UTAH GEOLOGICAL SURVEY
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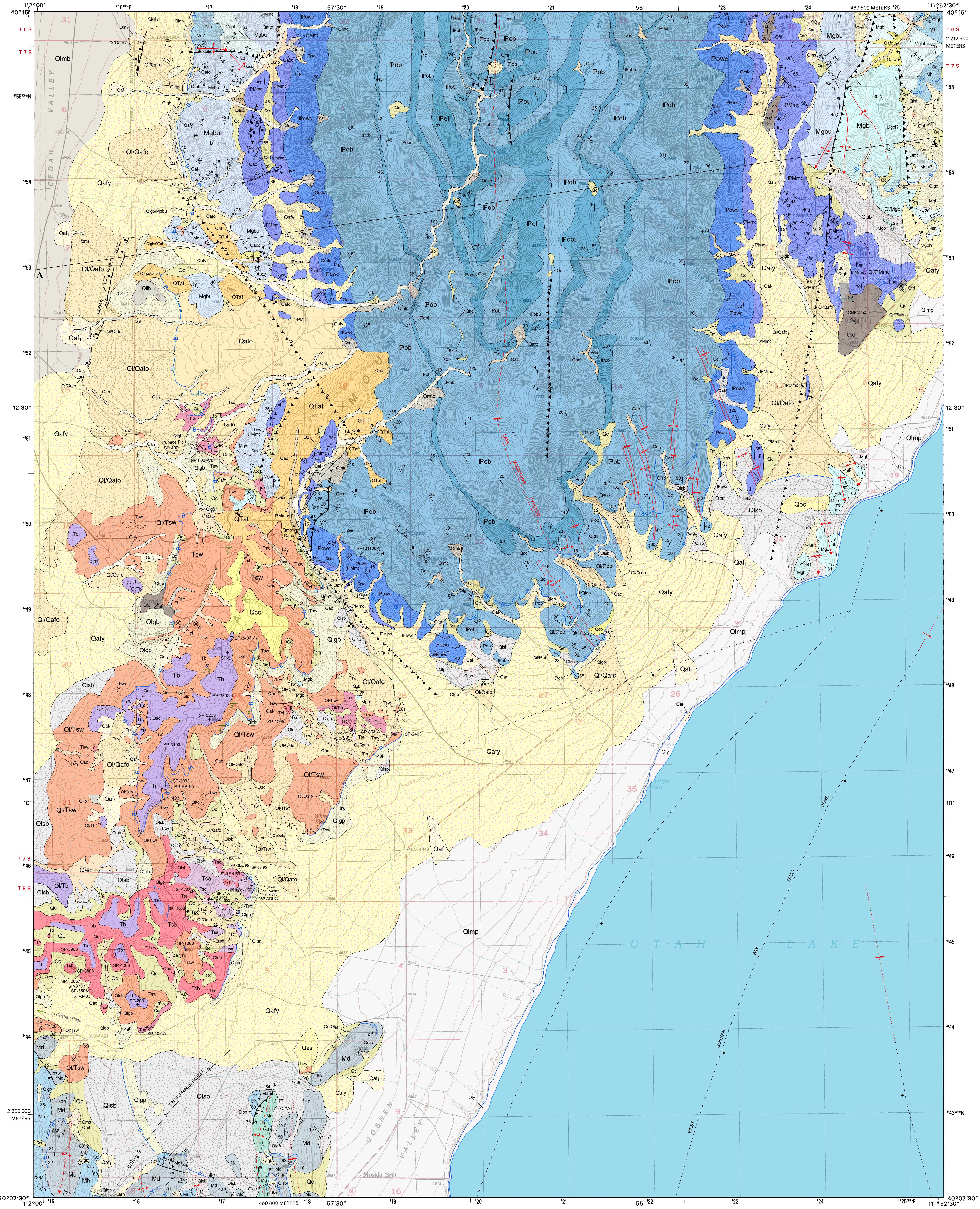
Plate I
Utah Geological Survey Map 235
Geologic Map of the Soldiers Pass Quadrangle



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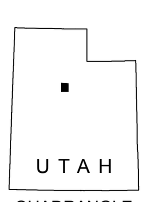
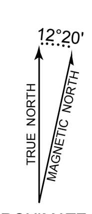
SCALE 1:24,000
1 0.5 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 0.5 0 1 KILOMETER
CONTOUR INTERVAL 20 FEET



QUADRANGLE LOCATION



APPROXIMATE MEAN DECLINATION, 2009

GEOLOGIC MAP OF THE SOLDIERS PASS QUADRANGLE, UTAH COUNTY, UTAH

by
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2009

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Base from USGS Soldiers Pass 7.5' Quadrangle (1997)
Projection: UTM Zone 12
Datum: NAD 1927
Spheroid: Clarke 1886

Field mapping by authors in 2006
Digital Photogrammetry: Kent Brown
GIS and Cartography: Kent Brown and Jay C. Hill
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1	2	3
4		5
6	7	8

1. Cedar Fort
2. Saratoga Springs
3. Pelican Point
4. Goshen Pass
5. Lincoln Point
6. Allens Ranch
7. Goshen Valley North
8. West Mountain

ADJOINING 7.5' QUADRANGLE NAMES

MAP UNIT DESCRIPTIONS

QUATERNARY

Alluvial Deposits

Qal$_1$ — **Modern stream deposits** (Holocene) − Moderately sorted sand, silt, clay, and pebble to boulder gravel deposited in active stream channels and flood plains; locally includes small alluvial-fan and colluvial deposits, and minor terraces up to about 10 feet (3 m) above current base level; mapped in ephemeral washes draining the Lake Mountains and low hills to the south; typically less than 20 feet (<6 m) thick.

Qaf$_1$ — **Level-1 alluvial-fan deposits** (Holocene) − Poorly to moderately sorted, non- stratified, clay- to boulder-size sediment deposited principally by debris flows and debris floods at the mouths of active drainages; upper parts typically characterized by abundant boulders and debris-flow levees that radiate away from the apex of the fan; equivalent to the younger part of Qafy, but differentiated because they form smaller, isolated fans; probably less than 20 feet (<6 m) thick.

Qafy — **Young undifferentiated alluvial-fan deposits** (Holocene) − Similar to level-1 alluvial-fan deposits (Qaf$_1$), but forms coalesced apron of post-Bonneville sediment shed off the Lake Mountains and low hills to the south; upper parts of fans are locally deeply incised; older parts of deposit are equivalent to Qaf$_2$, which is locally present in the adjacent Saratoga Springs quadrangle (Biek, 2004); thickness unknown, but likely as much as several tens of feet thick.

Qafo — **Old alluvial-fan deposits** (upper to middle Pleistocene) − Similar to young undifferentiated alluvial-fan deposits (Qafy), but forms deeply dissected alluvial apron truncated by, and thus predating, the Bonneville shoreline; a few of these deposits, for example in the lower reaches of Long Canyon, may grade to the Bonneville shoreline, but are undivided on this map; upper parts of fans locally receive sediment from minor washes; thickness unknown, but may locally exceed several tens of feet thick.

Artificial Deposits

Qfm — **Mine-dump deposits** (Historical) − Waste rock and overburden from clay quarries; as much as about 30 feet (9 m) thick.

Qfd — **Disturbed land** (Historical) − Land disturbed by clay and aggregate operations; only the larger operations are mapped, and their outlines are based in part on the 1997 topographic base map; land within these areas contains a mix of cuts and fills as well as excellent exposures of Manning Canyon Shale and the White Knoll Member of the Soldiers Pass Formation.

Colluvial Deposits

Qc — **Colluvial deposits** (Holocene to upper Pleistocene) − Poorly to moderately sorted, angular, clay- to boulder-size, locally derived sediment deposited by slope wash and soil creep on moderate slopes and in shallow depressions; locally grades upslope into talus deposits and downslope into mixed alluvial and colluvial deposits; because many bedrock slopes are covered by at least a veneer of colluvium, only the larger, thicker deposits are mapped; typically 0 to 20 feet (0-6 m) thick.

Qco — **Older colluvial deposits** (upper to middle Pleistocene) − Similar to colluvial deposits (Qc), but forms deeply dissected slopes at the base of Long Ridge and in the lower reaches of Mercer Canyon where it is as much as about 30 feet (9 m) thick; also mapped in sections 20 and 29, T. 7 S., R. 1 W., where it is generally less than 10 feet (< 3 m) thick, consisting of silt, clay, and bedrock detritus derived from the White Knoll Member of the Soldiers Pass Formation.

Eolian Deposits

Qes — **Eolian sand deposits** (Holocene) − Well- to very well-sorted, fine- to medium-grained, well-rounded, windblown sand near The Knolls and west of Clyde Knoll; forms small dunes mostly stabilized by vegetation; typically 0 to 10 feet (0-3 m) thick.

Lacustrine Deposits

Deposits of the Provo (regressive) phase of the Bonneville lake cycle (Currey and Oviatt, 1985) are identified with the last map symbol letter "p," and deposits of the Bonneville (transgressive) phase of the Bonneville lake cycle are identified with the last map symbol letter "b." Lake Bonneville rose to its highest level, the Bonneville shoreline, about 18,300 calendar years B.P., and overflowed its threshold intermittently until about 17,400 calendar years B.P. when the threshold failed and the lake fell to the Provo level. The lake occupied the Provo level from about 17,400 to 14,400 calendar years B.P. Table 1, modified from Solomon (2007), shows ages and elevations of major shorelines of Lake Bonneville and Utah Lake in the Soldiers Pass quadrangle. Solomon and Biek (2009) discuss the history and features of the Bonneville lake cycle in the nearby Lincoln Point quadrangle.

Qly — **Younger lacustrine and marsh deposits** (Holocene) − Silt, clay, and minor fine-grained sand deposited along the margin of Utah Lake; locally organic rich, and locally includes pebbly beach gravel; Brimhall and others (1976) reported that Holocene-age gray clayey silt composed mostly of calcite comprise the upper 15 to 30 feet (5-9 m) of the lake sediments under Utah Lake; sediments of the Bonneville lake cycle underlie these beds.

Qlgp, Qlgb — **Lacustrine gravel and sand** (upper Pleistocene) − Moderately to well-sorted, moderately to well-rounded, clast-supported, pebble to cobble gravel and lesser pebbly sand; thin to thick bedded; typically interbedded with or laterally gradational to sand and silt facies; gastropods common in sandy lenses; locally partly cemented with calcium carbonate; typically forms wave-cut or wave-built benches, bars, and spits; wave-cut benches are commonly partly covered by colluvium derived from adjacent oversteepened slopes; intermediate shorelines are locally well developed on Provo-level deposits; Qlgp (regressive deposits) deposited at and below the Provo shoreline, and Qlgb (transgressive deposits) deposited at and below highest Bonneville shoreline but above the Provo shoreline; typically 0 to 30 feet (0-9 m) thick.

Qlsp, Qlsb — **Lacustrine sand and silt** (upper Pleistocene) − Fine- to coarse-grained sand and silt with minor gravel; typically well sorted and laminated in thick beds; gastropods locally common; grades downslope from sandy nearshore deposits to finer grained offshore deposits; shorelines typically poorly developed on this facies; locally concealed by loess veneer; Qlsp (regressive deposits) deposited at and below the Provo shoreline, and Qlsb (transgressive deposits) deposited at and below highest Bonneville shoreline but above the Provo shoreline; probably less than 30 feet (<9 m) thick.

Qlmp, Qlmb — **Lacustrine silt and clay** (upper Pleistocene) − Calcareous silt (marl) with minor clay and fine-grained sand; typically laminated, but weathers to appear thick bedded; locally grades upslope into lacustrine sand and silt (Qlsb, Qlsp) and locally concealed by loess veneer; shorelines typically poorly developed on this facies; contact with distal parts of younger alluvial-fan deposits is difficult to identify and commonly based on subtle geomorphic differences; Qlmp (regressive deposits) deposited below the Provo shoreline, and Qlmb (transgressive deposits) deposited below Bonneville shoreline but above the Provo shoreline; thickness uncertain, but may exceed several tens of feet thick.

Qllp, Qllb — **Lagoon-fill deposits** (upper Pleistocene) − Forms level, grassy areas behind offshore gravel bars; not exposed, but likely consists of thick-bedded silt with sand and minor pebbles washed in from adjacent slopes; may be capped by loess, and is typically concealed by a veneer of colluvial deposits; probably less than 20 feet (<6 m) thick.

Mass-movement Deposits

Qms — **Landslide deposits** (Historical? to upper Pleistocene) − Very poorly sorted, locally derived material deposited by rotational and translational movement; typically clay- to boulder-size debris, but some landslides include large bedrock blocks; characterized by hummocky topography, numerous internal scarps, and chaotic bedding attitudes; basal slip surfaces most commonly form in the Manning Canyon Shale and in fine-grained lake deposits over bedrock; undivided as to inferred age because new research shows that even landslides with subdued morphology (suggesting that they are older, weathered, and have not moved recently) may continue to exhibit slow creep or are capable of renewed movement if stability thresholds are exceeded (Francis Ashland, Utah Geological Survey, verbal communication, April 2006); age and stability determinations require detailed geotechnical investigations; thickness highly variable.

Qmt — **Talus deposits** (Holocene to upper Pleistocene) − Very poorly sorted, angular cobbles and boulders and finer-grained interstitial sediment deposited principally by rock fall on or at the base of steep slopes; only a few deposits are mapped because most talus in the area is gradational with colluvial deposits and is thus mapped as talus and colluvium undivided (Qmtc); generally less than 20 feet (<6 m) thick.

Mixed-Environment Deposits

Qac — **Alluvial and colluvial deposits** (Holocene to upper Pleistocene) − Poorly to moderately sorted, generally poorly stratified, clay- to boulder-size, locally derived sediment deposited in swales and small drainages by fluvial, slope-wash, and creep processes; generally less than 20 feet (6 m) thick.

Qaco — **Older alluvial and colluvial deposits** (upper Pleistocene) − Similar to mixed alluvial and colluvial deposits (Qac), but form isolated remnants deeply incised by adjacent streams; generally less than 20 feet (<6 m) thick.

Qafc — **Alluvial-fan and colluvial deposits** (Holocene to upper Pleistocene) – Poorly to moderately sorted, clay-to boulder-size sediment deposited by debris flows and slopewash in large, partly enclosed basins on Lake Mountain; 0 to about 40 feet (0-12 m) thick.

Qmtc — **Talus and colluvium** (Holocene to upper Pleistocene) − Very poorly sorted, angular to subangular cobbles and boulders and finer-grained interstitial sediment deposited by rock fall and slope wash on and at the base of steep slopes; includes minor alluvial sediment in the bottom of washes; generally less than 20 feet (<6 m) thick.

Stacked-Unit Deposits

Qc/Qlgp — **Colluvial deposits over regressive lacustrine gravel and sand deposits** (Holocene/upper Pleistocene) − Mapped at Clyde Knoll, where colluvial deposits partly conceal gravel and sand associated with the regressive (Provo) phase of Lake Bonneville.

The following stacked units are used to denote various surficial and bedrock units that are partly eroded by wave action associated with the rise and fall of Lake Bonneville, and that are concealed by a discontinuous veneer of undifferentiated lacustrine gravel, sand, silt, or clay (Ql); coarser-grained lacustrine facies commonly exhibit intermediate-level shorelines. These deposits are found on the margins of the Lake Mountains. The southern part of the Lake Mountains were formerly referred to as the Fox Hills and Mosida Hills, but are not indicated as such on the topographic base map. The Fox Hills lie between Soldiers Pass and Goshen Pass, and the Mosida Hills lie south of Goshen Pass.

Ql/Qafo — **Undifferentiated lacustrine deposits over older alluvial-fan deposits** (upper Pleistocene/upper Pleistocene) − Mapped along the margins of the Lake Mountains and the low hills to the south.

Qlgb/QTaf — **Transgressive lacustrine gravel and sand over oldest alluvial-fan deposits** (upper Pleistocene/lower Pleistocene-Pliocene) − Mapped west of Mercer Canyon.

Ql/Tb — **Undifferentiated lacustrine deposits over Mosida Basalt** (upper Pleistocene/lower Miocene) − Mapped along the west side of Fox Hills.

Ql/Tsw — **Undifferentiated lacustrine deposits over White Knoll Member of the Soldiers Pass Formation** (upper Pleistocene/upper Eocene to lower Oligocene) − Mapped along the margins of Fox Hills.

Ql/Tsc — **Undifferentiated lacustrine deposits over Chimney Rock Pass Tuff Member of the Soldiers Pass Formation** (upper Pleistocene/upper Eocene) – Mapped along the east margin of the Fox Hills.

Ql/IPob — **Undifferentiated lacustrine deposits over Butterfield Peaks Formation of the Oquirrh Group** (upper Pleistocene/Middle-Lower Pennsylvanian) − Mapped just north of Burnt Canyon on the southeast flank of the Lake Mountains.

Ql/IPowc — **Undifferentiated lacustrine deposits over West Canyon Limestone of the Oquirrh Group** (upper Pleistocene/Lower Pennsylvanian [Morrowan]) – Mapped along the margins of Lake Mountain.

Ql/IPMmc — **Undifferentiated lacustrine deposits over Manning Canyon Shale** (upper Pleistocene/Lower Pennsylvanian? to Upper Mississippian) − Mapped near Big Cove in the northeast part of the quadrangle.

Ql/Mgb — **Undifferentiated lacustrine deposits over undifferentiated Great Blue Limestone** (upper Pleistocene/Upper Mississippian) − Mapped near Big Cove in the northeast part of the quadrangle.

Qlgb/Mgbu — **Transgressive lacustrine gravel and sand over the upper part of the Great Blue Limestone** (upper Pleistocene/Upper Mississippian) − Mapped west of the entrance to Mercer Canyon on the west side of the mountain.

Ql/Mh — **Undifferentiated lacustrine deposits over Humbug Formation** (upper Pleistocene/Upper Mississippian) − Mapped in the Mosida Hills in the southwest corner of the quadrangle.

Ql/Md — **Undifferentiated lacustrine deposits over Deseret Limestone** (upper Pleistocene/Upper Mississippian) − Mapped in the Mosida Hills in the southwest corner of the quadrangle.

Unconformity

QUATERNARY – TERTIARY

QTaf — **Oldest alluvial-fan deposits** (lower Pleistocene to Pliocene) − Poorly to moderately sorted, clay- to boulder-size sediment deposited principally by debris flows and debris floods; consists of Butterfield Peaks Formation clasts shed off the southwest side of the Lake Mountains; forms cobble- and boulder-covered, deeply dissected remnant between Mercer and Long Canyons; forms steeper slopes than older alluvial-fan deposits (Qafo), probably due to better cementation; maximum thickness exceeds 200 feet (60 m).

Unconformity

TERTIARY

Volcanic rocks of the Soldiers Pass quadrangle are part of the Soldiers Pass volcanic field, which covers about 33 square miles (85 km^2) at the southern end of the Lake Mountains and adjacent area (Christiansen and others, 2007). This area contains two distinctive suites of volcanic rocks that record the transition from subduction-related to extension-related volcanism in this part of the Great Basin, which are described in detail and given new formal and informal names by Christiansen and others (2007). Major- and trace-element whole-rock geochemical data, and $^{40}Ar/^{39}Ar$ raw analytical data, is available on the UGS Web site http://geology.utah.gov/online/analytical_data.htm (see also UGS and NMGRL [2007] for $^{40}Ar/^{39}Ar$ raw analytical data); rock names for lava flows and tuffs are derived from the total alkali-silica classification diagram of LeBas and others (1986). The southern part of the Lake Mountains were formerly referred to as the Fox Hills and Mosida Hills, but are not indicated as such on the topographic base map. The Fox Hills lie between Soldiers Pass and Goshen Pass, and the Mosida Hills lie south of Goshen Pass.

Tb — **Mosida Basalt** (lower Miocene) – Medium-dark-gray, weathering to light olive gray and blue gray, porphyritic, potassic trachybasalt (or absarokite in some classifications) lava flow; phenocrysts (10 to 20%) of olivine (Fo_{60}), plagioclase (An_{60} to An_{70}), and clinopyroxene (Mg# 0.78 to 0.72) in a fine-grained groundmass; olivine commonly altered to iddingsite and appears as rust-colored blebs; locally vesicular to scoriaceous; caps ridges of Fox Hills and forms blocky ledges and small cliffs; discontinuous outcrops in adjacent quadrangles show that this pahoehoe lava flow was probably at least 9 miles (15 km) long with a source vent, not exposed, located near Soldiers Pass; type area for this unit is about 1.2 miles (2 km) south of Soldiers Pass at 40.180° N. and 111.974° W.; unconformably overlies the White Knoll Member of the Soldiers Pass Formation, or, locally, the breccia member; major- and trace-element analyses indicate extensive fractionation of the parent magma and contamination by continental crust; represents one of the oldest basaltic magmas in the eastern Great Basin; two samples yielded $^{40}Ar/^{39}Ar$ isochron ages on groundmass of 19.47 ± 0.17 Ma (sample SP-3303) and 19.65 ± 0.15 Ma (sample SP-4003), slightly older than the K-Ar age of about 17.0 Ma reported in McKee and others (1993); thickness from 0 to 120 feet (0-35 m).

Unconformity

Soldiers Pass Formation (lower Oligocene to upper Eocene) – Defined by Christiansen and others (2007) to include, in ascending order: trachydacite tuff member, Chimney Rock Pass Tuff Member, andesite member, breccia member, and White Knoll Member. They considered the trachydacite, andesite, and breccia members as informal members due to their limited lateral extent, and considered the more laterally extensive Chimney Rock Pass Tuff and White Knoll Members as formal members.

Tsb — **Breccia member** (lower Oligocene to upper Eocene) − Dark-gray, white, pale-reddish-brown, and pale-red shoshonite lava flow; exposed mostly as distinctive, brecciated, carbonate-impregnated lava, but also occurs as a medium-gray, blue-gray, and pale-red, locally vesicular lava flow; fine-grained with trachytic to felty groundmass of plagioclase, olivine (typically altered), and Fe-Ti oxides; lava breccia fragments are as much as 3 feet (1 m) across and commonly have reddened, quenched, vesicular rinds and more massive crystalline interiors; pillow structures are locally present; interfingers with and is partly overlain by the carbonate and clastic strata of the White Knoll Member (Tsw), and calcite near the margins of the flow appears to be primary, forming as the flow entered a shallow lake; mapped in the southern Fox Hills near Goshen Pass where it forms slopes, ledges, rounded knobs, and small cliffs; source vent unknown; type area is about 0.3 mile (0.5 km) east of Goshen Pass at 40.149° N. and 111.996° W.; sample SP-3205 yielded an $^{40}Ar/^{39}Ar$ isochron groundmass age of 33.73 ± 0.65 Ma; 0 to 160 feet (0-50 m) thick.

Tsw — **White Knoll Member** (lower Oligocene to upper Eocene) − White and pale-yellowish-orange, yellowish-gray-weathering limestone with interbedded very pale orange, white, and pale-red claystone; bedding is laminated to medium to indistinct; locally contains thin, light-gray pyroclastic-fall beds, altered to clay, and the limestone is locally sandy and conglomeratic; limestone contains uncommon fossilized plant remains, and locally exhibits vertical laminae of travertine and algal laminations suggestive of spring deposits; deposited in a shallow lake over paleotopography developed on Paleogene volcanic rocks and Paleozoic strata; interfingers locally with the breccia member (Tsb); these generally flat-lying deposits form ledges and slopes in Fox Hills and northernmost Mosida Hills; claystone is excavated from quarries and pits in the quadrangle, including the Fox Hills clay pit in the SW1/4 section 20, T. 7 S., R. 1 W. (Stringham and Sharp, 1950); query indicates uncertain identification west of Mercer Canyon due to limited exposures; type area is at White Knoll about 2.5 miles (4 km) south-southeast of Soldiers Pass at 40.164° N. and 111.962° W.; 0 to 240 feet (0-75 m) thick.

Unconformity?

Tsa — **Andesite member** (upper Eocene) − Medium-gray andesitic lava flow with no phenocrysts that weathers to pale yellowish brown and pale brown; has platy fracture and weathers to blocks and chips; exposed near Black Point, the type area about 3 miles (5 km) south of Soldiers Pass at 40.178° N. and 111.972° W., as ledges and rounded hills of limited extent; source vent unknown; sample SP-4103 yielded a disturbed $^{40}Ar/^{39}Ar$ age of about 34.9 million years, whereas McKee and others (1993) reported a K-Ar age of 32.6 ± 1.0 Ma; 0 to 40 feet (0-12 m) thick.

Unconformity

Tsc — **Chimney Rock Pass Tuff Member** (upper Eocene) − Yellowish-gray, weathering to grayish orange and medium dark gray, non-welded, pumice-rich, porphyritic, rhyolitic ash-flow tuff; contains about 20% phenocrysts of quartz, reversely zoned plagioclase (An_{30} to An_{50}), Ba-rich sanidine (Or_{50} to Or_{75}), biotite, and Fe-Ti oxides in a glassy groundmass; pumice fragments constitute about 20% of the rock and are as large as 3 feet (1 m) across, but most are less than 6 inches (15 cm) in length; lithic fragments, mostly of fine-grained volcanic rock, are locally abundant and in the vicinity of Black Point are as large as 3 feet (1 m) across; vent location unknown, but given size of pumice and lithic fragments, may be near Black Point; exposed as ledges and slopes north of Soldiers Pass and in Fox Hills, but it extends into the adjacent Allens Ranch quadrangle where it is well exposed at Chimney Rock Pass (the type area at 40.062° N. and 112.037° W. in the Allens Ranch quadrangle), about 13 miles (20 km) to the southwest; in the Soldiers Pass quadrangle, unconformably overlies the trachydacite tuff member (Tst) and Paleozoic strata; three samples yielded $^{40}Ar/^{39}Ar$ ages on sanidine of 34.70 ± 0.07 Ma (sample SP-603A), 34.70 ± 0.07 Ma (sample SP-1603B), and 34.73 ± 0.08 Ma (sample AR-105 from the Allens Ranch quadrangle); Moore and others (2007) reported an $^{40}Ar/^{39}Ar$ age of 34.2 ± 0.2 Ma on sanidine; exposed thickness as much as 60 feet (20 m).

Unconformity

Tst — **Trachydacite tuff member** (upper Eocene) − Medium-gray, weathering to light olive gray, densely welded, porphyritic, trachydacite ash-flow tuff; contains about 30% phenocrysts of quartz, strongly zoned plagioclase (An_{40} to An_{85}), and Mg-rich biotite, hornblende, clinopyroxene, and Fe-Ti oxides in a glassy groundmass; has local red and black banding; exposed as rounded ledges on the east side of Fox Hills, where it unconformably overlies folded and faulted Paleozoic strata; source vent unknown; type area is about 2 miles (3 km) southeast of Soldiers Pass at 40.170° N. and 111.950° W.; new $^{40}Ar/^{39}Ar$ age of 34.79 ± 0.10 Ma on biotite (sample SP-1903), prior $^{40}Ar/^{39}Ar$ age of 34.7 ± 0.2 Ma on biotite (Moore and others, 2007); exposed thickness as much as 60 feet (20 m).

Major unconformity

PENNSYLVANIAN

Oquirrh Group (Pennsylvanian) − Principally calcareous sandstone, sandy limestone, limestone, and minor orthoquartzite that form the bulk of the Lake Mountains; divided into, in ascending order, the West Canyon Limestone and Butterfield Peaks Formation; believed to be part of the Bingham sequence of Tooker and Roberts (1970); best exposed along or just below ridge crests – elsewhere, slopes are commonly covered by a veneer of colluvium and talus not practical to map at a scale of 1:24,000; ages from Webster (1984), Davis and others (1994), and Biek (2004); deposited in the Oquirrh marine basin of north-central Utah and southern Idaho, with fine arkosic sand derived principally from the Weber shelf and Uncompahgre uplift (Welsh and Bissell, 1979); only the lower 4850 to about 5500 feet (1480-1675 m) is preserved in the Lake Mountains syncline, but the group is in excess of 17,800 feet (5425 m) thick in the Oquirrh Mountains (Tooker and Roberts, 1970) and about 25,000 feet (7600 m) thick near Mt. Timpanogos (Baker, 1964).

IPob — **Butterfield Peaks Formation** (Middle – Lower Pennsylvanian [Desmoinesian – uppermost Morrowan]) − Interbedded, brown-weathering, fine-grained calcareous sandstone, medium-gray, fine-grained sandy limestone, minor orthoquartzite, and several limestone intervals, four of which are mapped separately; typically cyclically interbedded with several tens of feet of calcareous sandstone capped by gray limestone several feet thick, which Konopka (1999) interpreted as due to glacio-eustatic control of sea level; contains minor siltstone and shale interbeds that typically form very poorly exposed slopes, except in section 21, T. 7 S., R. 1 W. where the lower part (from about 250 to 450 feet [75-135 m] above the base of the formation) contains several yellowish-brown, grayish-orange, pale-reddish-brown, and dusky-red shale intervals that are well exposed on ridge crests and that collectively total about 80 feet (25 m) thick; forms ledgy to cliffy slopes. Calcareous sandstone is typically medium to thick bedded, light brownish gray to medium gray but grayish orange to brown weathering, very fine to fine grained, locally with planar, low-angle, and ripple cross-stratification and bioturbation; sandstone is commonly non-calcareous on weathered surfaces and so appears similar to orthoquartzite, but fresh surfaces are invariably calcareous. Orthoquartzite is grayish orange pink to light brown, very thick bedded, very fine to fine grained, with faint low-angle cross-stratification and a prominent conchoidal fracture; it is restricted to a prominent, 35-foot-thick (11 m) ledge between the "upper" (IPou) and "lower" (IPol) limestones, and to a few thinner beds above the "upper" limestone. Unmapped limestone intervals are typically medium gray, medium to thick bedded, locally with fine-grained sand, locally fossiliferous with syringoporid and rugose corals, bryozoans, brachiopods, and fossil hash, locally with irregularly shaped black chert nodules and ribbon chert, and commonly grade upward to finer grained, platy weathering limestone and argillaceous limestone; *Chaetetes* coral bed is about 325 feet (100 m) above the base of the formation. An incomplete measured section on the west flank of the Lake Mountains, just north of the quadrangle, is 3823 feet (1166 m) thick (Konopka [1999] measured 3854 feet [1175 m] of Butterfield Peaks strata on the east flank of the mountain), but the incomplete thickness of the formation at the Lake Mountains is as much as 4500 feet (1370 m) (Biek, 2004); Tooker and Roberts (1970) reported the formation is 9070 feet (2765 m) thick in the Oquirrh Mountains.

IPou — **Upper limestone** (upper to middle Desmoinesian) − Thin- to medium-bedded, medium-gray, fine-grained limestone and very fine to fine-grained sandy limestone with minor, brown-weathering, irregularly shaped black chert nodules; locally includes sandstone interbeds that pinch out along strike; locally difficult to trace unit across fold axes and areas of poor exposure; forms ledgy slopes at the top of Lake Mountain; contains uncommon crinoid, brachiopod, bryozoan, and fusulinid fossils; about 220 feet (67 m) thick.

IPol — **Lower limestone** (upper to middle Desmoinesian) − Thin- to medium-bedded, platy weathering, light- to medium-gray, fine-grained limestone with common, irregularly shaped black chert nodules; lower part contains minor spherical black chert nodules; upper part is typically medium to thick bedded, coarser grained, has less chert, and contains crinoid, bryozoan, and brachiopod fossils; forms slopes; locally includes sandstone interbeds that pinch out along strike; locally difficult to trace unit across fold axes and areas of poor exposure, and as mapped, may locally include adjacent thin limestone intervals; about 320 feet (98 m) thick.

IPobu — **Upper billiard ball limestone** (middle Desmoinesian) − Light-gray-weathering, medium-dark-gray, thin-bedded, fine-grained limestone and argillaceous limestone with characteristic black spherical chert nodules and spherical limestone concretions 0.25 to 2 inches (0.5-5 cm) in diameter in the lower two-thirds of the unit; upper part typically medium- to thick-bedded, medium- to coarse-grained limestone and fine-grained sandy limestone with common, irregularly shaped black chert nodules, and, in the upper 10 feet (3 m), brachiopod and crinoid fossils and fossil hash; well developed in section 2, T. 7 S., R. 1 W.; conspicuously platy weathering, forming slopes and saddles high on the flanks of Lake Mountains; 295 feet (90 m) thick.

IPobl — **Lower billiard ball limestone** (middle to lower Desmoinesian) − Divisible into two parts not mapped separately: lower half has a ledge-forming basal bed several feet thick of medium-dark-gray, medium- to coarse-grained fossiliferous limestone with crinoid fossils and fossil hash overlain by thin- to medium-bedded, laminated and platy weathering, fine-grained limestone and argillaceous limestone with typically abundant black spherical chert nodules and spherical limestone concretions 0.25 to 2 inches (0.5-5 cm) in diameter; upper half is locally light- to medium-gray, medium- to thick-bedded limestone with planar and low-angle cross-stratification and uncommon irregularly shaped black chert nodules; conspicuously platy weathering, forming slopes and saddles; 105 to 140 feet (32-43 m) thick.

IPowc — **West Canyon Limestone** (Lower Pennsylvanian [Morrowan]) − Medium-light-gray to medium-gray, thick- to very thick bedded, fine- to medium-grained sandy limestone and fossiliferous limestone; locally thin- to medium-bedded and laminated, and locally with brown-weathering silt and very fine grained sand laminae; macrofossils include typically sparse crinoid columnals, brachiopods, bryozoans, and rugose corals, although exposures southeast of Soldiers Pass, in section 21, T. 7 S., R. 1 W., are locally quite fossiliferous; lower part forms ledges and slopes, upper part contains three prominent cliff-forming limestone beds with brown- to black-weathering irregularly shaped chert nodules and irregular beds that impart a slight "black banded" appearance, especially to the upper cliff; 15- to 20-foot-thick (4-6 m), cliff-forming, light-brown- to grayish-orange-pink-weathering, light-olive-gray to olive-gray, very thick bedded, fine-grained calcareous sandstone with planar and low-angle cross-stratification is present near middle of formation; upper and lower contacts are gradational and conformable; upper and lower parts correspond to slope-forming intervals about 180 feet (55 m) and 145 feet (45 m) thick, respectively, that contain interbedded calcareous sandstone, limestone, and minor shale (Biek, 2004); Webster and others (1984) reported on Early Pennsylvanian conodonts from the lower West Canyon Limestone at Enoch Divide, and on late Early Pennsylvanian conodonts from the uppermost West Canyon Limestone in the southern Oquirrh Mountains; sample SP101106-1 yielded *Adetognathus lautus*, a shallow-water conodont that ranged from absolute latest Mississippian to Early Permian; in his work on the Bridal Veil Limestone at Cascade Mountain, as this unit is known in the Wasatch Range, Shoore (2005; see also Shoore and Ritter, 2007) recognized 21 sequence boundaries caused by world-wide glacio-eustatic sea-level fluctuations, and reasoned that the unit was deposited in cool, shallow-marine water, showing evidence of shoaling and steady progradation of the Weber shelf; 1025 feet (313 m) thick at Lake Mountains (Biek, 2004).

PENNSYLVANIAN – MISSISSIPPIAN

IPMmc — **Manning Canyon Shale** (Lower Pennsylvanian? to Upper Mississippian) − Interbedded shale, limestone, and quartzitic sandstone divisible into three informal parts, not mapped separately, of approximately equal thickness: (1) the lower third contains about 200 feet (60 m) of slope-forming, olive-gray to dark-greenish-gray shale overlain by fine- to medium-grained quartzitic sandstone that upholds a prominent ridge; sandstone is grayish orange pink, light brownish gray, pale red, grayish pink, dusky yellow green, and olive gray, commonly has a vitreous and scintillating luster, locally exhibits low-angle and ripple cross-stratification, and contains rare small quartzite pebbles and locally pebbly conglomerate in the uppermost beds; (2) the middle third typically forms a strike valley and contains interbedded limestone and shale; limestone is medium gray, fetid, generally lacks macrofossils and chert, and forms both blocky weathering medium to thick beds and platy weathering laminated to thin beds; shale is typically more brightly colored than in the lower third of the formation and is light gray, dark reddish brown, pale red, and olive gray; slopes developed on this middle unit tend to weather to slight lavender hues; and (3) ledge- and slope-forming, pale-yellowish-brown, fine-grained quartzitic sandstone and several limestone ledges form the upper part; sandstone is similar to that in the lower unit, but lacks pebbles; limestone is medium gray, medium to thick bedded, and typically fossiliferous with brachiopods, bryozoans, trilobites, and fossil hash; upper contact is conformable and gradational and corresponds to a change from ledge-forming, grayish-orange to light-brown-weathering, light-brownish-gray, fine-grained sandstone and interbedded, medium-gray, fine-grained sandy limestone, to a slope-forming, thin-bedded, medium-gray limestone with fossil hash and local black chert nodules. Tidwell (1962, 1967) and Tidwell and others (1974) reported on fossil flora of the formation; Webster and others (1984) reported the Early Pennsylvanian conodont *Rhachistognathus primus* from the uppermost Manning Canyon limestone at Enoch Divide; age from Webster (1984) and Webster and others (1984); in the southern Oquirrh Mountains, Davis and others (1994) reported that the Pennsylvanian-Mississippian boundary, marked by the first occurrence of the conodont *Declinognathodus noduliferus*, is 121 feet (37 m) below the base of clean limestone of the West Canyon Limestone, in an interval apparently transitional to the Manning Canyon Shale but which they assigned to the West Canyon Limestone; Bullock (1951) reported thicknesses of 1121 feet (west side) and 1419 feet (east side) (342-433 m) at the Lake Mountains, but the thicker section on the east side of the mountain results from structural complications; we measured 1176 feet (359 m) of Manning Canyon Shale on the west side of the range south of Ivans Canyon; Calderwood (1951) reported 1130 feet (345 m) in this same area.

MISSISSIPPIAN

Great Blue Limestone (Upper Mississippian)

Mgb — **Great Blue Limestone, undivided** − Undivided in the vicinity of Soldiers Pass, at The Knolls, and in the northeast corner of the quadrangle due either to limited exposure or structural complications; query indicates uncertain designation in section 21, T. 7 S., R. 1 W., southeast of Soldiers Pass, where these limestone beds may belong to the Manning Canyon Shale.

Mgbu — **Upper limestone member** − Medium- to very thick bedded, bluish-gray limestone, locally cherty and commonly fossiliferous with brachiopods, corals, and bryozoans; contains interbedded shale in lower part; typically forms ledges and cliffs; upper contact marks a prominent change from cliff-forming limestone to slope-forming shale; Gordon and others (2000) reported a thickness of 1540 feet (470 m) for the upper limestone unit in the southern Oquirrh Mountains, but in the Lake Mountains, we estimate the member is about 2100 feet (640 m) thick.

Mgbl — **Long Trail Shale Member and lower limestone member, undivided** − Long Trail Shale Member is interbedded, reddish-brown, dark-gray, and grayish-purple calcareous and locally carbonaceous shale, and thin-bedded, medium-gray limestone and fossiliferous limestone; locally abundant rugose corals, pelecypods, brachiopods, and bryozoans; weathers to form strike valleys and saddles; locally contains limonite pseudomorphs after pyrite; neither the lower nor upper contact of the Long Trail Shale Member is well exposed, but regionally both appear conformable and gradational; Gordon and others (2000) reported a thickness of 108 feet (33 m) for the Long Trail Shale Member in the southern Oquirrh Mountains; the member is about 90 feet (28 m) thick in the Lake Mountains (Bullock, 1951). Lower limestone member is medium- to very thick bedded, light- to dark-gray but typically medium-gray limestone and fossiliferous limestone; upper part is typically thin-bedded and platy weathering argillaceous limestone and interbedded gray to grayish-purple shale; bryozoans are locally abundant; the lower limestone member is 850 feet (260 m) thick in the southern Oquirrh Mountains (Gordon and others, 2000), but appears to be only about 300 feet (90 m) thick in the Lake Mountains. Queried where designation is uncertain.

Mh — **Humbug Formation** (Upper Mississippian) − Interbedded calcareous quartz sandstone, orthoquartzite, and limestone that weather to ledgy slopes. Sandstone is light- to dark-brown weathering, pale yellowish brown to olive gray, medium to very thick bedded, variably calcareous or siliceous, locally with planar or low-angle cross-stratification. Limestone rarely contains dark-gray chert nodules and is: (1) light-gray weathering, medium dark gray, medium to thick bedded, and fine grained with local small white chert blebs; (2) dark gray, very thick bedded with small white calcite blebs; or (3) locally medium to coarse grained with sparse fossil hash. Upper half contains several distinctive, ledge-forming, white, medium- to thick-bedded sublithographic limestone beds as much as 10 feet (3 m) thick. Upper contact is not exposed in Mosida Hills, but in the main part of the Lake Mountains it is conformable and gradational and represents a change from interbedded sandstone and limestone to limestone; age from Morris and Lovering (1961); about 700 to 750 feet (210-230 m) thick.

Md — **Deseret Limestone** (Upper to Lower Mississippian) − Medium- to very thick bedded, medium-dark-gray, variably sandy and fossiliferous limestone; contains distinctive white calcite nodules and blebs and local to common brown-weathering chert nodules and brown-weathering bands (case-hardened surfaces); fossils include rugose corals, uncommon brachiopods, crinoids, bryozoans, and fossil hash; locally contains few thin calcareous sandstone beds. Lower part (about 100 feet [30 m]) is marked by slope-forming, light-red phosphatic shale and thin-bedded cherty limestone of the Delle Phosphatic Member. At Clyde Knoll, the Deseret contains uncharacteristic limestone beds with irregularly shaped black chert nodules and interbeds of calcareous sandstone in what may be equivalent to a less well-developed sandy facies of the medial Deseret present in the SW1/4SE1/4 section 29, T. 6 S., R. 1 W. Upper contact is conformable and gradational and corresponds to a change from locally fossiliferous limestone to predominantly sandstone; age from Morris and Lovering (1961) and Sandberg and Gutschick (1984); about 700 to 750 feet (210-230 m) thick in Lake Mountains and about 1000 feet (300 m) thick in Mosida Hills.

Mg — **Gardison Limestone** (Lower Mississippian) − Medium- to very thick bedded, medium-gray to medium-dark-gray limestone, cherty limestone, and fossiliferous limestone; contains minor medium-dark-gray, medium- to thick-bedded dolomite near the base; chert is present as black, irregularly shaped nodules and thin, discontinuous beds; fossils include rugose and colonial corals, brachiopods, gastropods, and bryozoans replaced by white calcite. Upper contact appears conformable and gradational and generally corresponds to a break in slope, with ledgy, thicker bedded, cherty limestone below and slope-forming shale and thin bedded limestone (Delle) above; age from Morris and Lovering (1961); thickness uncertain due to structural complications, but probably about 500 to 650 feet (150-200 m) thick.

Pzu — **Paleozoic, undivided** – Shown in cross section only.

REFERENCES

Baker, A.A., 1964, Geology of the Aspen Grove quadrangle: U.S. Geological Survey Geologic Quadrangle Map GQ-239, scale 1:24,000.

Baxter, N., Ward, T., Chandler, M.R., Zobell, E.A., Christiansen, E.H., Dorais, M.J., and Kowallis, B.J., 2005, Cenozoic extension and volcanism in the southern Lake Mountains, central Utah [abs.]: Geological Society of America Abstracts with Programs, vol. 37, no. 7, p. 72.

Biek, R.F., 2004, Geologic maps of the Cedar Fort and Saratoga Springs quadrangles, Utah County, Utah: Utah Geological Survey Maps 201 and 202, 3 plates, scale 1:24,000.

Bissell, H.J., 1948, Pleistocene sedimentation in southern Utah Valley, Utah: Iowa City, University of Iowa, Ph.D. dissertation, 364 p.

Bissell, H.J., 1963, Lake Bonneville – geology of southern Utah Valley: U.S. Geological Survey Professional Paper 257-B, 130 p., 1 plate, scale 1:48,000.

Brimhall, W.H., Bassett, I.G., and Merritt, L.B., 1976, Reconnaissance study of deep-water springs and strata of Utah Lake: Provo, Utah, Mountainlands Association of Governments, Technical Report 3, 21 p.

Brimhall, W.H., and Merritt, L.B., 1981, Geology of Utah Lake – implications for resource management, *in* Utah Lake monograph: Provo, Utah, Brigham Young University, Great Basin Naturalist Memoirs, no. 5, p. 24-42.

Bullock, K.C., 1951, Geology of Lake Mountain, Utah: Utah Geological and Mineralogical Survey Bulletin 41, 46 p.

Calderwood, K.W., 1951, Geology of the Cedar Valley Hills area, Utah: Provo, Utah, Brigham Young University, M.S. thesis, 1 plate, scale 1:12,000, 116 p.

Christiansen, E.H., Baxter, Nichelle, Ward, T.P., Zobell, Elizabeth, Chandler, M.R., Dorais, M.J., Kowallis, B.J., and Clark, D.L., 2007, Cenozoic Soldiers Pass volcanic field, central Utah – implications for the transition to extension-related magmatism in the Basin and Range Province, *in* Willis, G.C., Hylland, M.D., Clark, D.L., and Chidsey, T.C., Jr., editors, Central Utah – diverse geology of a dynamic landscape: Utah Geological Association Publication 36, p. 123-142.

Cook, K.L., Edgerton, D.A., Serpa, L.F., and DePangher, M., 1997, Complete bouguer gravity anomaly map and geological interpretation of the southern Wasatch Front, Utah: Utah Geological and Mineral Survey Contract Report 97-1, 20 p., 1 plate, scale 1:100,000.

Currey, D.R., and Oviatt, C.G., 1985, Durations, average rates, and probable causes of Lake Bonneville expansions, stillstands, and contractions during the last deep-lake cycle, 32,000 to 10,000 years ago, *in* Kay, P.A., and Diaz, H.F., editors, Problems of and prospects for predicting Great Salt Lake levels – Proceedings of a NOAA conference, March 26-28, 1985: Salt Lake City, University of Utah, Center for Public Affairs and Administration, p. 9-24.

Davis, L.E., Webster, G.D., and Dyman, T.S., 1994, Correlation of the West Canyon, Lake Point, and Bannock Peak Limestones (Upper Mississippian to Middle Pennsylvanian), basal formations of the Oquirrh Group, northern Utah and southeastern Idaho: U.S. Geological Survey Bulletin 2088, 30 p.

Floyd, A.R., 1993, An integrated gravity and magnetic analysis of the Mosida Hills, Utah County, Utah: Provo, Brigham Young University, M.S. thesis, 78 p.

Godsey, H.S., Currey, D.R., and Chan, M.A., 2005, New evidence for an extended occupation of the Provo shoreline and implications for regional climate change, Pleistocene Lake Bonneville, Utah, USA: Quaternary Research, v. 63, p. 212-223.

Gordon, M., Jr., Tooker, E.W., and Dutro, J.T., Jr., 2000, Type locality for the Great Blue Limestone in the Bingham nappe, Oquirrh Mountains, Utah: U.S. Geological Survey Open-File Report 00-012, 61 p.

Hoffman, F.H., 1951, Geology of the Mosida Hills area, Utah: Provo, Utah, Brigham Young University, M.S. thesis, scale 1:12,000, 68 p.

Hughen, K.A., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Bertrand, C.J.H., Blackwell, P.G., Buck, C.E., Burr, G.S., Cutler, K.B., Damon, P.E., Edwards, R.L., Fairbanks, R.G., Friedrich, M., Guilderson, T.P., Kromer, B., McCormac, F.G., Manning, S.W., Bronk Ramsey, C., Reimer, P.J., Reimer, R.W., Remmele, S., Southon, J.R., Stuiver, M., Talamo, S., Taylor, F.W., van der Plicht, J., and Weyhenmeyer, C.E., 2004, Marine04 Marine radiocarbon age calibration, 26 - 0 ka BP: Radiocarbon v. 46, p. 1059-1086.

Konopka, E.H., 1999, Stratigraphy and sedimentology of the Butterfield Peaks Formation (Middle Pennsylvanian), Oquirrh Group, in central Utah: University of Wisconsin-Madison, Ph.D. dissertation, 316 p.

LeBas, M.J., LeMaitre, R.W., Streckeisen, A., and Zanettin, B., 1986, A chemical classification of volcanic rocks based on the total alkali-silica diagram: Journal of Petrology, v. 27, p. 745-750.

Machette, M.N., 1992, Surficial geologic map of the Wasatch fault zone, eastern part of Utah Valley, Utah County and parts of Salt Lake and Juab Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2095, 26 p., 1 plate, scale 1:50,000.

McKee, E.H., Best, M.G., Barr, D.L. and Tingey, D.L., 1993, Potassium-argon ages of mafic and intermediate-composition lava flows in the Great Basin of Nevada and Utah: Isochron/West, v. 60, p. 15-18.

Moore, D.K., Keith, J.D., Christiansen, E.H., Kim, C.S., Tingey, D.G., Nelsen, S.T., and Flamm, D.S., 2007, Petrogenesis of the Oligocene East Tintic volcanic field, Utah, *in* Willis, G.C., Hylland, M.D., Clark, D.L., and Chidsey, T.C., Jr., editors, Central Utah – diverse geology of a dynamic landscape: Utah Geological Association Publication 36, p. 163-180.

Morris, H.T., and Lovering, T.S., 1961, Stratigraphy of the East Tintic Mountains, Utah: U.S. Geological Survey Professional Paper 361, 145 p.

Murchison, S.B., 1989, Fluctuation history of Great Salt Lake, Utah, during the last 13,000 years: Salt Lake City, University of Utah, Ph.D. dissertation, 137 p.

Okerlund, M.D., 1951, A study of the calcite-aragonite deposits of Lake Mountain, Utah: Provo, Utah, Brigham Young University, M.S. thesis, scale 1:12,000, 44 p.

Ornelas, R.H., 1953, Clay deposits of Utah County, Utah: Provo, Utah, Brigham Young University, M.S. thesis, scale 1:12,000, 80 p.

Oviatt, C.G., 1997, Lake Bonneville fluctuations and global climate change: Geology, v. 25, no. 2, p. 155-158.

Oviatt, C.G., Currey, D.R., and Miller, D.M., 1990, Age and paleoclimatic significance of the Stansbury shoreline of Lake Bonneville, northeastern Great Basin: Quaternary Research, v. 33, p. 219-305.

Oviatt, C.G., Currey, D.R., and Sack, Dorothy, 1992, Radiocarbon chronology of Lake Bonneville, eastern Great Basin, USA: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 99, p. 225-241.

Oviatt, C.G., Miller, D.M., McGeehin, J.P., Zachary, C., and Mahan, S., 2005, The Younger Dryas phase of Great Salt Lake, Utah, USA: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 219, no. 3-4, p. 263-284.

Oviatt, C.G., and Thompson, R.S., 2002, Recent developments in the study of Lake Bonneville since 1980, *in* Gwynn, J.W., editor, Great Salt Lake—An overview of change: Utah Department of Natural Resources Special Publication, p. 1-6.

Sandberg, C.A., and Gutschick, R.C., 1984, Distribution, microfauna, and source-rock potential of Mississippian Delle Phosphatic Member of Woodman Formation and equivalents, Utah and adjacent states, *in* Woodward, J., Meissner, F.F., and Clayton, J.L., editors, Hydrocarbon source rocks of the greater Rocky Mountain region: Rocky Mountain Association of Geologists Field Conference Guidebook, p. 135-178.

Shoore, D.J., 2005, Sequence stratigraphy of the Bridal Veil Falls Limestone, Carboniferous, lower Oquirrh Group, on Cascade Mountain, Utah – a standard Morrowan cyclostratigraphy for the Oquirrh Basin: Provo, Utah, Brigham Young University, M.S. thesis, 203 p.

Shoore, D.J., and Ritter, S.M., 2007, Sequence stratigraphy of the Bridal Veil Limestone Member of the Oquirrh Formation (Lower Pennsylvanian) in the central Wasatch Range, Utah – towards a Bashkirian cyclostratigraphy for the Oquirrh Basin, *in* Willis, G.C., Hylland, M.D., Clark, D.L., and Chidsey, T.C., Jr., editors, Central Utah – diverse geology of a dynamic landscape: Utah Geological Association Publication 36, p. 57-74.

Smith, G.M., 1951, Geology of southwest Lake Mountains, Utah: Provo, Utah, Brigham Young University, M.S. thesis, scale 1:12,000, 41 p.

Solomon, B.J., 2007, Geologic map of the Kaysville quadrangle, Davis County, Utah: Utah Geological Survey Map 224, 2 plates, scale 1:24,000.

Solomon, B.J., and Biek, R.F., 2009, Geologic map of the Lincoln Point quadrangle, Utah County, Utah: Utah Geological Survey Map 232, 2 plates, scale 1:24,000.

Stringham, B.F., and Sharp, B.J., 1950, Fox clay deposit, Utah: American Journal of Science, v. 248, p. 726-733.

Stuiver, M., and Reimer, P.J., 1993, Extended ^{14}C database and revised CALIB radiocarbon calibration program: Radiocarbon, v. 35, p. 215-230.

Tidwell, W.D., 1962, An Early Pennsylvanian flora from the Manning Canyon Shale, Utah: Brigham Young University Geology Studies, v. 9, part 2, p. 83-101.

Tidwell, W.D., 1967, Flora of Manning Canyon Shale, part 1 – a lowermost Pennsylvanian flora from the Manning Canyon Shale, Utah, and its stratigraphic significance: Brigham Young University Geology Studies, v. 14, part 1, p. 3-66.

Tidwell, W.D., Medlyn, D.A., and Simper, A.D., 1974, Flora of Manning Canyon Shale, part 2 – Lepidodrendrales: Brigham Young University Geology Studies, v. 21, part 3, p. 119-146.

Tooker, E.W., and Roberts, R.J., 1970, Upper Paleozoic rocks in the Oquirrh Mountains and Bingham mining district, Utah, with a section on biostratigraphy and correlation by MacKenzie, Gordon, Jr., and Duncan, H.M.: U.S. Geological Survey Professional Paper 629-A, 76 p.

Utah Geological Survey and New Mexico Geochronology Research Laboratory, 2007, $^{40}Ar/^{39}Ar$ geochronology results for the Soldiers Pass, Granite Peak, Granite Peak SE, Camels Back Ridge NE, Flat Top, Blind Lake, and Deer Creek Lake quadrangles: Utah Geological Survey Open-File Report 504, variously paginated, also available online, <http://geology.utah.gov/online/ofr/ofr-504.pdf>.

Webster, G.D., 1984, Conodont zonations near the Mississippian-Pennsylvanian boundary in the eastern Great Basin, *in* Lintz, Joseph, Jr., editor, Western geological excursions: Geological Society of America, 1984 annual meeting guidebook, p. 78-82.

Webster, G.D., Gordon, M., Jr., Langenheim, R.L., and Henry, T.W., 1984, Road logs for the Mississippian-Pennsylvanian boundary in the eastern Great Basin – Salt Lake City, Utah to Las Vegas, Nevada, *in* Lintz, Joseph, Jr., editor, Western geological excursions: Geological Society of America, 1984 annual meeting guidebook, v. 1, p. 1-86.

Welsh, J.E., and Bissell, H.J., 1979, The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States: U.S. Geological Survey Professional Paper 1110-Y, 35 p.

ADDITIONAL REFERENCES (Not cited in text)

Bryant, B., 1992, Geologic and structure maps of the Salt Lake City 1° x 2° quadrangle, Utah and Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-1997, 3 plates, scale 1:125,000.

Williams, F.E., 1951, Geology of the north Selma Hills area, Utah County, Utah: Provo, Brigham Young University, M.S. thesis, 63 p., scale 1:12,000.

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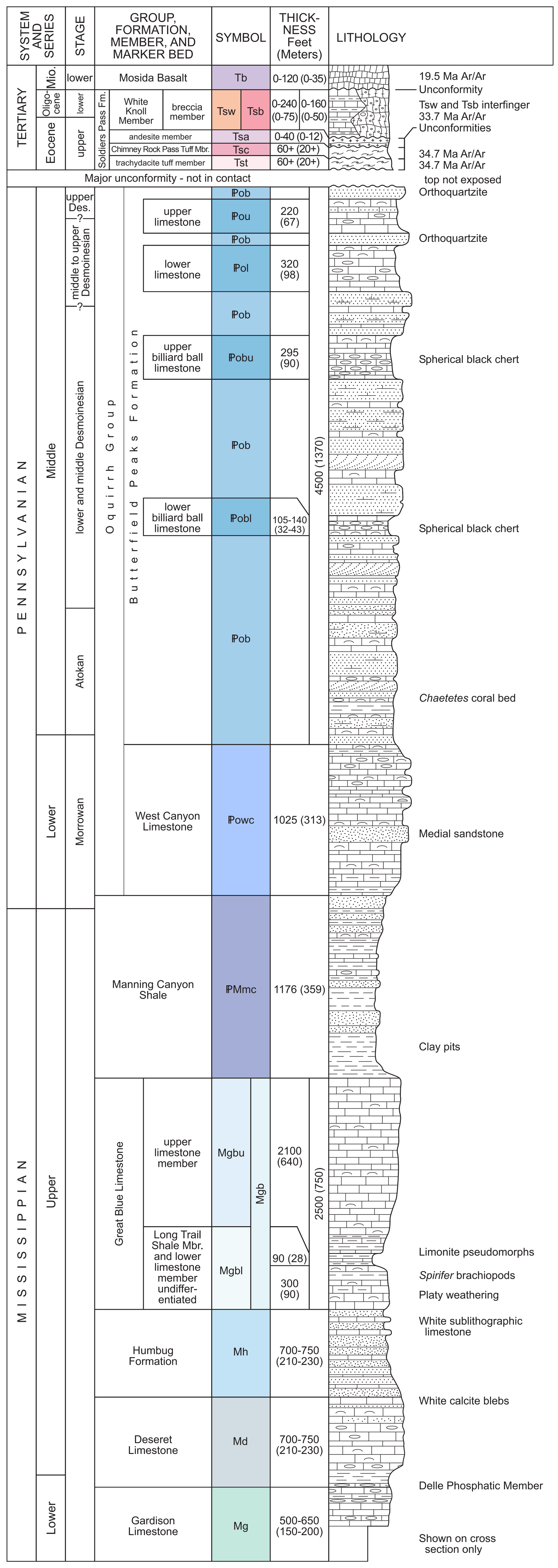
LITHOLOGIC COLUMN



GEOLOGIC SYMBOLS

Contact – Dashed where approximately located, queried where uncertain

Normal fault, concealed – Inferred principally from gravity data (Floyd, 1993; Cook and others, 1997) and shallow sonar-like data (Brimhall and Merritt, 1981); very approximately located; bar and ball on down-dropped side

Thrust or reverse fault – Dashed where approximately located, dotted where concealed, queried where uncertain; saw teeth on upper plate

Normal fault – Dashed where approximately located, dotted where concealed, dotted and queried where inferred; bar and ball on down-dropped side

Tear fault – Dotted where concealed; arrows show direction of relative offset

Oblique slip fault, dotted where concealed, arrows and bar and ball show relative displacement

Axial trace of anticline – Dashed where approximately located; dotted where concealed; arrow shows direction of plunge

Axial trace of syncline – Dashed where approximately located; dotted where concealed; arrow shows direction of plunge

Axial trace of monocline, dotted where concealed; after Brimhall and Merritt (1981)

Lacustrine shorelines – Major shorelines of the Bonneville lake cycle and Utah Lake. Mapped at the top of the wave-cut platform, dashed where approximately located

B Highest shoreline of the Bonneville (transgressive) phase

P Highest shoreline of the Provo (regressive) phase

Y Other transgressive shorelines of the Bonneville phase (present above the Provo shoreline)

X Other mostly regressive shorelines of the Provo phase (present below the Provo shoreline)

U Utah Lake highstand

Crest – Lacustrine barrier bar or spit

Landslide main scarp – Hachures on down-dropped side

21 Strike and dip of inclined bedding; green symbols indicate attitudes from BYU students

20 Approximate strike and dip of inclined bedding

Approximate strike and dip direction of inclined bedding

Strike of vertical bedding

Horizontal bedding

Sand and gravel pit

Quarry, cl = clay, p = pumice, no letter = crushed rock

Prospect, cl = clay, c = calcite, no letter = metals or unknown; not all clay prospects shown due to limitations of scale

Prospect trench, clay

Adit, c = calcite

Spring

SP-2103 Rock sample location and number

Measured section

CORRELATION OF MAP UNITS

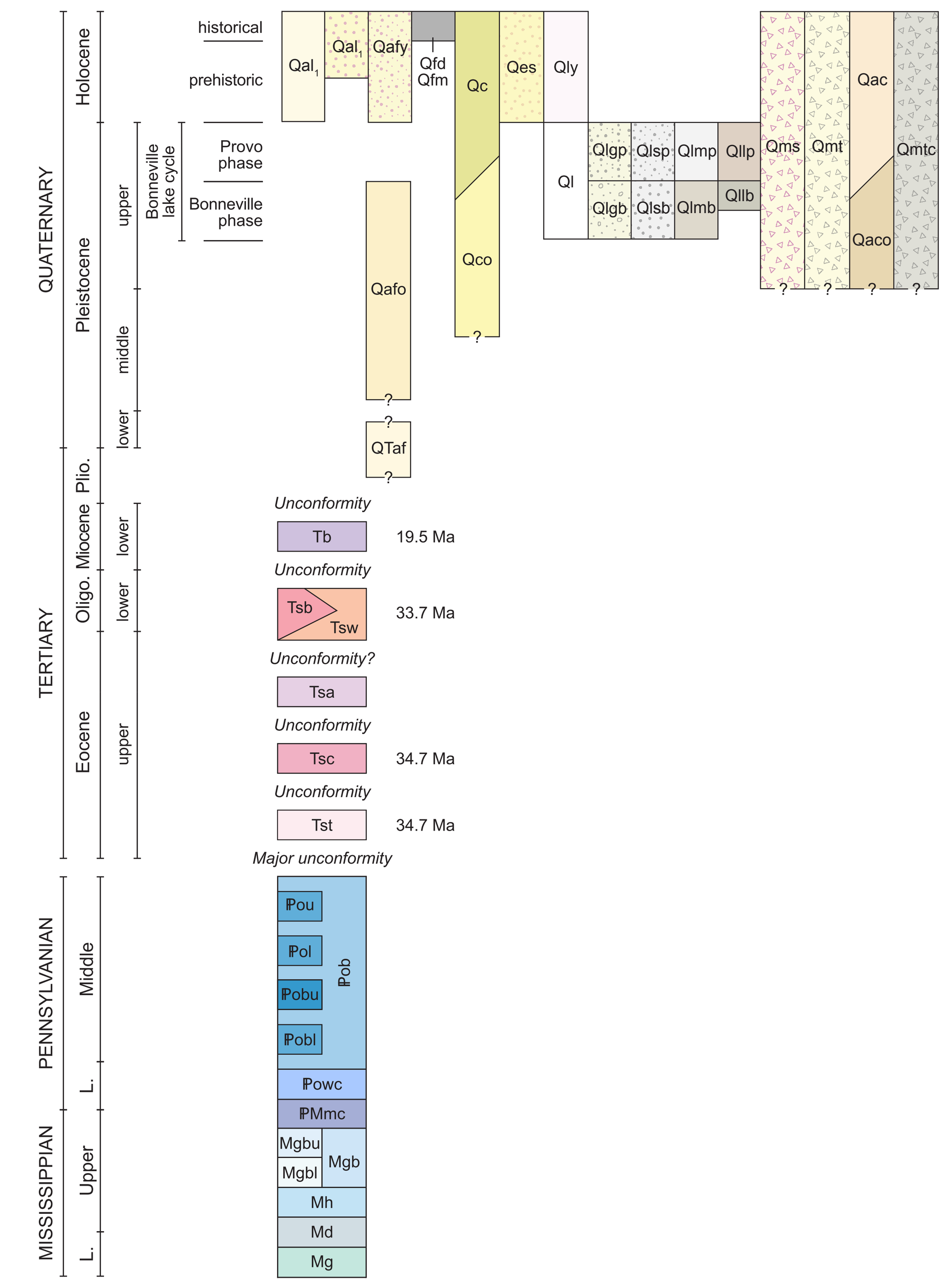
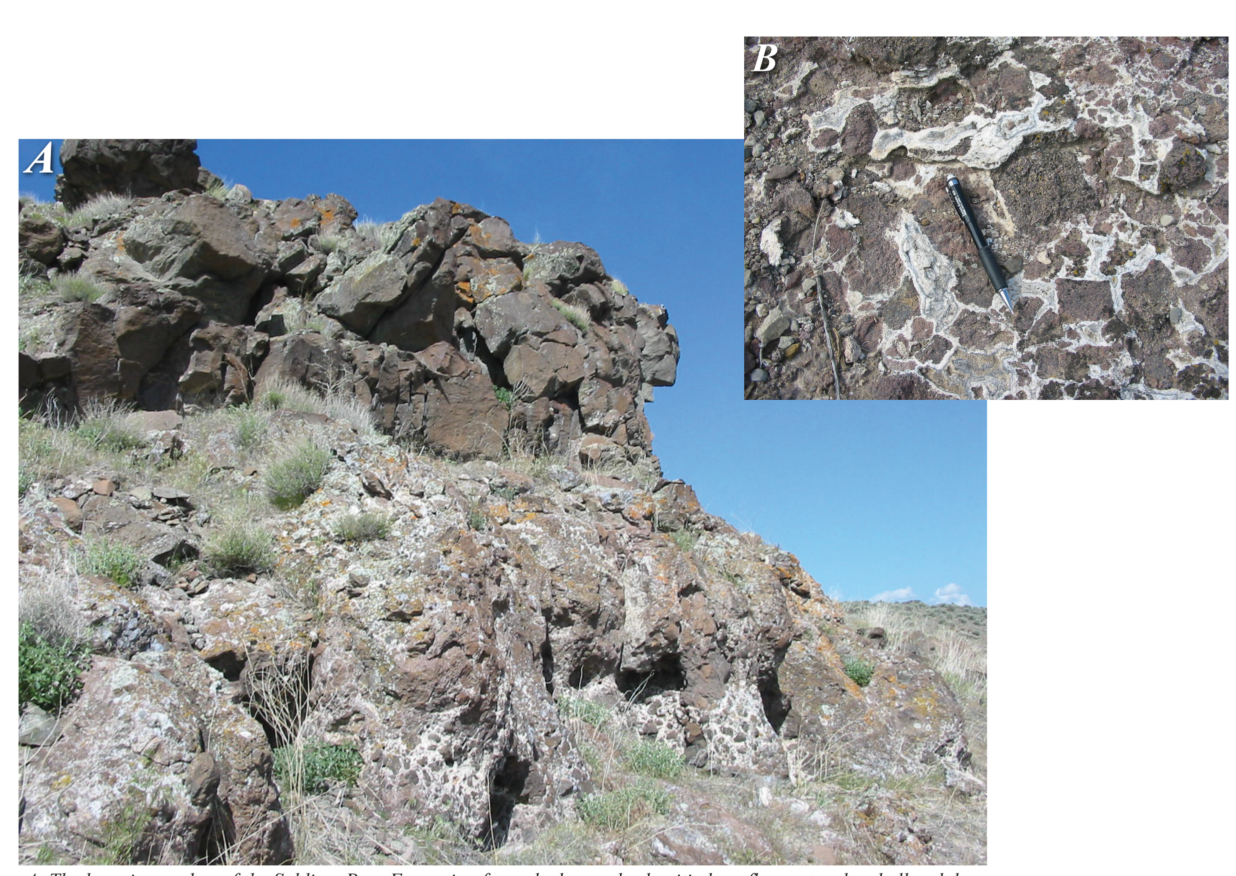


Table 1. Ages and elevations of major shorelines of Lake Bonneville and Utah Lake in the Soldiers Pass quadrangle (modified from Solomon, 2007).

Lake Cycle and Phase	Shoreline (map symbol)	Age		Elevation feet (meters)
		radiocarbon years B.P.	calendar-calibrated years B.P.	
Lake Bonneville				
Transgressive Phase	Stansbury	22,000-20,000[1]	27,000-24,000[2]	Not present
	Bonneville (B)	15,000-14,500[3]	18,300[4]-17,400[5]	5130-5150 (1564-1570)
	flood			
Regressive Phase	Provo (P)	14,500-12,000[6]	17,400[5]-14,400[7]	4765-4775 (1453-1456)
	Gilbert	10,500-10,000[8]	12,500-11,500[9]	Not present
Utah Lake				
	Utah Lake highstand (U)	12,000-11,500[10]	-----	4497-4500 (1371-1372)

[1] Oviatt and others (1990).
[2] Calendar calibration using Fairbanks and others (2005; http://www.radiocarbon.ldeo.columbia.edu/research/radcarbcal.htm).
[3] Oviatt and others (1992), Oviatt (1997).
[4] Oviatt (written communication, 2009), using Stuiver and Reimer (1993) for calibration.
[5] CRONUS-Earth Project (2005), using Stuiver and others (2005) for calibration.
[6] 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 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.
[7] Godsey and others (2005), using Stuiver and Reimer (1993) for calibration.
[8] Oviatt and others (2005)
[9] Calendar calibration of data in Oviatt and others (2005), using Stuiver and Reimer (1993) and Hughen and others (2004).
[10] Estimated data from 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.

Soldiers Pass is the low point between the Lake Mountains on the north (right) and a low juniper-capped ridge on the south (left). The Lake Mountains expose Mississippian and Pennsylvanian marine strata that were folded into a broad syncline during the Cretaceous to Early Tertiary Sevier orogeny. The ridge on the south is capped by the Miocene Mosida Basalt and underlain by tan sedimentary beds of the Oligocene White Knoll Member of the Soldiers Pass Formation. View northwest toward Soldiers Pass.



A. The breccia member of the Soldiers Pass Formation formed when a shoshonitic lava flow entered a shallow lake. The flow brecciated and formed crude pillows that were cemented together by seams of coarse calcite formed as the lake waters heated. Fragments of brecciated lava are as much as 1 m across. The upper part of the flow is massive and was apparently above the surface of the lake.
B. The fragments in the breccia commonly have reddened, quenched, vesicular rinds, and more massive crystalline interiors. They are surrounded by thin layers of coarse-grained, vuggy calcite.

The Chimney Rock Pass Tuff Member of the Soldiers Pass Formation is a poorly welded rhyolite ignimbrite that erupted 34.7 Ma from unknown vents. It has small phenocrysts of quartz, sanidine, plagioclase, and biotite. The largest pumice clasts are found in the central part of the Soldiers Pass quadrangle, but are considerably smaller to the south.