UTAH GEOLOGICAL SURVEY
a division of
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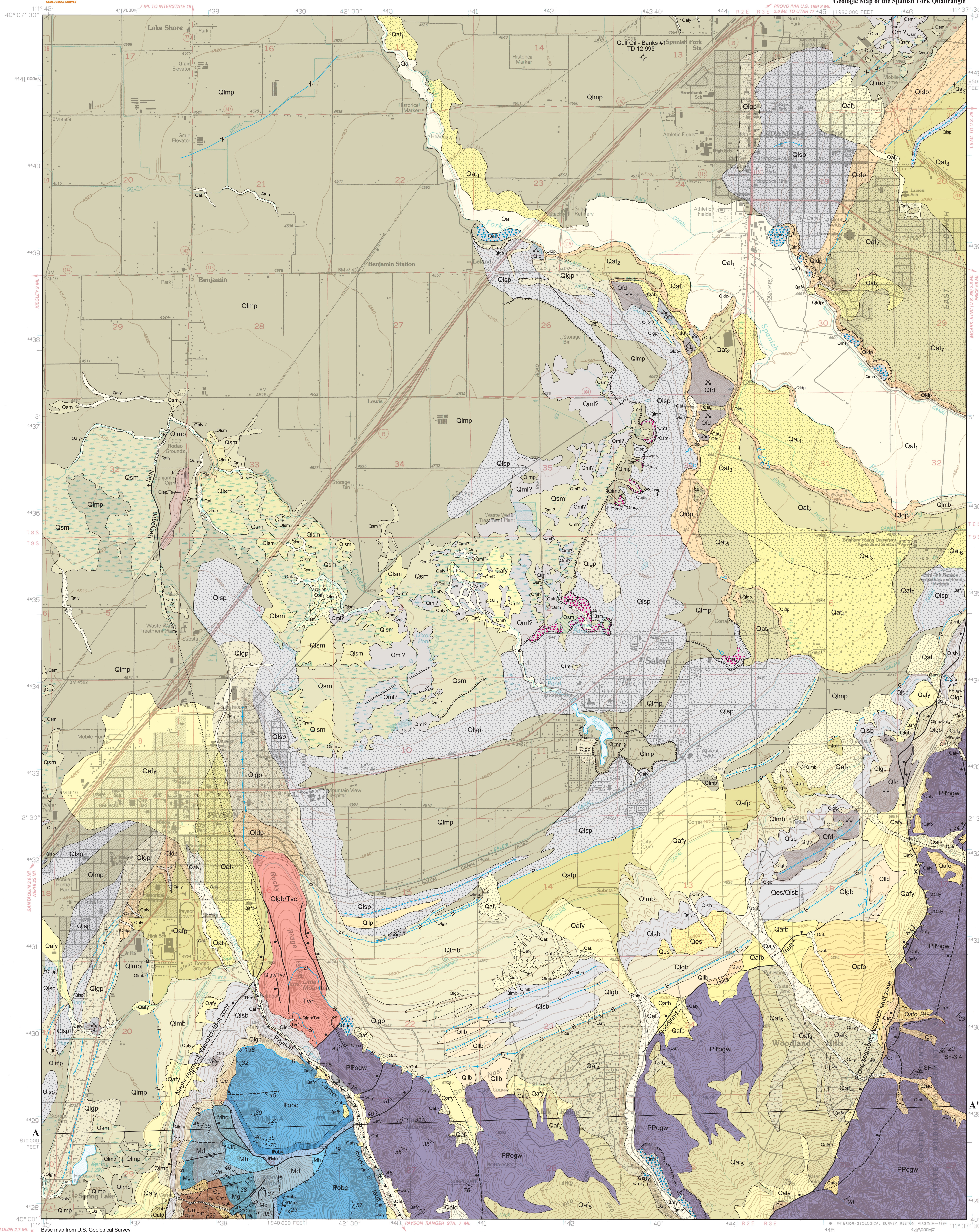

Base map from U.S. Geological Survey
Spanish Fork 7.5' quadrangle, 1994
Geologic data and base map in NAD 1927

SCALE 1:24,000

1 — 1/2 — 0 — 1 MILE

1000 — 0 — 1000 — 2000 — 3000 — 4000 — 5000 — 6000 — 7000 FEET

1 — .5 — 0 — 1 KILOMETER

CONTOUR INTERVAL 20 FEET

Digital Cartography: Lucas Shaw, Kent Brown, and Donald Clark
Aerial Photo and Field Mapping: 2005-2006
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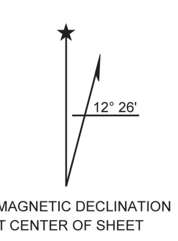

2007 MAGNETIC DECLINATION
AT CENTER OF SHEET

GEOLOGIC MAP OF THE SPANISH FORK QUADRANGLE, UTAH COUNTY, UTAH

by

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2007

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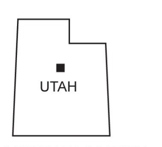

QUADRANGLE LOCATION

1	2	3	1 Lincoln Point 2 Provo 3 Springville 4 West Mountain 5 Spanish Fork Peak 6 Santaquin 7 Payson Lakes 8 Birdseye
4		5	
6	7	8	

ADJOINING 7.5' QUADRANGLE NAMES

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INTRODUCTION

Location and Geographic Setting

The Spanish Fork quadrangle covers part of southeast Utah Valley and the adjacent Wasatch Range, and includes the cities of Spanish Fork, Salem, and Payson (figure 1). Spanish Fork, Peteetneet Creek, Salem Lake, and Spring Lake are the primary hydrologic features. U.S. Interstate Highway 15 extends from northeast to southwest through the map area.

Geologic Summary

Bedrock Stratigraphy and Geologic Structure

The bedrock of the quadrangle is sedimentary, highly faulted, and Tertiary to Cambrian in age. These sedimentary strata are largely exposed on the southwest, south, and southeast margins of the quadrangle. On the southwest margin south of Payson, in the Payson salient of the Wasatch fault zone, the bedrock is highly faulted with two low-angle normal (detachment) faults, more steeply dipping normal faults, tear faults, and the Payson Canyon thrust fault. Little Mountain in the Payson salient is a down-dropped block of Tertiary volcanic conglomerate (map unit Tvc); a small hill underlain by Tertiary tuffaceous sandstone (map unit Ts) is about 3 miles (5 km) northwest of Little Mountain. A small exposure of synorogenic conglomerate of possible Tertiary-Cretaceous (Sevier) age (map unit TKs) is located at the mouth of Payson Canyon. Other bedrock formations of the Payson salient are Permian, Pennsylvanian, Mississippian, and Cambrian in age (map units ₽obc, ₽obv, ₽Mmc, Mh, Md, Mg, Ꞓu, Ꞓd). Bedrock east of the Payson Canyon thrust is mapped as undivided Permian-Pennsylvanian Granger Mountain and Wallsburg Ridge Members of the Oquirrh Formation (P₽ogw) because it lacks adequate exposures and fossil data. North of the bedrock exposures, Pliocene and Miocene rocks are present in the subsurface below Quaternary deposits. The Gulf Oil – Banks #1 petroleum exploration well (plate 1), in the northeast part of the quadrangle (drilled in 1977-1978), is interpreted to have penetrated Quaternary and Tertiary basin fill and bottomed in Miocene sedimentary rock at a depth of 12,995 feet (3962 m) (Davis and Cook, 1983; Utah Division of Oil, Gas and Mining files).

Strata in the region were deformed by Late Cretaceous to early Tertiary contractional folding and faulting of the Sevier orogeny (for example, DeCelles, 2006), early to middle Tertiary regional extensional collapse or relaxation (Constenius and others, 2003), and late Tertiary to recent basin-and-range extensional faulting (for example, Zoback and others, 1981). The quadrangle lies in the Charleston-Nebo (or Provo) salient of the Sevier thrust belt (Tooker, 1983; Willis, 1999; Constenius and others, 2003; DeCelles, 2006). Two detachment blocks in the Payson salient are suggestive of the extensional collapse event. Prior maps showed these blocks as younger-on-older "thrusts," but thinning of the Bridal Veil Limestone (₽obv) and Manning Canyon Shale (₽Mmc) and the younger-on-older relationship indicate detachment faulting of poorly constrained age. The map area is also located at the boundary between the Provo and Nephi segments of the late Tertiary to present Wasatch fault zone (Machette, 1992; Harty and others, 1997). The Payson salient south of Payson separates the Nephi segment to the south from the Provo segment to the east and north.

The Benjamin fault, which is the probable northern extension of the Nephi segment, dies out to the north in Utah Valley. Machette (1992) measured fault scarp heights of 3 to 6 feet (1-2 m) in two locations along the southern part of the Benjamin fault, and mapped the fault northward along the west edge of a linear hill underlain by tuffaceous sandstone possibly of Pliocene or Miocene age (map unit Ts). We map the fault about 300 to 400 feet (90-120 m) farther to the west, where a prominent scarp of similar size forms the eastern boundary of marsh deposits (map unit Qsm) and coincides with a canal used to drain the marsh.

Quaternary Geology

Most of the surficial deposits in the Spanish Fork quadrangle were deposited by latest Pleistocene Lake Bonneville during the last glacial advance (about 12,000 to 23,000 radiocarbon years ago; Richmond, 1986) and overlie coalesced older (middle to upper Pleistocene) alluvial fans (Currey and Oviatt, 1985; Oviatt and others, 1992) (table 1). The alluvial-fan deposits underlie piedmont slopes on the margin of Utah Valley, and are extensively exposed above the highest Lake Bonneville shoreline on the south margin of the quadrangle between the Provo and Nephi segments of the Wasatch fault zone.

Other surficial deposits in the quadrangle are mostly younger than Lake Bonneville. Incision of the lake threshold in southern Idaho and drying climatic conditions reduced the size of Lake Bonneville, leaving Utah Lake as one of its remnants (Jarrett and Malde, 1987; O'Conner, 1993). Younger stream alluvium, deposited as the lake level fell, forms extensive terraces on the Lake Bonneville delta on the east margin of the quadrangle. Streams were incised in response to the lowering lake level, and small alluvial fans formed at the mouths of range-front drainages. Locally, the banks of incised stream channels failed, and this process of landsliding continues sporadically today, particularly along the banks of Spanish Fork where landslides are commonly derived from Bonneville deltaic deposits. On gentler slopes, possible earthquake-induced lateral spreads formed, followed by headward erosion of scarps due to spring sapping and minor landsliding on locally steeper slopes of small alcoves surrounding springs. Wind eroded the desiccated Bonneville lake beds and deposited a thin, widespread, and unmapped mantle of calcareous loess (Machette, 1992).

Paleoseismology

Utah Valley and valley margins in the Spanish Fork quadrangle are the result of late Cenozoic displacement along the Wasatch fault zone. Quaternary displacement indicates significant seismic hazards near the fault zone, with potential earthquakes of about magnitude 7.0 to 7.1 (see Wells and Coppersmith, 1994). Based on currently available information on earthquake timing and displacement, the preferred vertical slip-rate estimate for the Provo segment is 1.2 mm/yr (with a possible range from 0.6 to 3.0 mm/yr), and for the Nephi segment is 1.1 mm/yr (with a possible range from 0.5 to 3.0 mm/yr) (Lund, 2005).

Many paleoseismic investigations have been conducted in the area, including two in the Spanish Fork quadrangle. The first investigation in the quadrangle was conducted in 1987, when the U.S. Bureau of Reclamation (USBR) excavated two trenches on a valley splay of the Provo segment (Woodland Hills fault), northwest of the mouth of Maple Canyon (SW1/4 section 18, T. 9 S., R. 3 E., Salt Lake Baseline and Meridian [SLBM]). The trenches revealed evidence for three or four surface-faulting events since about 130 ka, based on correlations of faulted alluvial-fan soils with similar soils in the area (Machette, 1992; Machette and others, 1992). The slip rate at the site was estimated to be from 0.01 to 0.02 mm/year with an average recurrence interval of about 40 to 65 ky (Machette and others, 1992). Movement on the fault splay near the Bonneville shoreline apparently occurred during only some of the events on the main fault to the east, with the most recent event on the splay occurring about 1.0 ka, prior to the most recent event (about 0.6 ka) on the main fault near Mapleton in the adjacent Spanish Fork Peak quadrangle (Lund, 2005; see also Machette, 1992, p. 11).

The USBR also excavated two trenches in alluvial-fan deposits on the main fault at the mouth of Water Canyon (NW1/4 section 17, T. 9 S., R. 3 E., SLBM), about 1.25 miles (2 km) northeast of the previous trenches (Ostenaa, 1990). The Water Canyon trenches revealed evidence for at least three Holocene surface-faulting events. Two events occurred in the last 1.0 ky, conflicting with evidence of only one event in the same time period from other trenches on the Provo segment. This conflict may be explained by fault overlap of the Nephi and Provo segments, with surface-faulting events on both segments occurring at the Water Canyon site (Ostenaa, 1990; Machette, 1992).

Previous Investigations

Several investigators have mapped the geology of the Spanish Fork and adjacent quadrangles. Students at Brigham Young University (Brown, 1950; Hodgson, 1951; Demars, 1956; Petersen, 1956; Rawson, 1957; Brady, 1965; Lyman, unpublished data for the Payson Lakes and Santaquin quadrangles) and Ohio State University (Metter, 1955) mapped bedrock in the area, although most of these projects were not done on 7.5' quadrangle topographic base maps. Hintze (1962) compiled a smaller-scale bedrock map of the southern Wasatch Range. Machette (1992) and Harty and others (1997) previously mapped surficial deposits in and near the quadrangle. Constenius and others (2006) conducted regional-scale mapping of adjacent areas, and Clark (2006) also mapped adjacent areas. This map is part of a larger project to map the Provo 30' x 60' quadrangle, during which geology of the adjacent West Mountain quadrangle (Clark, 2006) was mapped; surficial geologic mapping in the Springville and Provo areas (work in progress by B.J. Solomon) is ongoing (figure 2).

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We thank A.J. Wells (independent consultant-Exxon retired) for paleontologic expertise in identifying fusulinids from Oquirrh strata, and Scott Ritter (Brigham Young University) for his paleontologic proficiency. UGS staff Gary Christenson, Grant Willis, Jon K. King, Bob Biek, and Michael Hylland improved this map through their reviews. UGS staff Lucas Shaw, Kent Brown, Jim Parker, and Lori Douglas assisted in preparation of the map and supporting materials.

MAP UNIT DESCRIPTIONS

QUATERNARY

Alluvial deposits

Qal$_1$ **Level-1 stream deposits** (upper Holocene) – Moderately sorted pebble and cobble gravel in a matrix of sand, silt, and minor clay; contains thin discontinuous sand lenses; subangular to rounded clasts; thin to medium bedded. Deposited by perennial streams such as Peteetneet Creek and Spanish Fork, and by smaller streams draining areas of shallow ground water and marshes from Spring Lake to near Spanish Fork city; includes deposits on active flood plains and minor terraces less than 5 feet (1.5 m) above stream level; locally includes small colluvial deposits along steep stream embankments; deposits in Peteetneet Creek grade downslope into Holocene to upper Pleistocene alluvial-fan deposits (Qafy); equivalent to the younger part of young alluvial deposits (Qaly), but differentiated where modern deposits with active channels and bar-and-swale topography can be mapped separately. Exposed thickness less than 15 feet (5 m).

Qal$_2$ **Level-2 stream deposits** (middle Holocene to upper Pleistocene) – Moderately sorted pebble and cobble gravel in a matrix of sand, silt, and minor clay; contains thin discontinuous sand lenses; subangular to rounded clasts; thin to medium bedded. Deposited east of Spanish Fork city and south of Spring Lake; equivalent to the older part of Qaly, but differentiated where deposits in abandoned channels and associated flood plains characterized by subdued bar-and-swale topography can be mapped separately. Exposed thickness less than 15 feet (5 m).

Qaly **Young alluvial deposits, undivided** (Holocene to upper Pleistocene) – Moderately sorted pebble and cobble gravel in a matrix of sand and minor silt and clay. Deposited by perennial streams in mountain canyons and ephemeral streams on the valley floor; locally includes small alluvial-fan and colluvial deposits; includes level-2 stream deposits (Qal$_2$) incised by active stream channels and partly overlain by level-1 stream deposits (Qal$_1$) that cannot be differentiated because of map scale or in areas where the specific age of Holocene deposits cannot be determined; postdates regression of Lake Bonneville from the Provo shoreline and lower levels. Thickness variable, probably less than 15 feet (5 m).

Qalo **Old alluvial deposits** (upper to middle Pleistocene) – Slightly indurated sand and well-rounded gravel with red-brown, oxidized clay film on clasts; mapped on the southern edge of the quadrangle south of Tithing Mountain and extending southward into the Payson Lakes quadrangle on the saddle between Peteetneet Creek (Payson Canyon) and the piedmont north of Loafer Mountain where the unit intertongues with or is overlain by middle Pleistocene fan alluvium (Qaf$_5$) (Machette, 1992). Machette (1992) stated that the deposits are probably equivalent to, and older than, the latest middle Pleistocene Little Valley lake cycle of Scott and others (1983). The old alluvial deposits are apparently related to headward erosion of Peteetneet Creek and subsequent capture of an ancient stream tributary of Payson Canyon east of Tithing Mountain (discussed in further detail by Machette, 1992). Thickness probably less than 20 feet (6 m) in the Spanish Fork quadrangle, but may be as much as 30 feet (10 m) thick to the south (Machette, 1992).

Qat (Qat$_1$, Qat$_2$, Qat$_3$, Qat$_4$, Qat$_5$, Qat$_6$, Qat$_7$, Qat$_8$) **Stream-terrace deposits** (middle Holocene to upper Pleistocene) – Poorly to moderately sorted pebble and cobble gravel in a matrix of sand, silt, and minor clay; contains thin sand lenses; subangular to rounded clasts; thin to medium bedded. Deposited on several levels of gently sloping terraces, with subscripts denoting relative height above modern stream channels, 1 being the lowest level; level 1 deposits (Qat$_1$) lie 5 to 15 feet (1.5-5 m) above modern streams and are incised by them; levels 2 through 8 lie at increasing relative heights of 30 to 40 feet (9-12 m) (Qat$_2$), 40 to 50 feet (12-15 m) (Qat$_3$), 50 to 60 feet (15-18 m) (Qat$_4$), 60 to 75 feet (18-23 m) (Qat$_5$), 75 to 90 feet (23-27 m) (Qat$_6$), 90 to 100 feet (27-30 m) (Qat$_7$), and 100 to 120 feet (30-37 m) (Qat$_8$) above modern streams; where subscripts are absent, closely spaced terrace levels cannot be differentiated at map scale. Small undifferentiated terrace remnants lie adjacent to Peteetneet Creek and drainages in Loafer and Maple Canyons, but the most extensive deposits lie on regressive Lake Bonneville deltaic deposits at the mouth of Spanish Fork Canyon where Machette (1992) mapped them as regressive-phase stream alluvium.

Numbered subscripts do not indicate a specific age and only Qat$_7$ appears to be equivalent to a particular regressive shoreline. The oldest and highest terrace levels (Qat$_7$ and Qat$_8$) are northeast of Spanish Fork and grade to the steep front of a regressive (Provo phase) delta (Qldp) at elevations of 4700 to 4710 feet (1430-1435 m), whereas younger terraces lie south of the river and grade to delta fronts at lower elevations of from 4600 to 4660 feet (1400-1420 m). This indicates a shift of the river to the south of its current course as the level of Lake Bonneville fell from the Provo shoreline, and the river occupied its current channel after northward migration from level 6 to level 1 as the lake receded farther. Thicknesses typically 5 to 15 feet (1.5-5 m).

Qaf$_1$ **Level-1 alluvial-fan deposits** (upper Holocene) – Poorly to moderately sorted, weakly to non-stratified, pebble to cobble gravel, with boulders near bedrock sources, in a matrix of sand, silt, and minor clay; clasts angular to subrounded, with sparse well-rounded clasts derived from Lake Bonneville gravel; medium to very thick bedded. Coarser-grained material deposited principally by debris flows at the mouths of small, intermittent stream channels that drain bedrock (P₽ogw) on the east side of Tithing Mountain and coarse-grained alluvial-fan deposits (Qaf$_4$) near Elk Ridge, and at the mouth of the perennial stream that drains similar bedrock in Flat and Water Canyons on the east edge of the Spanish Fork quadrangle; finer grained material deposited by debris floods from small drainages in finer grained Lake Bonneville deposits (Qlmb and Qlsb); equivalent to the younger part of young alluvial-fan deposits (Qafy) but differentiated where modern deposits of small, discrete fans, not incised by younger channels, overlie lacustrine deposits and can be mapped separately. Exposed thickness less than 10 feet (3 m).

Qaf$_2$ **Level-2 alluvial-fan deposits** (middle Holocene to upper Pleistocene) – Poorly sorted pebble and cobble gravel, locally bouldery, in a matrix of sand, silt, and minor clay; clasts angular to subrounded, with sparse well-rounded clasts derived from Lake Bonneville gravel; medium to very thick bedded. Deposited by debris flows and debris floods in Water Canyon, at the mouths of two drainages to the north of Water Canyon, and in the city of Spanish Fork; equivalent to the older part of Qafy, but differentiated where deposits are graded slightly above modern stream level or are at the mouth of an abandoned stream channel, and can be mapped separately. Exposed thickness less than 15 feet (5 m).

Qafy **Young alluvial-fan deposits, undivided** (Holocene to upper Pleistocene) – Poorly to moderately sorted, pebble to cobble gravel with boulders near bedrock sources, in a matrix of sand, silt, and clay. Deposited by debris flows and debris floods at the mouths of large and small mountain canyons and streams locally incising Lake Bonneville deposits, and from the stream on the valley floor draining Salem Lake. Includes level-1 and -2 alluvial-fan deposits (Qaf$_1$ and Qaf$_2$) that postdate the regression of Lake Bonneville from the Provo shoreline and lower levels that cannot be differentiated because of map scale or are in areas where the specific age of Holocene deposits cannot be determined; no shorelines are found on these alluvial fans. Thickness variable, probably less than 40 feet (12 m).

Qafp **Alluvial-fan deposits, regressive (Provo) phase of Lake Bonneville** (upper Pleistocene) – Poorly to moderately sorted, pebble to cobble gravel, locally bouldery, in a matrix of sand, silt, and minor clay; clasts angular but well rounded where derived from Lake Bonneville gravel; medium to very thick bedded. Deposited by debris flows and debris floods near the Provo shoreline at the mouth of Payson Canyon, on the piedmont between Payson and Water Canyons, and on the west flank of Mollies Nipple; locally extends below the Provo shoreline; incised by Holocene streams (Qal$_1$ and Qaly) and covered by young alluvial fans (Qafy); equivalent to the younger part of level-3 alluvial-fan deposits (Qaf$_3$) but differentiated where deposits related to the regressive phase of Lake Bonneville, typically below the Bonneville shoreline, can be separated from deposits related to the transgressive phase of the lake (Qafb), typically above the Bonneville shoreline. Exposed thickness less than 30 feet (10 m).

Qafb **Alluvial-fan deposits, transgressive (Bonneville) phase of Lake Bonneville** (upper Pleistocene) – Poorly sorted, pebble and cobble gravel, locally bouldery, in a matrix of sand, silt, and minor clay; clasts angular to subangular; medium to very thick bedded. Deposited by debris flows near the Bonneville shoreline between Loafer and Maple Canyons and in Payson Canyon; locally extends below the Bonneville shoreline; incised by Holocene streams; equivalent to the older part of level-3 alluvial-fan deposits (Qaf$_3$) but differentiated where deposits related to the transgressive phase of Lake Bonneville are near the Bonneville shoreline. Exposed thickness less than 15 feet (5 m).

Qaf$_3$ **Level-3 alluvial-fan deposits, Bonneville lake cycle, undivided** (upper Pleistocene) – Poorly to moderately sorted, pebble to cobble gravel, locally bouldery, in a matrix of sand, silt, and minor clay. Mapped near the mouth of Maple Canyon above the Bonneville shoreline and related alluvial-fan deposits (Qafb). Level-3 alluvial-fan deposits are incised into, and overlie, alluvial-fan deposits that predate Lake Bonneville (Qaf$_4$, Qaf$_5$, and Qafo); may include alluvial-fan deposits of both the transgressive and regressive phases of Lake Bonneville that are undifferentiated because correlation with a specific lake phase cannot be established. Thickness probably less than 40 feet (12 m).

Qaf$_4$ **Alluvial-fan deposits, pre-Bonneville lake cycle to Little Valley lake cycle** (upper to middle Pleistocene) – Poorly sorted, clast-supported pebble to cobble gravel, with matrix-supported interbeds in the upper part; locally bouldery in a matrix of sand, silt, and clay; clasts angular to subrounded; medium to very thick bedded. Fan remnants are mainly on the piedmont between Payson and Maple Canyons, are above and cut by the Bonneville shoreline, and are incised into still older alluvial-fan deposits (Qaf$_5$). Machette (1992) stated that correlative deposits likely underlie Lake Bonneville deposits, forming the piedmont slopes within Utah Valley, and probably grade laterally to lacustrine sediment of the Little Valley lake cycle below an elevation of about 4900 feet (1490 m) (Scott and others, 1983). Equivalent to the younger part of older alluvial-fan deposits (Qafo) but differentiated where pre-Bonneville deposits can be divided into Qaf$_4$ and Qaf$_5$ based on fan morphology, degree of dissection, and incision of younger into older deposits. Exposed thickness less than 15 feet (5 m).

Qaf$_5$ **Alluvial-fan deposits, pre-Little Valley lake cycle** (middle Pleistocene) – Poorly sorted, clast-supported pebble to cobble gravel, with matrix-supported interbeds in the upper part; locally bouldery, in a matrix of sand, silt, and clay; deposits are deeply dissected, lack fan morphology, and are typically preserved remnants of high surfaces on bedrock. On the piedmont between Payson and Maple Canyons; appear incised by level-4 alluvial-fan deposits (Qaf$_4$). Machette (1992) reported that level 5 alluvial fan-deposits are exposed in a stream gully on the divide east of Peteetneet Creek in the adjacent Payson Lakes quadrangle, and contain isolated pods of 0.62 Ma Lava Creek B volcanic ash (Izett and Wilcox, 1982, Utah locality 9). Correlative alluvial deposits likely underlie Lake Bonneville deposits and probably grade laterally to lacustrine sediment of the Pokes Point and other lake cycles older than the Little Valley lake cycle (Scott and others, 1983; Machette and Scott, 1988), although not observed in Utah Valley (Machette, 1992). Equivalent to the older part of older alluvial-fan deposits (Qafo) but differentiated where Little Valley and pre-Little Valley deposits can be separated based on fan morphology, degree of dissection, and incision of younger into older deposits. Exposed thickness less than 60 feet (20 m).

Qafo **Older alluvial-fan deposits, pre-Bonneville lake cycle, undivided** (upper to middle Pleistocene) – Poorly sorted, pebble to cobble gravel, locally bouldery, in a matrix of sand, silt, and clay. Mapped between Maple and Water Canyons where pre-Bonneville lake cycle alluvial-fan deposits (Qaf$_4$ and Qaf$_5$) are undifferentiated because they are poorly exposed or lack distinct geomorphic expression. Thickness probably less than 60 feet (20 m).

Artificial deposits

Qf **Artificial fill (Historical)** – Engineered fill used as a debris-basin dam and an irrigation-water pond in Payson Canyon; unmapped fill is locally present in developed areas like Payson, Salem, and Spanish Fork.

Qfd **Disturbed land (Historical)** – Land disturbed by sand, gravel, and aggregate operations; only the larger operations are mapped and their outlines are based on aerial photographs taken in 1998; faults and barrier-beach deposits mapped within disturbed land are based on 1965 aerial photographs taken before disturbance. Land within these areas contains a complex, rapidly changing mix of cuts and fills; most operations are extracting material from upper Pleistocene deltaic deposits of the regressive phase of the Bonneville lake cycle (Qldp) beneath a thin cover of middle Holocene to upper Pleistocene stream-terrace deposits (Qat), and from upper Pleistocene lacustrine gravel of the transgressive phase of the Bonneville lake cycle (Qlgb). Faults mapped or exposed in Qfd on the east margin of the quadrangle are based on 1965 aerial photographs that show fault scarps in probable Qlgb prior to disturbance; these faults do not cut the human disturbances.

Colluvial deposits

Qc **Colluvial deposits (Holocene to upper Pleistocene)** – Pebble, cobble, and boulder gravel, commonly clast supported, in a matrix of sand, silt, and clay; angular to subangular clasts, poorly sorted, poorly stratified, locally derived sediment deposited by slopewash, and soil creep in steep-sided stream canyons; includes landslides, rock falls, and debris flows too small to map separately; most bedrock is covered by at least a thin veneer of colluvium, and only the larger, thicker deposits are mapped. Maximum thickness about 15 feet (5 m).

Lacustrine deposits

Sediments deposited by Pleistocene Lake Bonneville dominate the surficial geology of the Spanish Fork quadrangle. Lake Bonneville was a large ice-age lake that covered much of northwestern Utah between about 32,500 and 11,600 calendar years ago. Four regionally extensive shorelines of Lake Bonneville are found in the Bonneville Basin, but only two (the Bonneville and Provo shorelines) are found in the Spanish Fork quadrangle (table 1). The earliest of the regional shorelines is the Stansbury shoreline, which resulted from a climatically induced oscillation from about 24,400 to 23,200 years ago during expansion of Lake Bonneville. The Stansbury shoreline formed at elevations below those in the Spanish Fork quadrangle. The lake continued to rise, entering the northwest corner of the Spanish Fork quadrangle at an elevation of about 4500 feet (1370 m) about 23,000 years ago. In the Bonneville Basin, the lake reached its highest level of about 5093 feet (1552 m) about 18,000 years ago; this level was controlled by overflow at a threshold near Zenda in southern Idaho. This highstand created the Bonneville regional shoreline. On the south margin of the Spanish Fork quadrangle, the Bonneville shoreline forms a bench at the mountain front and along the piedmont.

About 16,800 years ago, rapid erosion at the Zenda threshold resulted in catastrophic lowering of the lake by 340 feet (100 m) in less than one year (Jarrett and Malde, 1987; O'Conner, 1993). Lake Bonneville then stabilized at a new lower threshold near Red Rock Pass, Idaho, and the Provo regional shoreline was formed on the piedmont slope in this quadrangle.

The lake oscillated at or near the Provo level until about 13,500 years ago (Godsey and others, 2005), when climatic factors induced further lowering of the lake level within the Bonneville basin. Lake Bonneville later fell below the altitude of the natural threshold of Utah Valley, which thereby isolated Utah Lake from the main body of Lake Bonneville (Machette, 1992). The level of Lake Bonneville eventually fell below the elevation of present Great Salt Lake, but a subsequent expansion of Lake Bonneville due to climatic variations from about 12,800 to 11,600 years ago formed the Gilbert regional shoreline. During the expansion of Lake Bonneville, flow from Utah Lake over the threshold in Utah Valley increased, preventing the lake level from rising (Machette, 1992). Lake Bonneville fell to near present levels about 10,000 years ago, leaving Great Salt Lake and Utah Lake as two of its prominent remnants.

Isostatic rebound following reduction in the volume of water in Lake Bonneville, as well as displacement along the Wasatch fault zone, have uplifted regional shorelines in the Bonneville basin (Crittenden, 1963). The amount of isostatic uplift increases toward the center of the basin where the weight of removed water was greatest, and Crittenden (1963) estimated a maximum isostatic uplift of 210 feet (64 m). Machette (1992) reported combined isostatic and fault uplift of the Bonneville and Provo shorelines as much as 110 feet (34 m) and 65 feet (20 m), respectively, in eastern Utah Valley. In the Spanish Fork quadrangle near the basin margin, isostatic uplift of both shorelines on the hanging wall of the fault is only about 15 feet (5 m) and shoreline elevations are closer to threshold elevations in Idaho.

Deposits younger than the Bonneville lake cycle

Qly **Young lacustrine deposits** (Holocene) – Silt, clay, and minor sand deposited in ponds along Beer Creek (W1/2 section 33, T. 8 S., R. 2 E., SLBM). Maximum thickness about 5 feet (1.5 m).

Deposits of the Provo (regressive) phase of the Bonneville lake cycle

Only mapped below the Provo shoreline. The Provo shoreline is at elevations from about 4735 to 4750 feet (1445-1450 m) in the Spanish Fork quadrangle (table 1). Currey (1982) estimated an elevation of 4744 feet (1446 m) for the Provo shoreline on a north-facing beach ridge east of Rocky Ridge (SW1/4 section 15, T. 9 S., R.2 E., SLBM).

Qldp **Deltaic deposits** (upper Pleistocene) – Moderately to well-sorted, clast-supported, pebble and cobble gravel in a matrix of sand and silt, interbedded with thin pebbly sand beds; clasts subround to round; locally weakly cemented with calcium carbonate. Deposited as foreset beds having original dips of 30 to 35 degrees and bottomset beds having original dips of 1 to 5 degrees; deposited in deltas below the Provo shoreline at the mouth of the Spanish Fork; commonly capped by a thin veneer of stream-terrace deposits (Qat) and exposed along terrace escarpments. Exposed thickness about 75 feet (25 m).

Qlgp **Lacustrine gravel and sand** (upper Pleistocene) – Moderately to well-sorted, subrounded to rounded, clast-supported, pebble to cobble gravel and pebbly sand with minor silt. Gastropods locally common in sandy lenses; gravel commonly cemented with calcium carbonate. Thin to thick bedded; bedding ranges from horizontal to dips of 10 to 15 degrees on steeper piedmont slopes or in bars, barrier beaches, and beach ridges; commonly interbedded with or laterally gradational to lacustrine sand and silt of the regressive phase (Qlsp). Exposed thickness less than 30 feet (10 m).

Qlsp **Lacustrine sand and silt** (upper Pleistocene) – Moderately to well-sorted, subrounded to rounded, fine to coarse sand and silt with minor pebbly gravel. Thick to very thick bedded; commonly has ripple marks and scour features; gastropods locally common. Deposited at and below the Provo shoreline in relatively shallow water near shore; overlies and grades downslope into lacustrine silt and clay of the regressive phase (Qlmp) and laterally to sandy deltaic deposits (Qldp). Exposed thickness less than 30 feet (10 m).

Qlmp **Lacustrine silt and clay** (upper Pleistocene) – Calcareous silt (marl) and clay with minor fine sand; typically laminated or thin bedded but appears unstratified at a distance; ostracodes locally common. Deposited in quiet water below the Provo shoreline in moderately deep basins and sheltered bays; overlies lacustrine silt and clay of the transgressive phase (Qlmb). Likely includes or may be entirely lagoon-fill deposits (Qllp) in the flat area south of Payson between beach ridges (Qlgp) along U.S. Highway 6 on the west and the Provo shoreline on the east. Machette (1992) reported that silt and clay of the regressive phase can be differentiated from silt and clay of the transgressive phase by the presence of conchoidal fractures in blocks of transgressive deposits and their absence in regressive deposits, but Qlmp may include some undifferentiated transgressive deposits. Exposed thickness less than 15 feet (5 m).

Qllp **Lagoon-fill deposits** (upper Pleistocene) – Silt and clay, with minor fine-grained sand and pebbles. One small lagoon-fill deposit is mapped below the Provo shoreline, underlying level, grass-covered ground in a closed depression behind a Lake Bonneville barrier beach about one mile (1.6 km) southwest of Spanish Fork city (NW1/4 section 25, T. 8 S., R.2 E., SLBM). Elsewhere in the Bonneville Basin, similar deposits commonly contain wood that has been used to establish Lake Bonneville chronology (Machette, 1992). Maximum thickness about 10 feet (3 m).

Deposits of the Bonneville (transgressive) phase of the Bonneville lake cycle

Mapped between the Bonneville and Provo shorelines. The Bonneville shoreline is at elevations from about 5085 to 5100 feet (1550-1555 m) in the Spanish Fork quadrangle; Currey (1982) estimated an elevation of 5095 feet (1553 m) for the Bonneville shoreline on a northwest-facing beach ridge south of Salem (SW1/4 section 18, T. 9 S., R.3 E., SLBM).

Qlgb **Lacustrine gravel and sand related to the transgressive (Bonneville) phase of the Bonneville lake cycle** (upper Pleistocene) – Moderately to well-sorted, clast-supported pebble to cobble gravel in a matrix of sand and silt; interbedded with pebbly sand. Clasts commonly subround to round, but some deposits consist of poorly sorted, angular gravel derived from nearby bedrock outcrops. Gastropods locally common in sandy lenses; gravel locally cemented with calcium carbonate. Thin to thick bedded; bedding ranges from horizontal to primary dips of 10 to 15 degrees on steeper piedmont slopes or in bars, barrier beaches, and beach ridges; commonly interbedded with or laterally gradational to lacustrine sand and silt of the transgressive phase (Qlsb); commonly covered by a thin veneer of colluvium. Forms wave-cut benches at the highest (Bonneville) shoreline in bedrock on the southwest and southeast margins of the quadrangle and in pre-Bonneville alluvial-fan deposits (Qaf$_4$) on the piedmont near Elk Ridge, and forms constructional bars and barrier beaches on the piedmont at the highest shoreline between Tithing Mountain and Water Canyon, bounding extensive lagoon-fill deposits upslope. Exposed thickness less than 30 feet (10 m).

Qlsb **Lacustrine sand and silt** (upper Pleistocene) – Moderately to well-sorted, subrounded to rounded, fine to coarse sand and silt with minor pebbly gravel. Thick to very thick bedded; commonly has ripple marks and scour features; gastropods locally common. Deposited in relatively shallow water near shore; overlies coarse-grained beach gravel (Qlgb), implying deposition in increasingly deeper water of a transgressing lake; grades downslope into lacustrine silt and clay of the transgressive phase (Qlmb). Exposed thickness less than 15 feet (5 m).

Qlmb **Lacustrine silt and clay** (upper Pleistocene) – Calcareous silt (marl) and clay with minor fine sand; typically thick bedded or massive; ostracodes locally common. Deposited in quiet water, either in sheltered bays between headlands or offshore in deeper water; overlies lacustrine gravel, sand, and silt of the transgressive phase (Qlgb and Qlsb). A small outcrop of the unit is also present beneath regressive deposits at the base of the slope near Grimes Pond, northwest of Salem, but the outcrop is too small to map; Machette (1992) reported that silt and clay of the transgressive phase is characterized by the presence of conchoidal fractures in dense (compact) blocks. Exposed thickness less than 15 feet (5 m).

Qllb **Lagoon-fill deposits** (upper Pleistocene) – Silt and clay with minor fine sand and pebbles; lies in closed depressions behind Lake Bonneville bars and barrier beaches between the Bonneville and Provo shorelines; the three largest lagoon-fill deposits lie upslope of constructional bars at the Bonneville shoreline level, near the base of Elk Ridge and Woodland Hills, including the lagoon-fill deposit at Goose Nest which is partly overlain by young alluvial-fan deposits (Qafy); two smaller lagoons were just north of Goose Nest behind barrier beaches. Locally contains wood that has been used to establish Lake Bonneville chronology. Maximum thickness about 10 feet (3 m).

Eolian deposits

Qes **Eolian sand** (Holocene) – Moderately to well sorted, very fine to medium sand, with minor silt and clay. Calcareous, loose to moderately firm where cemented by secondary calcium carbonate; forms small dunes locally; derived from transgressive Bonneville beach sand (Qlsb) between alluvial fans at the mouths of Loafer and Water Canyons. The sand dunes are from 3 to 10 feet (1-3 m) tall.

Unmapped eolian silt (loess), with minor sand and clay, forms a thin mantle on stable geomorphic surfaces throughout the quadrangle; the silt is friable to moderately firm, homogenous, nonstratified, porous, and forms steep to vertical faces where exposed in stream cuts; most argillic B horizons of late Pleistocene age soils are derived from this silt (Machette, 1992). The silt is from 3 to 5 feet (1-1.5 m) thick

Mass-movement deposits

Qml? **Lateral-spread deposits?** (middle Holocene to upper Pleistocene) – Pebbly sand, sand, and silt below (post-dating) the Provo shoreline, typically with scarps upslope and hummocky terrain with swampy swales where the deposits are mapped. Although interpretations other than lateral spreading are possible, two features are mapped here as possible lateral-spread deposits because they are in an area having high liquefaction potential (Anderson and others, 1986). Miller (1982), Machette (1992), and Harty and Lowe (2003) previously mapped these lateral-spread landslides with different extents than those shown on this map. Machette (1992) removed the query Miller (1982) put on these features, while Harty and Lowe (2003) were unsure of their origin. The one northwest of Salem was named the Beer Creek feature by Harty and Lowe (2003). The other, northeast of Spanish Fork city and extending into the adjacent Provo and Springville quadrangles, was named the Springville/Spanish Fork feature by Harty and Lowe (2003). Thickness of the deposits is unknown but probably less than 50 feet (15 m).

The Beer Creek feature is characterized by a linear main scarp up to 6 feet (2 m) high upslope extending for about 3 miles (5 km), a large amphitheater about 1.5 miles (2.5 km) across on the northeastern end of the main scarp, small alcoves about 1000 feet (300 m) in diameter upslope from the main scarp, minor linear internal scarps up to 3 feet (1 m) high in the upper part of the deposit, and several small hummocks and swampy swales less than 3 feet (1 m) deep in the lower part of the deposit. Harty and Lowe (2003) excavated a trench along the main scarp of the Beer Creek feature (NE1/4 section 2, T. 9 S., R.2 E., SLBM) and found evidence of rotational landsliding. Hummocks within small alcoves along the main scarp are evidence of localized rotational landsliding or flow failure. Stream-cut exposures show that the main scarp commonly marks the boundary between fine-grained and coarse-grained lacustrine deposits (Qlmp and Qlgp), and the main scarp curves to the northwest at its northern end, forming a large amphitheater. Harty and Lowe (2003) concluded that landsliding is only one of several possible modes of origin; another possible mechanism they suggested for the Bear Creek feature is headward erosion due to spring sapping which ceased when relatively resistant gravels were encountered along a lacustrine shoreline.

The Springville/Spanish Fork feature includes a few isolated hummocks and small depressions, and also includes two lineaments interpreted by Harty and Lowe (2003) as regressive shorelines of Lake Bonneville. Although most of the Springville/Spanish Fork feature and included lineaments are in adjacent quadrangles, the southwest part of the southern lineament extends onto the northeast corner of the Spanish Fork quadrangle. Harty and Lowe (2003) excavated three trenches on the feature in adjacent quadrangles and concluded the feature is either the result of liquefaction and ground oscillation, minor sliding unrelated to earthquake-induced liquefaction, or spring sapping along the margin of the delta at the mouth of Spanish Fork Canyon (Qldp).

Spring sapping downslope from Lake Bonneville gravels (Qlgp, Qldp) has undoubtedly occurred in both features, but until definitive evidence eliminates earthquake-induced liquefaction as their cause, it is prudent to err on the side of safety and consider these features to be lateral-spread deposits. The presence of shallow ground water and granular soils near the margin of Utah Valley, with high levels of seismicity on the Wasatch fault zone, suggests that large-scale liquefaction may have occurred during past large earthquakes along the Wasatch fault zone and liquefaction poses a significant hazard to existing and future development.

Qms$_1$ **Landslide deposits, unit 1** (Historical to upper Pleistocene) – Poorly sorted, fine to medium sand, sandy silt, and pebble and cobble gravel; composition reflects local sources of material; mapped along bluffs on the southwest and, more commonly, on the northeast side of the Spanish Fork flood plain, and in similar deposits east of Salem, on the east side of Little Mountain, and in Loafer Canyon; characterized by moderately fresh scarps and hummocky topography, with freshest scarps in areas of historical movement. Maximum thickness about 20 feet (6 m).

Landslides on the northeast side of Spanish Fork originate in Lake Bonneville deltaic deposits (Qldp), and may be a combination of rotational, translational, and flow failures, although only flow failures have been documented historically. Historic flow failures occurred in Spanish Fork city near 440 South Scenic Drive in 1994 (Black, 1996) and 830 South Scenic Drive in 1996 (Ashland, 1997), and Black (1996) reported a verbal communication of a similar landslide in the mid-1970s that damaged a home along Bottoms Road at the base of the bluffs.

Three other landslides may be a combination of rotational, translational, and flow failures. The landslide on the southwest side of the river, underlain by lacustrine silt and clay (Qlmp) with a cap of gravel and sand (Qlgp), lies just beyond the toe of the deltaic deposits. The landslide east of Salem is derived from lacustrine gravel, sand, and silt (Qlgb and Qlsb) and the Little Mountain landslide is derived from lacustrine gravel and sand (Qlgb).

The Loafer Canyon landslides are debris slides derived from Pleistocene alluvial-fan deposits (Qaf$_4$ and Qaf$_5$) and highly weathered Oquirrh Formation (P₽ogw).

Qms$_2$ **Landslide deposits, unit 2** (middle Holocene to upper Pleistocene) – Poorly sorted, fine to medium sand, silt, and clay with minor pebble and cobble gravel; form hummocky rims of alcoves along linear scarp of the Beer Creek feature north of Salem and alcove northeast of Salem, and possibly occurs as unmapped landslide deposits near scarps adjacent to Salem Lake, although landscaping and development obscure the possible exposure; deformed and tilted lake beds were exposed in a trench on the Beer Creek feature (Harty and Lowe, 2003), and were found in a small excavation in the alcove surrounding Grimes Pond during mapping for this project. The surface of unit 2 landslide deposits is typically subdued, suggesting that they are older than unit 1 landslide deposits, but this may be due to flow failure accompanying rotational sliding of deformed and tilted beds, rather than age. Thickness of the deposits is unknown but probably less than 30 feet (10 m).

Spring and marsh deposits

Qsm **Marsh deposits** (Holocene) – Fine, organic-rich sediment associated with springs, ponds, seeps, and wetlands; commonly wet, but seasonally dry where drained by canals northwest of Payson; may locally contain peat deposits as thick as 3 feet (1 m); overlies and grades into fine-grained regressive (Provo phase) deposits of Lake Bonneville (Qlmp); present where water table is high such as near Salem (Beer Creek feature), Spanish Fork city (Springville/Spanish Fork feature), Spring Lake, and north of Payson. Thickness commonly less than 10 feet (3 m).

Most marsh deposits in the Spanish Fork quadrangle occupy the center of a shallow, sinuous trough extending from north of Salem, westward along Beer Creek to the Benjamin fault, and farther west into the adjacent West Mountain quadrangle. Although the origin of the trough is unknown, possibilities include: (1) it is the result of its position in a shallow depression between the north-sloping piedmont and buried transgressive Lake Bonneville deltaic deposits that underlie the large, fan-shaped regressive delta at the mouth of Spanish Fork Canyon; or (2) it is a relict channel of Spanish Fork, formed before or during the transgression of Lake Bonneville, and covered and partially filled by later lacustrine deposits. Water in the trough accumulates from discharge in springs and seeps where unconfined granular deposits upslope meet less permeable fine-grained lake beds and from upward flow of ground water under artesian pressure through leaky confining lake beds from underlying aquifers (Brooks and Stolp, 1995)

Mixed-environment deposits

Qac **Alluvial and colluvial deposits, undivided** (Holocene to upper Pleistocene) – Poor to moderately sorted, generally poorly stratified, clay- to boulder-size, locally derived sediment mapped at the base of Woodland Hills, in Maple Canyon and the drainage to the north, and likely in most small drainages; deposits of alluvial, slopewash, and creep processes grade imperceptibly into one another. Thickness less than 20 feet (6 m).

Qlsm **Lacustrine and marsh deposits, undivided** (Holocene to upper Pleistocene) – Sand, silt, and clay in areas of mixed marsh and lacustrine deposits that are undifferentiated because the units are similar. Thickness less than 10 feet (3 m).

Qmtc **Talus and colluvium, undivided** (Holocene to upper Pleistocene) – Very poorly sorted, angular to subangular cobbles and boulders and finer-grained interstitial sediment, deposited principally by rock fall on steep bedrock slopes, that grades downslope into colluvial deposits; only thicker and larger deposits in Picayune Canyon mapped. Generally less than 20 feet (6 m) thick.

Stacked-unit deposits

Qes/Qlsb **Eolian sand over lacustrine sand and silt** (Holocene to upper Pleistocene) – Lacustrine sand and silt related to the transgressive (Bonneville) phase of Lake Bonneville is partly concealed by a discontinuous veneer of sand reworked by wind; mapped north of Woodland Hills, east of eolian sand (Qes). Eolian deposits are generally less than 3 feet (1 m) thick.

Qlsb/Ts **Lacustrine sand and silt over tuffaceous sandstone** (upper Pleistocene/Pliocene? to Miocene?) – A thin veneer of lacustrine sand and silt related to the regressive (Provo) phase of Lake Bonneville is reworked from underlying Tertiary tuffaceous sandstone on a small ridge south of Benjamin. Lacustrine deposits are generally less than 3 feet (1 m) thick.

Qlgb/Qaf$_4$ **Lacustrine gravel and sand over pre-Bonneville alluvial-fan deposits** (upper Pleistocene/upper to middle Pleistocene) – A thin veneer of lacustrine gravel and sand related to the transgressive (Bonneville) phase of Lake Bonneville is reworked from underlying alluvial-fan deposits older than Lake Bonneville but not older than the Little Valley lake cycle; the unit is downslope from pre-Bonneville alluvial-fan deposits (Qaf$_4$) above the Bonneville shoreline at the mouth of a small canyon on the east-central edge of the quadrangle. Lacustrine deposits are generally less than 3 feet (1 m) thick.

Qlgb/Tvc **Lacustrine gravel and sand over volcanic conglomerate** (upper Pleistocene/Oligocene? and/or upper to middle Eocene?) – Volcanic conglomerate partly concealed by a discontinuous veneer of lacustrine gravel and sand related to the transgressive (Bonneville) phase of Lake Bonneville reworked by Lake Bonneville wave action between the Provo and Bonneville shorelines on Rocky Ridge; closely spaced, well-preserved shorelines are common. Lacustrine deposits are generally less than 10 feet (3 m) thick.

Unconformity

TERTIARY

Ts **Tuffaceous sandstone** (Pliocene? to Miocene?) – Very pale orange weathering to light-gray volcaniclastic sandstone. Rock contains subrounded to rounded pebbles of volcanic rocks, quartzite, and carbonate in a sandy and ashy matrix; pebbles generally 1 inch (0.5 cm) or less in diameter; moderately consolidated. Poorly exposed in road cut on east side of Benjamin Cemetery. Apparently water-lain; source, age, and correlation unknown, but resembles distal, tuff-rich volcanic rocks such as the Salt Lake Formation (Pliocene to Miocene). Exposed thickness approximately 10 feet (3 m).

Not in contact – Unconformity?

Tvc **Volcanic conglomerate** (Oligocene? and/or upper to middle Eocene?) – Gray-weathering volcanic conglomerate consisting of subrounded to rounded pebbles, cobbles, and boulders of volcanic rocks, quartzite, and lesser dolomite and limestone in a matrix of light-gray volcanic ash and sand. Abundant volcanic clasts include andesitic and rhyolitic rocks that are commonly porphyritic, and very-pale-orange and white quartzite clasts are also common; boulders are as much as 3 feet (1 m) in diameter. Forms rubbly exposures on Little Mountain near mouth of Payson Canyon. Age, source, and correlation unknown, but clasts are similar to rocks of the Tintic Mountains area (volcanic rocks from about 39 to 33 Ma; Moore, 1993; Clark, 2003). Exposed thickness 400 feet (120 m).

Not in contact - Unconformity

TERTIARY and CRETACEOUS, undivided

TKs **Tertiary-Cretaceous strata** (Eocene or Paleocene? to Upper Cretaceous?) – Moderate-orange-pink to light-gray conglomerate and moderate-reddish-orange mudstone. Clast-supported conglomerate consists of subangular to rounded pebbles, cobbles, and boulders of quartzite, carbonate, and sandstone in a sandy, gritty, calcareous matrix; clasts as much as 1 foot (0.3 m) in diameter. Forms ledges and slopes of limited exposure at the mouth of Payson Canyon. Age unknown; estimate is based on mapping of similar strata in region (Clark, 2006; Constenius and others, 2006). May correlate to part of North Horn Formation, Uinta Formation, unnamed sandstone and conglomerate unit, or Tibble Formation (Constenius and others, 2006). Exposed thickness about 100 feet (30 m); regionally these conglomeratic strata are up to 2500 feet (760 m) thick (Hintze, 1962; Clark, 2006; Constenius and others, 2006).

Not in contact - Major Unconformity

PERMIAN - PENNSYLVANIAN

Terminology and subdivision of Oquirrh Formation/Group and associated Permian strata vary by thrust plate and location within the Oquirrh basin (Welsh and James, 1961; Tooker and Roberts, 1970; Swenson, 1975; Morris and others, 1977; Welsh and Bissell, 1979; Jordan and Douglas, 1980; Hintze, 1988, p. 34; Biek, 2004, 2005). Differing terminology is commonly applied west and east of Salt Lake and Utah Valleys (figure 3), since a comprehensive regional study of the basin has not been done. The terminology used here follows that of the southern Wasatch Range where the Oquirrh Formation is divided into, in ascending order, several Pennsylvanian units including the Bridal Veil Limestone Member, Bear Canyon Member, Shingle Mill Limestone Member, Wallsburg Ridge Member, and the Permian Granger Mountain Member (Baker and Crittenden, 1961; Baker, 1964, 1972). Portions of this section are exposed in the Spanish Fork quadrangle. The Permian-Pennsylvanian Oquirrh Formation is about 26,000 feet (8000 m) thick near Mt. Timpanogos in the Wasatch Range (Baker and Crittenden, 1961), and the Pennsylvanian Oquirrh Group and overlying Permian formations (Curry Peak and Freeman Peak) are about 21,900 feet (6700 m) thick in the Oquirrh Mountains (Welsh and James, 1961; Tooker and Roberts, 1970; Swenson, 1975).

Oquirrh Formation

P₽ogw **Granger Mountain and Wallsburg Ridge Members, undivided** (Lower Permian [Wolfcampian] to Upper Pennsylvanian [Virgilian-Missourian]) − Medium-gray weathering to very-pale-orange, fine-grained, calcareous sandstone interbedded with light-gray, light-red, and very pale orange quartzite, light-gray quartz sandstone, and few medium-gray, fine-grained sandy limestone beds. Limestone intervals are less than 40 feet (12 m) thick. Strata are laminated to thick bedded. Present east of Payson Canyon forming ledges, cliffs, and slopes of Tithing Mountain, Loafer Canyon, and heavily vegetated Loafer Mountain areas, often obscured by vegetation and unmapped colluvial cover. Mapped as undivided unit due to poor exposure and lack of fossil data. Sample SF-3 from near Maple Canyon yielded a primitive form of Triticites (fusilinid) indicating a Missourian age (A.J. Wells, written communication, August 11, 2006), and Wolfcampian fusilinids were reported in the vicinity by Rawson (1957), Baker (1976), and Kurt Constenius (unpublished A.J. Wells data for UGS, 2005). Largely correlative with Permian Freeman Peak and Curry Peak Formations and the Pennsylvanian Bingham Mine Formation of the Oquirrh Group to the west (figure 3). Base and top not exposed, maximum exposed thickness in quadrangle between Broad Hollow and Maple Canyon is approximately 3500 feet (1100 m); thickness of both members in southern Wasatch Range from 11,900 to 17,255 feet (3600-5260 m) (Constenius and others, 2006).

Payson Canyon thrust fault

₽obc **Bear Canyon Member** (Middle to Lower Pennsylvanian [Desmoinesian-uppermost Morrowan]) − Interbedded, medium-gray to light-brown, fine-grained, calcareous sandstone, with medium-gray, fine-grained, sandy, cherty limestone, and very pale-orange and light-gray quartzite. Limestone units locally contain sandy laminae and spherical chert. Strata are thin to thick bedded. Exposed west of Payson Canyon as ledges and slopes, commonly obscured by heavy vegetation and unmapped colluvial cover. Age from Baker (1976). Largely correlative with Butterfield Peaks Formation to the west (figure 3). Cut by faults such that top is not exposed. Conformably overlies Bridal Veil Limestone Member. Southern exposures in quadrangle previously mapped as Mississippian Humbug Formation by Brown (1950) and Demars (1956), but remapped here as the Bear Canyon Member based on lithologies and structural context. Exposed thickness in quadrangle is approximately 1800 feet (550 m); thickness in southern Wasatch Range is about 3250 feet (990 m) and thickens northward (Constenius and others, 2006).

₽obv **Bridal Veil Limestone Member** (Lower Pennsylvanian [Morrowan]) − Dark-gray, thin- to thick-bedded, fine- to medium-grained limestone and fossiliferous limestone. Rock unit locally contains black chert nodules and bands, and brown-weathering, fine- to medium-grained sandstone interbeds. Forms more resistant ledges between Bear Canyon Member above and Manning Canyon Shale below in two faulted blocks west of Payson Canyon. Limited age control in Wasatch Range from Baker (1964, 1972); regional age data from Webster and others (1984) and Davis and others (1994) are somewhat contradictory. Largely correlative with West Canyon Limestone to the west (figure 3). Relatively thin section of 100 to 200 feet (30-60 m) in quadrangle suggests member has been structurally thinned (see also Manning Canyon Shale description); regionally as much as 1245 feet (380 m) thick (Shoore, 2005; Constenius and others, 2006).

PENNSYLVANIAN - MISSISSIPPIAN

₽Mmc **Manning Canyon Shale** (Lower Pennsylvanian to Upper Mississippian) − Lithologically diverse unit of interbedded shale, siltstone, quartzite, sandstone, and limestone. Calcareous and carbonaceous shale and siltstone is pale yellowish brown to grayish brown to grayish red, commonly weathering to pale yellowish orange. Orthoquartzite is light-brown weathering, medium bedded, with a vitreous luster. Fine-grained sandstone and calcareous sandstone is very pale orange to light red, commonly seen as fragments rather than beds. Argillaceous and fossiliferous limestone is medium gray to bluish gray, and thin to medium bedded. Slope-forming unit at the base of two low-angle normal-fault-bounded (detachment) blocks west of Payson Canyon; southern block extends into the Payson Lakes quadrangle; base of Manning Canyon thinned by these faults. Age from Baker (1964, 1972). Exposed thickness as much as about 200 feet (60 m); regional thickness of 1000 to 1650 feet (300-500 m) (Hintze, 1962; Biek and others, 2006; Constenius and others, 2006).

Low-angle faults

MISSISSIPPIAN

Mhd **Humbug Formation and Deseret Limestone, undivided** (Upper to Lower Mississippian) – Combined unit of Humbug and Deseret in fault block northwest of Mollies Nipple where poor exposures preclude separation.

Mh **Humbug Formation** (Upper Mississippian) − Interbedded calcareous quartz sandstone, orthoquartzite, and limestone. Sandstone is pale yellowish brown to olive gray, weathering to light to dark brown, medium to very thick bedded, variably calcareous or siliceous, locally with planar or low-angle cross-stratification. Quartzite is very pale orange, dense, and vitreous. Limestone is medium to dark gray, weathering to light gray, medium to thick bedded, and fine grained with local small white chert and calcite blebs. Formation weathers to ledgy slopes northwest and northeast of Mollies Nipple; upper contact not exposed. Age from Morris and Lovering (1961). Exposed thickness is roughly 200 feet (60 m); regional thickness is 500 to 800 feet (150-250 m) (Hintze, 1962; Biek and others, 2006; Clark, 2006; Constenius and others, 2006).

Md **Deseret Limestone** (Upper to Lower Mississippian) − Medium- to very thick bedded, medium-gray limestone. Rock contains distinctive white calcite nodules and blebs and local brown-weathering chert nodules; local fossiliferous intervals contain rugose corals, uncommon brachiopods, crinoids, bryozoans, and fossil hash. Locally some calcareous sandstone and quartz sandstone interbeds in lower part; basal slope-forming interval (20 to 30 feet [6-9 m]) may include thin-bedded, black phosphatic chert of the Delle Phosphatic Member. Unit typically forms ledges and cliffs on and near Mollies Nipple. Upper contact is conformable and gradational and corresponds to a change from limestone (Deseret) to predominantly sandstone (Humbug). Age from Morris and Lovering (1961) and Sandberg and Gutschick (1984). Thickness is 900 feet (300 m) in quadrangle; regional thickness is about 600 to 900 feet (200-300 m) (Hintze, 1962; Biek and others, 2006; Clark, 2006; Clark and others, 2006; Constenius and others, 2006).

Mg **Gardison Limestone** (Lower Mississippian) − Medium- to very thick bedded, medium-gray to medium-dark-gray limestone, cherty limestone, and fossiliferous limestone. Chert occurs as black, irregularly shaped nodules and thin, discontinuous beds; fossils include rugose and colonial corals, brachiopods, gastropods, and bryozoans replaced by white calcite. Gardison crops out as ledges, cliffs, and slopes in and near Picayune Canyon; upper contact appears conformable and gradational, and generally corresponds to change from darker cherty and fossiliferous limestone below (Gardison) to limestone above (Deseret). Age from Morris and Lovering (1961). Thickness is 900 feet (300 m) in quadrangle; regional thickness is 300 to 900 feet (100-300 m) (Hintze, 1962; Biek and others, 2006; Clark, 2006; Clark and others, 2006; Constenius and others, 2006).

Unconformity

Devonian, Silurian, and Ordovician strata apparently missing, indicating the Stansbury uplift or Tooele arch (Hintze, 1959; Rigby, 1959; Morris and Lovering, 1961) extended this far south and east.

CAMBRIAN

Ꞓu **Cambrian dolomite, undivided** (Upper? to Middle? Cambrian) − Light-gray to medium-dark-gray dolomite that is commonly brecciated and fractured. Several rock units have likely been dolomitized along Picayune Canyon fault zone such that differentiation of the Cambrian formations exposed in the East Tintic Mountains (Morris and Lovering, 1961) and southern Wasatch Range (Hintze, 1962, 1988) is not possible. Map unit may also include dolomite of Mississippian Fitchville Formation near top where in contact with Gardison Limestone, but not distinguishable or mappable; the Cambrian Ajax Dolomite and part of Opex Formation may not be present in the immediate vicinity of the quadrangle (Brown, 1950; Metter, 1955; Demars, 1956). Crops out in and north of Picayune Canyon forming cliffs and ledges and locally hoodoos and arches. Apparently unconformable with overlying Gardison Limestone. Base not exposed. Age assumed from regional relations (Morris and Lovering, 1961). Thickness uncertain due to structural complications, but maximum exposed thickness estimated at 1400 feet (400 m). The total Cambrian carbonate section in the East Tintic Mountains is about 3000 feet (900 m) thick (Morris and Lovering, 1961), and total carbonate section in the southern Wasatch Range is about 2000 feet (600 m) thick (Hintze, 1988, p. 162, Chart 54).

Ꞓd? **Dagmar Dolomite?** (Middle Cambrian?) − Medium-gray, finely laminated dolomite, weathering to white color with a blocky fracture; less resistant than adjacent dolomite strata (Ꞓu); only exposed on south side of Picayune Canyon as marker bed within map unit Ꞓu. Age from Morris and Lovering (1961). Thickness about 25 feet (8 m); unit from 60 to 100 feet (20-30 m) thick in East Tintic Mountains (Morris and Lovering, 1961), and from 31 to 57 feet (9-17 m) thick in West Mountain (Clark, 2006).

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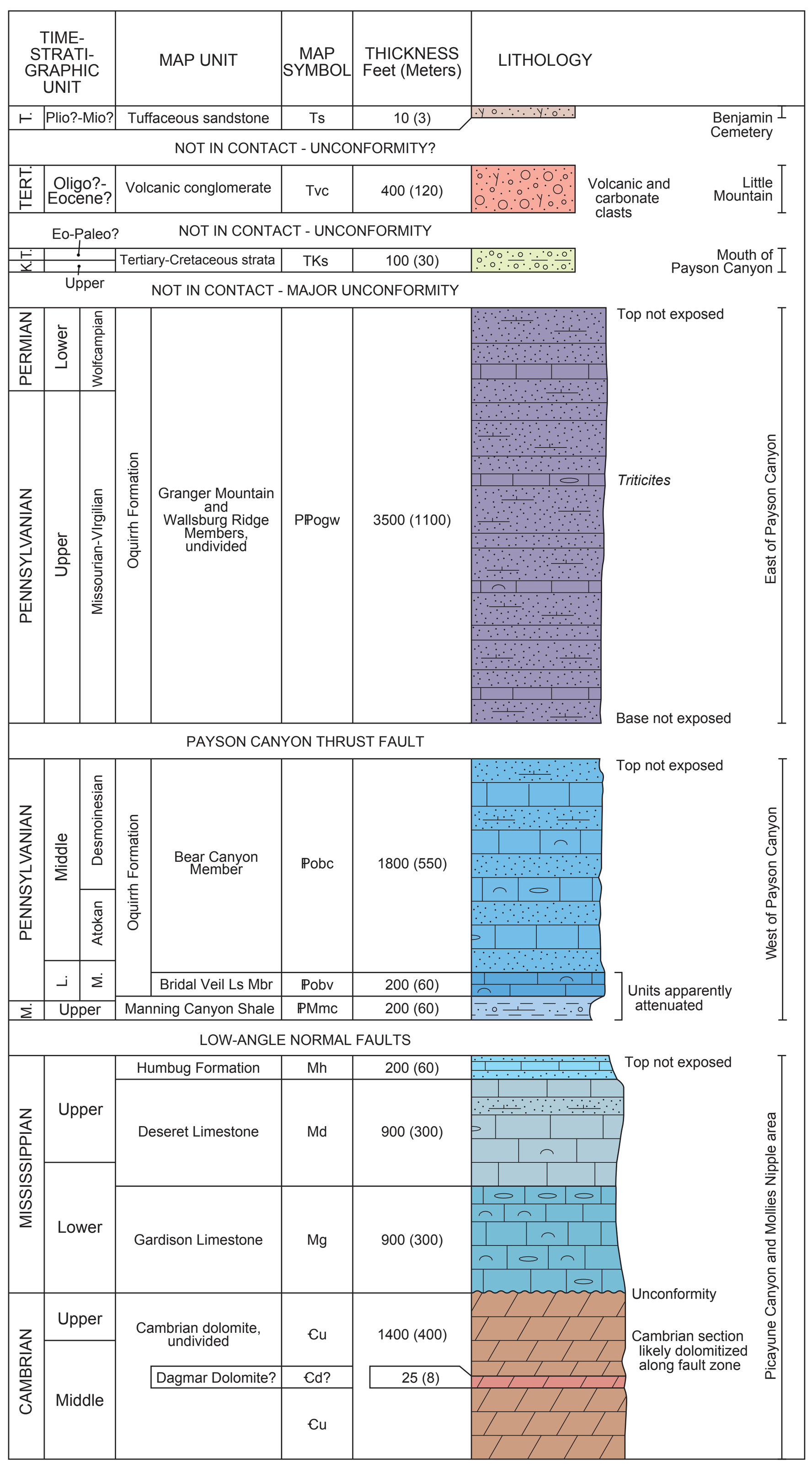
LITHOLOGIC COLUMN



GEOLOGIC SYMBOLS

- Contact – Dashed where approximately located; queried where uncertain
- Marker bed, map unit Cd?
- Normal fault – Dashed where approximately located, dotted where concealed; bar and ball on down-dropped side; arrows show relative displacement on cross section
- Thrust fault – Dashed where approximately located, dotted where concealed; teeth on upper plate; arrows show relative displacement on cross section
- Tear fault – Dashed where approximately located, dotted where concealed; arrows show direction of relative offset; may have strike-slip and dip-slip components
- Low-angle normal fault – Dashed where approximately located, dotted where concealed; half circles on upper plate
- Shorelines of the Bonneville lake cycle – Mapped at the wave-cut bench of erosional shorelines and the top of constructional bars and barrier beaches; may coincide with geologic contacts
  - B Bonneville shoreline
  - Y Other transgressive shorelines
  - P Provo shoreline
  - X Other regressive shorelines
- Crest of Lake Bonneville barrier beach or spit
- Landslide scarp – Hachures on down-dropped side
- Bedding form lines on cross section
- 20 Strike and dip of inclined bedding
- 20 Approximate strike and dip of inclined bedding
- Strike of vertical bedding
- Sand and gravel pit
- Prospect
- Adit
- Petroleum exploration well, plugged and abandoned
- Spring
- Trench sites for paleoseismic (Ostenaa, 1990; Machette, 1992; Machette and others, 1992) and lateral spread (Harty and Lowe, 2003) investigations
- SF-3 Rock/fossil sample location and number
- A—A' Line of cross section

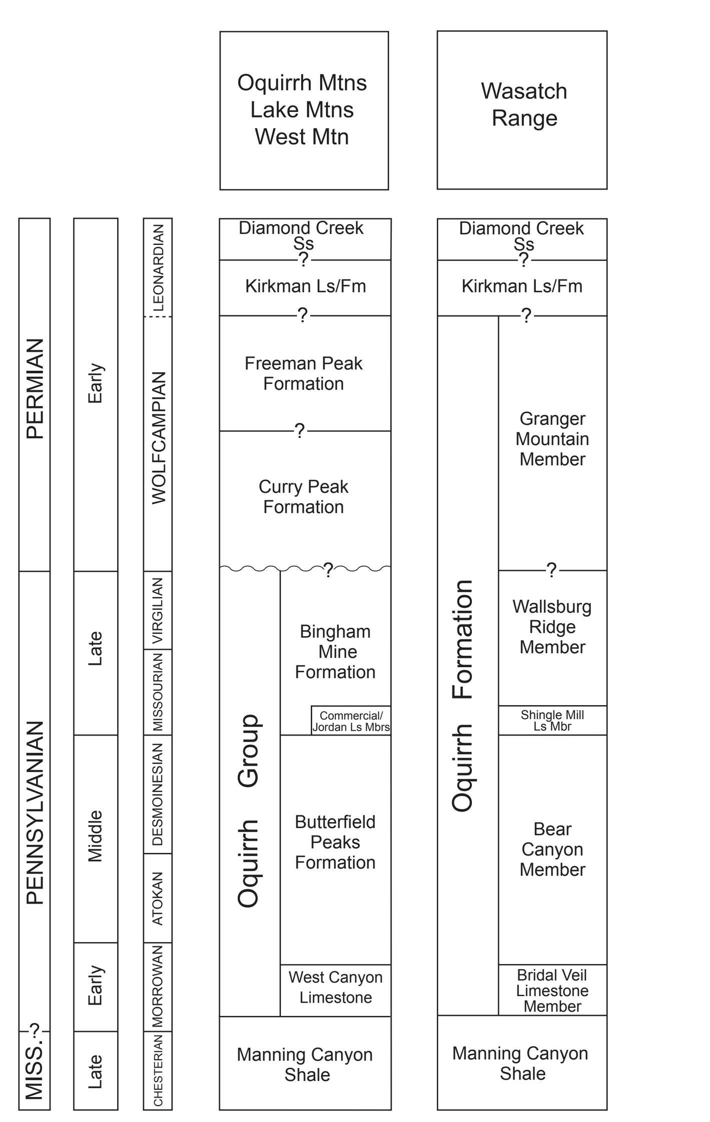


Figure 3. Comparison of stratigraphic nomenclature for the Oquirrh Formation/Group and associated strata near Salt Lake and Utah Valleys, north-central Utah.

Table 1. Ages of major shorelines of Lake Bonneville and Utah Lake and shoreline elevations in the Spanish Fork quadrangle.

Lake Cycle and Phase	Shoreline (map symbol)	Age: radiocarbon years B.P.	Age: calendar years B.P.[1]	Elevation feet (meters)
Lake Bonneville				
Transgressive Phase	Stansbury	22,000-20,000[2]	24,400-23,200	Not exposed
	Bonneville (B) — flood	15,500-14,500[3]	18,000-16,800	5,085-5,100 (1,550-1,555)
Regressive Phase	Provo (P)	14,500-12,000[4]	16,800-13,500[5]	4,735-4,750 (1,445-1,450)
	Gilbert	11,000-10,000[6]	12,800-11,600	Not exposed
Utah Lake				
	Utah Lake highstand	12,000-11,500[7]	-----	Not exposed

[1]Calendar-calibrated ages of most shorelines have not been published. Calendar-calibrated ages shown here, except for the age of the end of the Provo shoreline, are from D.R. Currey, University of Utah (written communication to Utah Geological Survey, 1996; cal yr B.P. = 1.16 ^{14}C yr B.P.).
[2]Oviatt and others (1990). Currey (written communication to Utah Geological Survey, 1996) assumed a maximum age for the Stansbury shoreline of 21,000 ^{14}C yr B.P., which is used in the conversion to calendar years.
[3]Oviatt and others (1992), Oviatt (1997).
[4]Godsey and others (2005) revised the timing of the occupation of the Provo shoreline and subsequent regression; Oviatt and others (1992) and Oviatt (1997) proposed a range from 14,500 to 14,000 ^{14}C yr B.P. Oviatt and Thompson (2002) summarized many recent changes in the interpretation of the Lake Bonneville radiocarbon chronology.
[5]Calendar-calibrated age of the end of the Provo shoreline estimated by interpolation from data in Godsey and others (2005), table 1, who used Stuiver and Reimer (1993) for calibration.
[6]Murchison (1989), figure 20.
[7]Estimated from data in Godsey and others (2005); Machette (1992) estimated the age of the regression of Lake Bonneville below the Utah Valley threshold at 13,000 ^{14}C yr B.P. from earlier data.

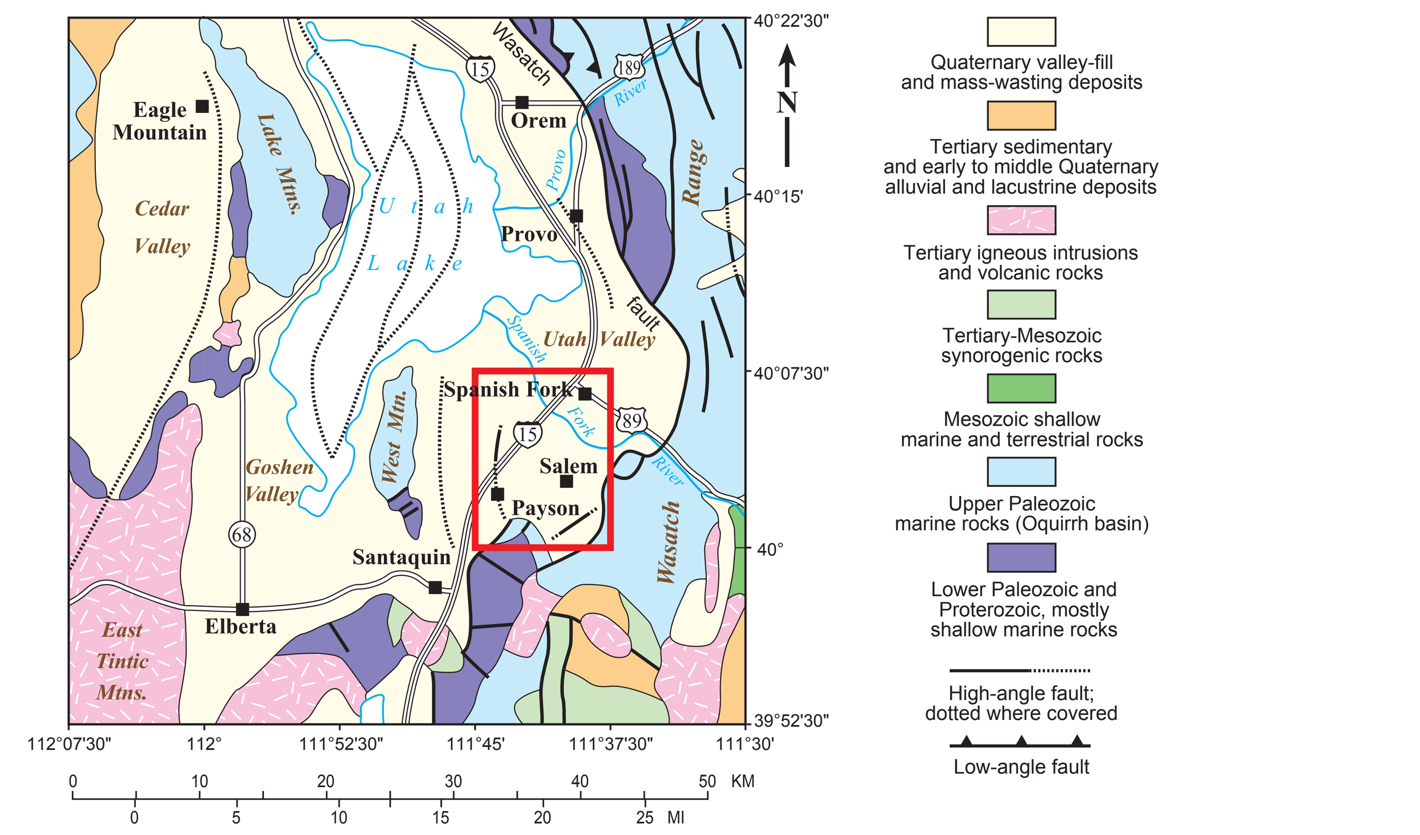
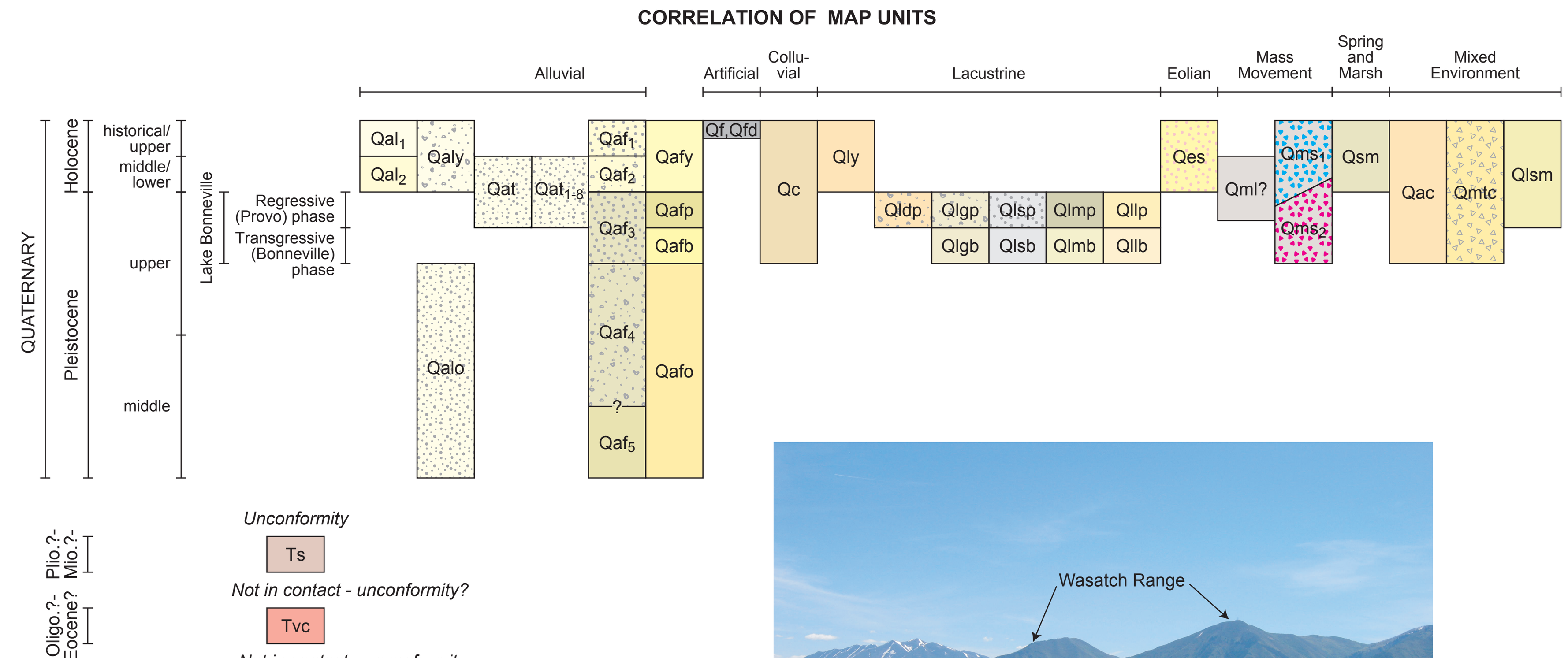


Figure 1. Index map showing the primary geographic features and generalized geology in the vicinity of the Spanish Fork quadrangle (red rectangle).

CORRELATION OF MAP UNITS



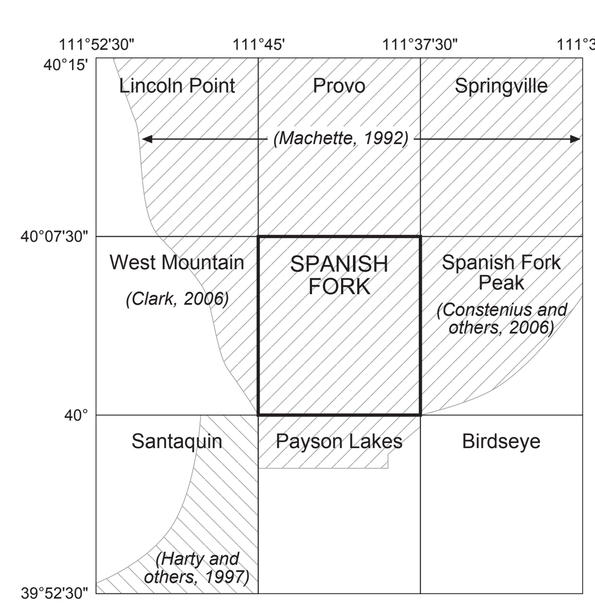
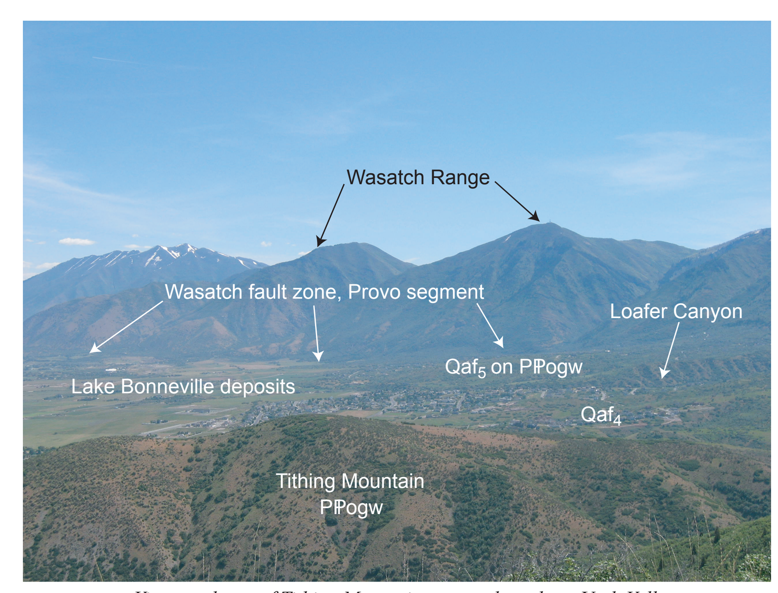
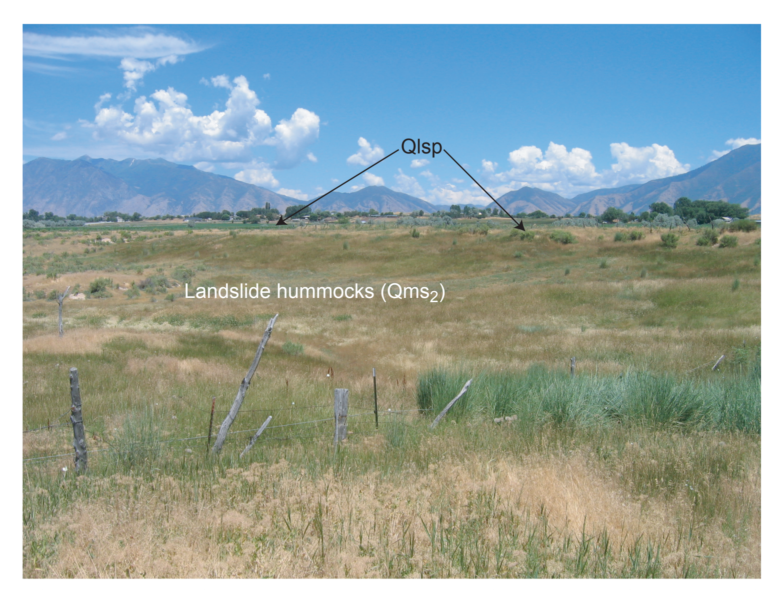


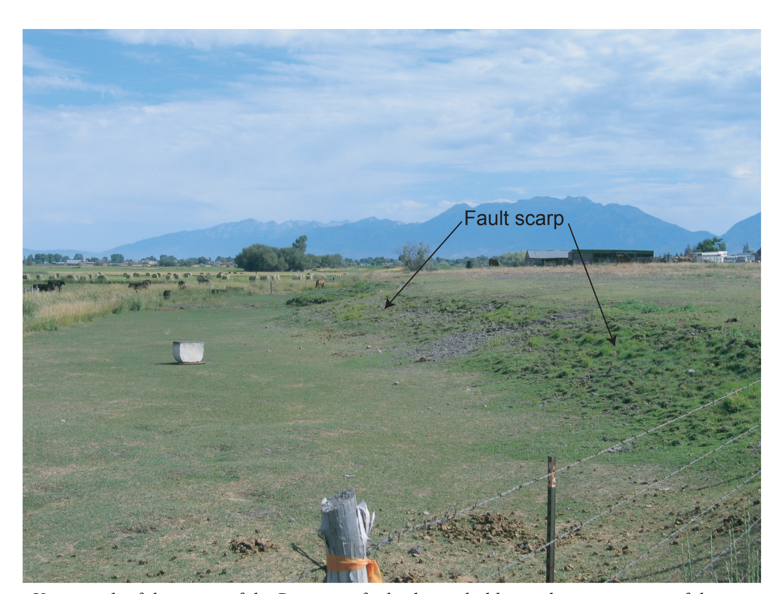
Figure 2. Index map showing selected geologic maps available for the Spanish Fork and surrounding 7.5' quadrangles.



View northeast of Tithing Mountain area and southern Utah Valley.



The hummocky rim of an alcove along the linear scarp of the Beer Creek feature, north of Salem.



View north of the scarp of the Benjamin fault, the probable northern extension of the Nephi segment of the Wasatch fault zone.