (see figure 16); 2 = locality K; 3 = locality R; 4 = locality L (see figure 15); 5 = locality J (see figure 11); 6 = locality L (see figure 15); 7 = locality C; 8 = locality L (see figure 15); 9 = locality B; 10 = locality M (see figure 17).

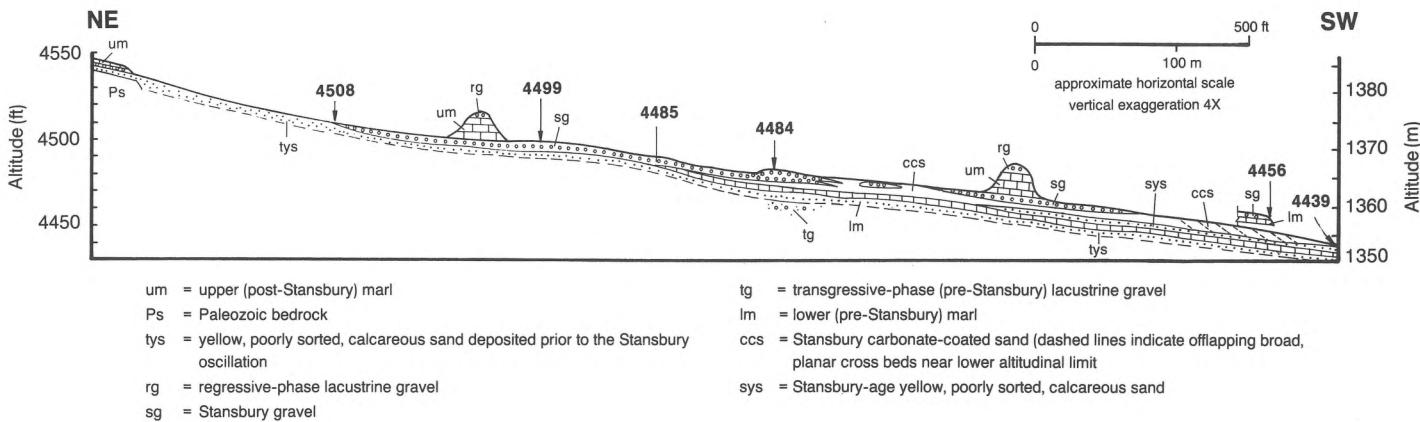


Figure 15. Schematic cross section through part of the Stansbury shoreline zone at locality L (table 2). Constructed from hand-level survey data and the Fish Springs SE 7.5' topographic map (vertical dimensions are generally more accurate than horizontal dimensions). The “floating” section at the right-hand side of the diagram labelled 4456 feet (1358 m) represents a small exposure on the valley side that is not connected to the main cross section.



Figure 16. Exposure in a gravel pit at locality J (table 2) near the north end of the Fish Springs Range. A = lower (pre-Stansbury) marl exposed in a hand-dug pit at base of exposure (the lower marl is covered along most of the length of the exposure); B = shovel handle for scale (about 5 ft or 1.5 m); C = Stansbury gravel and sand wedge, which thickens upslope (to the right) and becomes sandy downslope — two sand beds separated by a sandy marl unit are evident in the hand-dug pit and may indicate two fluctuations during the Stansbury oscillation; D = upper (post-Stansbury) marl; E = regressive-phase lacustrine gravel; F = Stansbury tufa-cemented gravel encrusted on Paleozoic bedrock.

The lower altitudinal limit of the Stansbury oscillation is also well represented in exposures at the north end of the Black Rock Hills (locality K, table 2, plate 1). At this locality (figure 14, #2) a wedge of lacustrine carbonate-coated sand (ccs) pinches out down-slope between two marl units. The lower limit of the carbonate-coated sand wedge is higher than at locality J (figure 14, #1) because slopes are not as steep at locality K, and there was much less gravel available for transport than at locality J. Therefore, the carbonate-coated sand was not swept as far offshore as the sand and gravel at locality J. The carbonate-coated sand is found in many exposures in Fish Springs Flat, always within the Stansbury altitudinal range, and always associated with Stansbury deposits and landforms (figure 14, numbers 2, 4, 10; figure 15).

At locality M, in a gravel pit at the south end of Fish Springs Flat, an attempt was made to obtain radiocarbon ages of deposits

of the Stansbury oscillation. At this locality, a gravel barrier beach encloses a shallow lagoon in which a thin lagoon marl was deposited above clean sand and gravel of the barrier (figure 17). Above the lagoon marl is about 0.7 foot (20 cm) of carbonate-coated sand which grades upward into sandy marl and offshore marl. The sequence is truncated artificially at the edge of the gravel pit.

I interpret the stratigraphic sequence at locality M as follows. The lower clean sand and gravel and the lagoon marl represent the first transgression of Lake Bonneville to this altitude, just prior to the Stansbury oscillation. The carbonate-coated sand represents the second transgression to this altitude at the end of the Stansbury oscillation — the lake had become concentrated in dissolved solids during the major Stansbury regression, and sand had become coated with carbonate. Sandy marl and marl above the carbonate-coated sand represent the continued transgression of the lake and deposition in deep water.

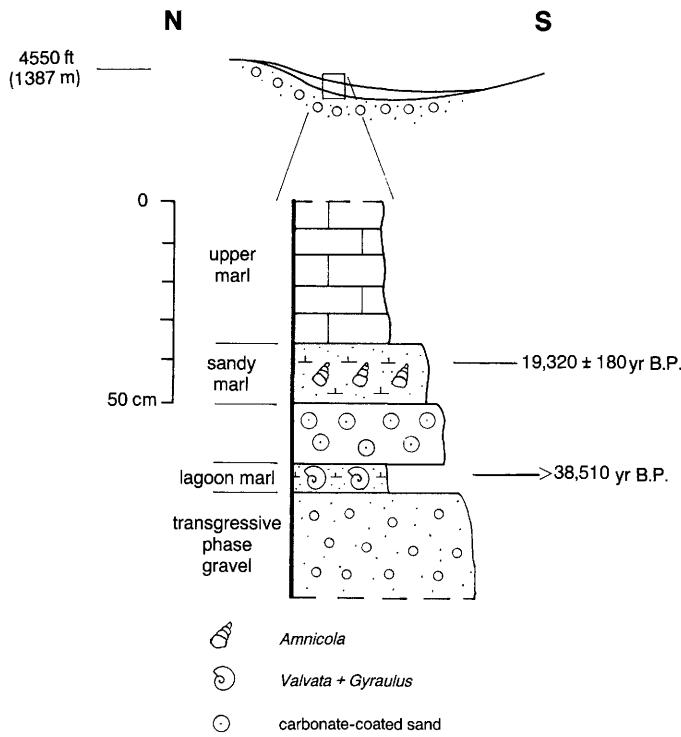


Figure 17. Schematic profile and measured stratigraphic section at locality M (table 2) — the collection site of radiocarbon samples 1 and 2 (table 1), and amino-acid samples (table 3). Snail shells were collected from two stratigraphic units exposed in a shallow gravel pit behind a gravel barrier beach at this locality. The samples are thought to have been deposited immediately prior to (#1) and immediately following (#2) the Stansbury oscillation (see text for discussion).

Radiocarbon ages of samples of gastropods from this section partially support the above hypothesis (figure 17; table 1, ages 1 and 2). *Amnicola* shells from the sandy marl above the carbonate-coated sand yielded an age of $19,320 \pm 180$ yr B.P., which is consistent with regional syntheses of Lake Bonneville (figure 2; Currey and Oviatt, 1985; Oviatt and others, 1990). Therefore, I regard this age as reliable and indicative of the age of the post-Stansbury transgression to this altitude.

The age of *Valvata* and *Gyraulus* shells from the lagoon marl, however, is greater than 38,510 yr B.P. and, if taken at face value, does not support the hypothesis that the clean gravel was deposited during the transgressive phase of Lake Bonneville. The anticipated age of this sample was approximately 22,000 yr B.P., and the reported “infinite” age is inconsistent with regional syntheses of radiocarbon ages from the Bonneville basin (Currey and Oviatt, 1985; Oviatt and others, 1990). In addition, there is no indication of a major unconformity between the lagoon marl and the overlying carbonate-coated sand, although the contact is sharp and probably disconformable. Therefore, I consider the infinite age unreliable, and I reject it. A possible explanation for the age being far too old is that the snails whose shells were analyzed were living and obtaining carbon from the shallow lagoon into which ^{14}C -depleted ground water may have been discharging. Another possibility is that the shells were reworked from older (pre-Bonneville) deposits. The first of these two explanations is supported by amino acid analyses of snail shells from this locality (table 3), which show that the *Valvata*, *Gyraulus*, and *Amnicola* shells are all Bonneville in age (W.D. McCoy, 1990, personal communication).

Table 3.
Results of amino-acid analyses of gastropod shells from locality M

Lab number	Genus	Alloisoleucine/Isoleucine ^b	
		Free	Hydrolysate
AGL1456	<i>Valvata</i>	0.148 ± 0.001	0.10 ± 0.01
AGL1457	<i>Gyraulus</i>	0.184 ± 0.005	0.121 ± 0.005
AGL1458	<i>Amnicola</i>	0.230 ± 0.005	0.142 ± 0.005

All analyses by William D. McCoy at the Amino Acid Geochronology Laboratory at the University of Massachusetts

^bRatio of alloisoleucine to isoleucine in the free fraction and in the total hydrolysate; all ratios indicate a Bonneville age.

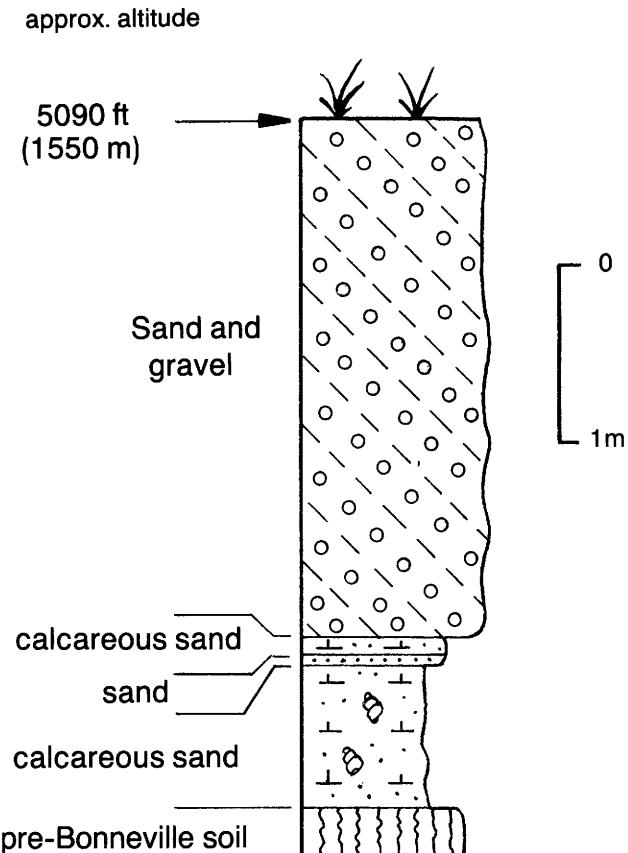
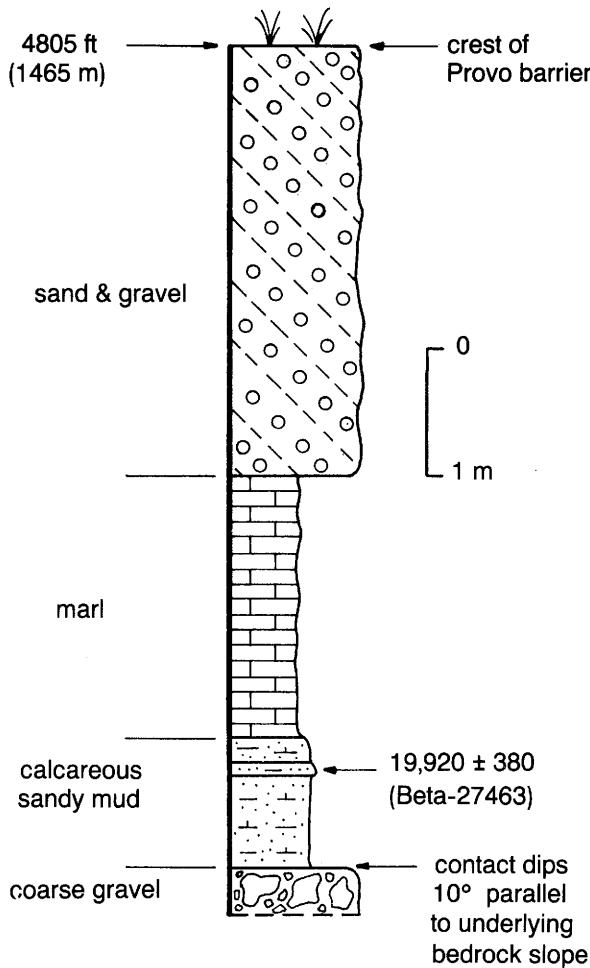
Support for the ground-water discharge hypothesis comes from another radiocarbon age for *Lymnaea* shells collected from locality N (plate 1; table 2). The *Lymnaea* shells were collected from the base of the white marl in an exposure below a Provo barrier-beach ridge on the west side of Table Knoll (figure 18). The anticipated age of the *Lymnaea* sample was approximately 18,500 yr B.P., which is about 1400 years younger than the reported age (table 1). An age of $19,920 \pm 380$ yr B.P. conflicts with regional syntheses, which include radiocarbon ages of wood from transgressive-phase deposits (figure 2). The collection site (figure 18) is near the head of a narrow elongate valley or embayment surrounded by hills of Paleozoic carbonate rock, and ^{14}C -depleted ground water may have been discharging into the shallow lake water at this site. The snails whose shells were analyzed were living at the margin of the open lake in shallow water and not in a restricted lagoon setting, such as the snails in sample 1 (table 1). Therefore, the ^{14}C -depleted ground waters may have been mixed with open lake waters to yield a carbon content that was not as far out of equilibrium with the atmosphere as the lagoon waters were. The result is a radiocarbon age that is slightly too old, but not “infinite.”

Bonneville shoreline and possible evidence for the Keg Mountain oscillation — The Bonneville shoreline represents the highest level of Lake Bonneville. It formed about 15,000 years ago while the lake was overflowing into the Snake River drainage in southern Idaho. In Fish Springs Flat the shoreline is locally well preserved as either barrier beaches or erosional shoreline notches at altitudes between 5194 and 5220 feet (1583 and 1591 m).

The Keg Mountain oscillation is a hypothesized drop in Lake Bonneville from its overflowing level at or slightly below the Bonneville shoreline to a level about 140 feet (42 m) below the Bonneville shoreline (figure 2; Currey and others, 1983; Currey and Oviatt, 1985; Currey and Burr, 1988). The most detailed interpretations of the Keg Mountain oscillation are based on geomorphic evidence at the Stockton Bar, south of Tooele, Utah (Burr and Currey, 1988); unequivocal stratigraphic evidence for the oscillation is scarce.

At locality O (plate 1; table 2), a well-exposed stratigraphic section of Bonneville deposits may show evidence for the Keg Mountain oscillation. A pre-Bonneville buried soil exposed in a gravel pit and in stream cuts at locality O is overlain by about 3 feet (1 m) of calcareous sand, which contains *Lymnaea* shells (figure 19). The calcareous sand is overlain by foreset (offlapping) lacustrine sand and gravel having a surface altitude of about 5090 feet (1550 m). This locality is about 130 feet (40 m) below the local Bonneville shoreline and is therefore within the hypothesized altitudinal range of the Keg Mountain oscillation.

There are two probable explanations, and one less probable explanation, for the depositional sequence at locality O. In all cases, the calcareous sand probably represents the initial transgres-



♂ *Lymnaea* sp.

Figure 18. Measured stratigraphic section at locality N (table 2), showing the collection site of radiocarbon sample 3 (table 1). The marl is the white marl deposited above the Stansbury shoreline, and slightly below the altitude of the Provo shoreline, during the transgressive and the deepest water phases of the lake. Calcareous sandy mud was deposited in shallow water shortly after the lake had transgressed across the bedrock hillslope and deposited the coarse basal gravel.

sion of Lake Bonneville to altitudes above the locality. However, the overlying foreset gravel could be interpreted as representing either a drop in water level prior to the lake actually reaching and overflowing at the Bonneville shoreline, or a noncatastrophic drop in lake level from the Bonneville shoreline prior to the Bonneville flood (i.e., the Keg Mountain oscillation). These two possibilities are shown in figure 2. In both cases fine-grained marly sediments, which presumably would have been deposited above the foreset gravel at higher lake stages, must have been stripped off by post-Bonneville erosion. Alternatively, the foreset gravel could have been deposited during the Bonneville flood, although this seems less probable than the other two hypotheses because of the postulated extremely rapid drawdown during the flood (Malde, 1968; Currey, 1982; Jarrett and Malde, 1987). In conclusion, it is not possible from the data available at locality O to determine which of the first two hypotheses is correct, or if some other hypothesis is more likely than either of these. However, locality O should be included in any systematic review of the basin-wide significance of the Keg Mountain oscillation.

Figure 19. Measured stratigraphic section at locality O (table 2), showing lacustrine sand and gravel overlying calcareous sand interpreted to be the lateral equivalent of the white marl. The sand and gravel may have been deposited during the Keg Mountain oscillation (figure 2; see text for discussion).

Provo shoreline — The Provo shoreline is the best developed of all the major shorelines of Lake Bonneville, both in Fish Springs Flat and throughout the Bonneville basin. In the Fish Springs Flat area, landforms at the Provo shoreline are well preserved and there are excellent exposures in stratigraphic sequences associated with the Provo shoreline. Some of these features are illustrated in figures 4, 6, 7, 8, 12, 20, and 21.

The Provo shoreline formed during the regressive phase of the lake, immediately following the Bonneville flood (figure 2). Evidence for this relative stratigraphic position can be seen in figures 4, 12, and 20. At locality P (plate 1; table 2; figure 20), a Provo wave-cut platform truncates Lake Bonneville transgressive-phase gravel and the white marl. Offshore from the platform, the white marl is overlain by sandy, reworked marl as much as 30 feet (10 m) thick that was deposited during the Provo stillstand. The Provo reworked marl is overlain by gravel deposited during the Provo stillstand at the margin of the platform, and by post-Provo gravel (figure 20) below the platform. These are typical Provo shoreline relationships and can be found at many localities throughout the Bonneville basin.

Another typical characteristic of the Provo shoreline is its occurrence as multiple barrier-beach ridges. This is illustrated in figure

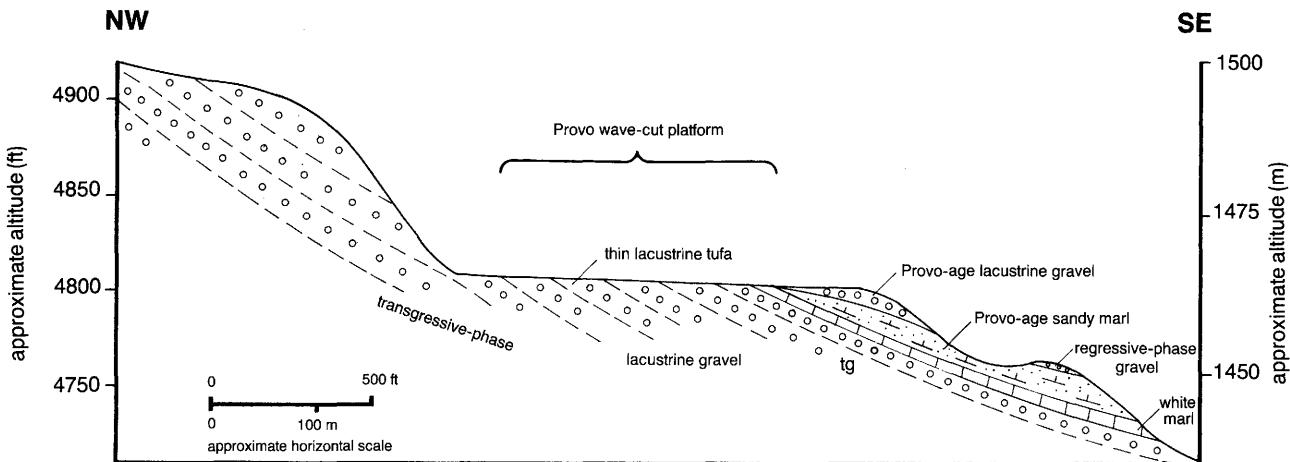


Figure 20. Schematic cross section across a wave-cut platform at the Provo shoreline at locality P (table 2) on the piedmont of the Fish Springs Range north of Sand Pass.

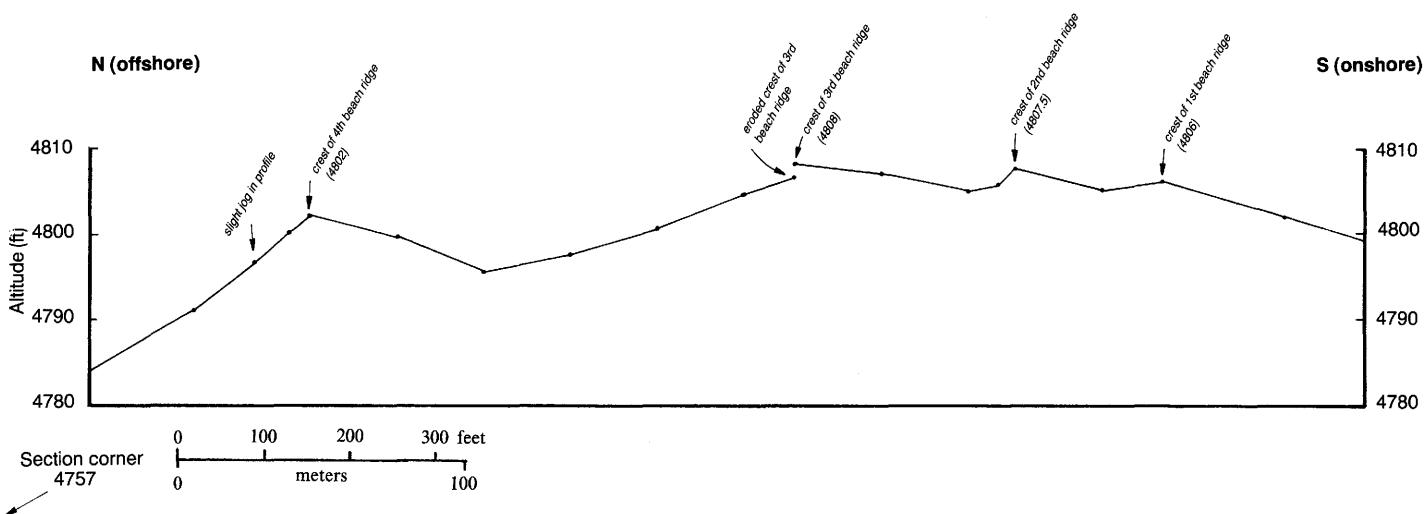


Figure 21. Profile of Provo barrier-beach complex at south end of Fish Springs Flat (locality A, table 2). Surveyed with hand level, rod, and tape. See text for discussion.

21, which shows a topographic profile across the Provo barrier-beach complex at locality A (plate 1; table 2). Four prograded barrier-beach ridges make up the profile. Their crestral altitudes, from oldest to youngest, are 4806 feet, 4807.5 feet, 4808 feet, and 4802 feet (1464.9, 1465.3, 1465.5, and 1463.7 m, respectively). The four beach ridges represent short periods of progradation and aggradation punctuated by instantaneous vertical drops in lake level, all of which were controlled by landslide infilling and down-cutting of the Red Rock Pass, Idaho, threshold of Lake Bonneville (Currey and Burr, 1988).

Holocene

In post-Lake Bonneville time stream processes have dominated the landscape in Fish Springs Flat, eroding lake deposits and older alluvium on the piedmonts, and depositing alluvium on the piedmonts and the margins of the flat valley floor. Alluvial and playa mud has been deposited in the lower parts of the valley and,

concurrently, eolian sand dunes have accumulated close to sources of sand and dust. Uplift of the Fish Springs Range has continued as shown by surface ruptures in the Fish Springs fault zone.

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