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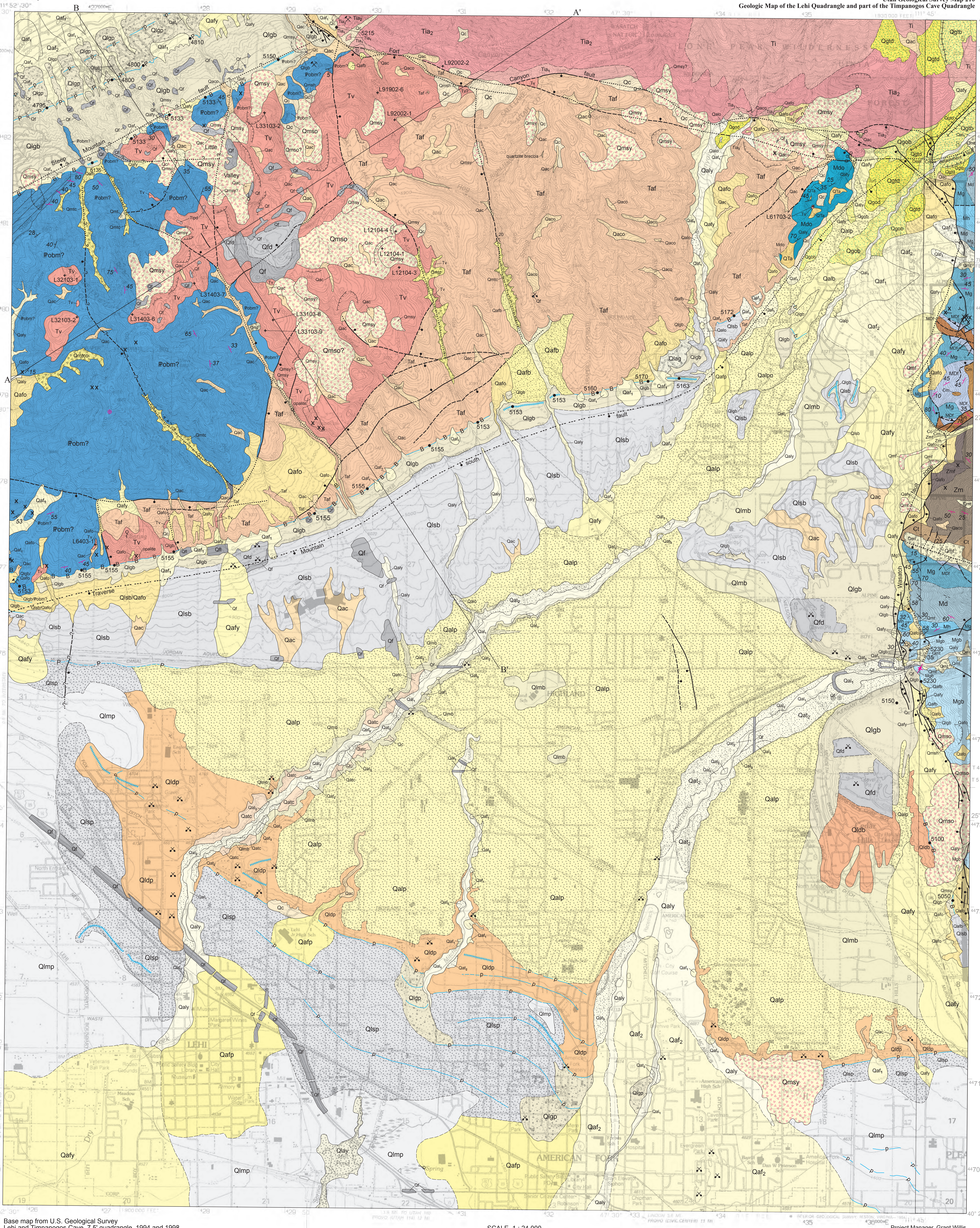

Base map from U.S. Geological Survey
Lehi and Timpanogos Cave 7.5' quadrangle, 1994 and 1998

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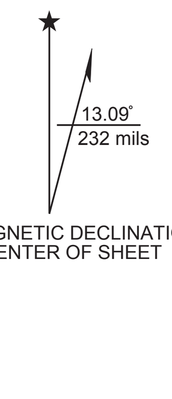
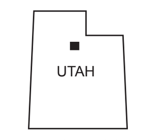
Field mapping by author, 2002-2003
Cartographers, Lori J. Douglas and
Kent D. Brown





1	2	3
4		5
6	7	8

1 Midvale
2 Draper
3 Dromedary Peak
4 Jordan Narrows
5 Timpanogos Cave
6 Saratoga Srings
7 Pelican Point
8 Orem

ADJOINING 7.5' QUADRANGLE NAMES

ISBN 1-55791-721-3

This geologic map was funded by the Utah Geological Survey and the U.S. Geological Survey, National Cooperative Geologic Mapping Program, through USGS STATEMAP award number 02HQAG0055.

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GEOLOGIC MAP OF THE LEHI QUADRANGLE AND PART OF THE TIMPANOGOS CAVE QUADRANGLE, SALT LAKE AND UTAH COUNTIES, UTAH

by

Robert F. Biek

2005

UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources

MAP UNIT DESCRIPTIONS

QUATERNARY

Alluvial deposits

Qal1 Stream deposits (Holocene) − *Moderately to well-sorted sand, silt, clay, and pebble to boulder gravel in river channels and flood plains; locally includes small alluvial-fan and colluvial deposits, and minor terraces up to 10 feet (3 m) above current base level; mapped principally along the larger streams in the quadrangle, including American Fork River and Dry Creek; generally 0 to 20 feet (0-6 m) thick.*

Qat2-3 Stream-terrace deposits (Holocene to Upper Pleistocene) – *Moderately to well-sorted sand, silt, clay, and pebble to boulder gravel that forms level to gently sloping terraces incised by modern streams; subscript denotes height above modern stream channels; level 2 deposits are 10 to 30 feet (3-9 m), and level 3 deposits are 30 to 75 feet (10-20 m) above modern drainages; deposited in river channels and flood plains; generally 0 to 20 feet (0-6 m) thick.*

Qaly Young alluvial deposits (Holocene to Upper Pleistocene) − *Moderately sorted sand, silt, clay, and pebble to boulder gravel deposited in river channels and flood plains; incised by active stream channels, and locally include small alluvial-fan and colluvial deposits; equivalent to modern stream deposits (Qal1) and older, post-Bonneville stream deposits that are undifferentiated because units are complexly overlapping; probably less than 20 feet (6 m) thick.*

Qalo Older alluvial deposits (Upper Pleistocene) − *Moderately sorted sand, silt, clay, and pebble to boulder gravel incised by younger alluvial deposits in Fort Canyon; probably less than 30 feet (9 m) thick; small deposit overlying Dry Creek glacial outwash (Qgod) in Fort Canyon is well-cemented, subangular to subrounded pebble conglomerate composed of Pennsylvanian or Permian calcareous sandstone clasts and is about 3 feet (1 m) thick.*

Qalp Alluvial deposits related to the Provo phase of the Bonneville lake cycle (Upper Pleistocene) − *Moderately to well-sorted sand, silt, and pebble gravel deposited principally in river channels; coarsens upgradient and includes boulder-size clasts in the upper reaches of Dry Creek; locally includes veneer of fine-grained eolian sand and silt, and may include loess veneer; large deposits in south-central part of quadrangle are mostly fluvial topset beds that grade into Provo-level deltaic deposits (Qldp) derived from American Fork and Dry Creek Canyons; generally 5 to 20 feet (2-6 m) thick.*

Qalpo Older alluvial deposits related to the Provo phase of the Bonneville lake cycle (Upper Pleistocene) − *Moderately to well-sorted sand, silt, and pebble to boulder gravel deposited in ancestral Dry Creek channel; forms terrace remnant north of Alpine that is about 30 feet (9 m) above adjacent Qalp deposits; may include loess veneer; exposed thickness about 30 feet (9 m).*

Qalb Alluvial deposits related to the Bonneville phase of the Bonneville lake cycle (Upper Pleistocene) − *Moderately sorted sand, silt, and pebble to boulder gravel deposits of ancestral Dry Creek that are graded to the Bonneville shoreline; about 20 feet (6 m) thick.*

Qaf1 Modern alluvial-fan deposits (Holocene) − *Poorly to moderately sorted, non-stratified, clay- to boulder-size sediment deposited principally by debris flows 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; generally less than 30 feet (9 m) thick.*

Qaf2 Level 2 alluvial-fan deposits (Holocene to Upper Pleistocene) − *Poorly to moderately sorted, clay- to boulder-size sediment deposited principally by debris flows; large deposits at American Fork likely also deposited by perennial and intermittent streams of the American Fork River distributary system; incised by modern alluvial-fan and alluvial deposits; forms moderately dissected surfaces equivalent to the lower part of Qafy; probably less than 30 feet (9 m) thick.*

Qaf3 Level 3 alluvial-fan deposits (Upper Pleistocene) − *Poorly to moderately sorted, clay- to boulder-size sediment deposited principally by debris flows; locally conceals the Bonneville shoreline and is incised by younger undifferentiated alluvial deposits; forms deeply dissected surface north of Alpine; probably less than 40 feet (12 m) thick.*

Qafy Younger undifferentiated alluvial-fan deposits (Holocene to Upper Pleistocene) − *Equivalent to modern, level-2, and the upper part of level-3 alluvial-fan deposits, but undifferentiated because units are complexly overlapping or too small to show separately; upper parts of fans are locally deeply incised; thickness unknown, but likely up to several tens of feet.*

Qafp Alluvial-fan deposits related to the Provo phase of the Bonneville lake cycle (Upper Pleistocene) − *Poorly to moderately sorted, clay- to cobble-size sediment deposited principally by debris flows; larger deposits at Lehi and American Fork are mostly reworked deltaic and fan-delta deposits; incised by younger alluvial and alluvial-fan deposits; deposited by streams associated with the Provo (regressive) phase of Lake Bonneville; thickness unknown, but likely up to several tens of feet.*

Qafb Alluvial-fan deposits related to the Bonneville phase of the Bonneville lake cycle (Upper Pleistocene) − *Poorly to moderately sorted, clay- to cobble-size sediment deposited principally by debris flows; incised by younger alluvial and alluvial-fan deposits; deposited by streams associated with the Bonneville (transgressive) phase of Lake Bonneville; probably less than about 40 feet (12 m) thick.*

Qafo Older alluvial-fan deposits (Upper Pleistocene) − *Similar to younger undifferentiated alluvial-fan deposits (Qafy), but forms deeply dissected alluvial apron truncated by, and thus predating, the Bonneville shoreline; upper parts of fans locally receive sediment from minor washes; thickness unknown, but likely up to several tens of feet.*

Artificial deposits

Qf Artificial fill (Historical) − *Engineered fill used in the construction of Interstate 15 and other road and railroad beds; larger areas of fill used to create new level building areas are also mapped based on aerial photographs taken in May 2002; although only larger fill deposits are shown, fill of variable composition may be present in any developed area; variable thickness up to about 90 feet (30 m).*

Qfl Landfill deposits (Historical) − *Miscellaneous fill, principally building and road construction debris, placed in sand and gravel or aggregate pits; variable thickness up to several tens of feet.*

Qfd Disturbed land (Historical) – *Land disturbed by sand and gravel operations; only the larger operations are mapped and their outlines are based on aerial photographs taken in May 2002; land within these areas contains a complex, rapidly changing mix of cuts and fills, as well as excellent exposures of Lake Bonneville sediments. Disturbed land at the top of the east Traverse Mountains is also mapped based on aerial photographs taken in May 2002; this area contains a complex mix of very large cuts and areas of fill in deeply weathered volcanic rocks of the east Traverse Mountains (Tv).*

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; may include older landslide deposits whose subtle features make positive identification impossible without detailed geotechnical investigations; because most bedrock is covered by at least a veneer of colluvium, only the larger, thicker deposits are mapped; 0 to about 20 feet (0-6 m) thick.*

Glacial deposits

Deposits of the Bells Canyon advance - *Pinedale equivalent; generally thought to be 12 to 30 ka (Madole, 1986),although some Pinedale moraines may be as old as 70 ka (Coleman and Pierce, 1979; Porter and others, 1983).*

Qgob Outwash (Upper Pleistocene) − *Moderately to well-sorted, subangular to subrounded, clast-supported, pebble to boulder sand and gravel; typically medium to thick bedded; clasts are little weathered and are derived from the Little Cottonwood stock and Mississippian and Pennsylvanian strata of Dry Creek Canyon; mapped north of Alpine where it forms moderately dissected, bouldery surfaces graded to Bells Canyon till immediately east of the Lehi quadrangle; probably 0 to at least 40 feet (0-12+ m) thick.*

Qgtb Till (Upper Pleistocene) − *Non-stratified, poorly sorted, sandy pebble to boulder gravel in a matrix of silt and minor clay; clasts are matrix supported, subangular to subrounded, and were derived from the Little Cottonwood stock; clasts typically lack weathering rind common on granitic clasts of the Dry Creek advance; mapped near the First Hamongog north of Alpine where lateral and end moraines are well preserved; also present as lateral moraines immediately east of the Lehi quadrangle along Dry Creek, where it has a more diverse clast composition (Machette, 1992); up to several tens of feet thick.*

Deposits of the Dry Creek advance (Bull Lake equivalent; 130 to 155 ka [Pierce and others, 1976]).

Qgod Outwash (Middle Pleistocene) − *Similar to outwash of Bells Canyon advance, but clasts are deeply weathered; granitic clasts typically have grussified rind; mapped north of Alpine where it forms a moderately dissected, bouldery surface adjacent to Dry Creek till; also mapped in upper Fort Canyon where it consists entirely of deeply weathered granitic clasts; probably 0 to 80 feet (0-25 m) thick.*

Qgtd Till (Middle Pleistocene) − *Non-stratified, poorly sorted, sandy pebble to boulder gravel in a matrix of silt and minor clay; clasts are matrix supported, subangular to subrounded, and were derived from the Little Cottonwood stock and Mississippian and Pennsylvanian strata of Dry Creek Canyon; clasts deeply weathered and granitic clasts especially exhibit grussified weathering rind; forms end and lateral moraines offset by the Wasatch fault at the mouth of Dry Creek Canyon; up to about 150 feet (45 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."

Qlgp, Qlgb Lacustrine gravel and sand (Upper Pleistocene) − *Moderately to well-sorted, moderately to well-rounded, clast-supported, pebble to cobble gravel and pebbly sand; thin to thick bedded; typically interbedded with or laterally gradational to sand and silt facies; gastropods locally common in sandy lenses; locally partly cemented with calcium carbonate; typically forms well-developed wave-cut or wave-built benches, bars, and spits; intermediate shorelines are locally well developed on Provo-level deposits; Qlgb deposited at and below highest Bonneville shoreline but above the Provo shoreline, and Qlgp deposited at and below the Provo shoreline; exposed thickness from 0 to about 150 feet (0-45 m).*

Qlsp, Qlsb Lacustrine sand and silt (Upper Pleistocene) − *Fine- to coarse-grained lacustrine sand and silt with minor gravel; typically thick bedded and well sorted; gastropods locally common; grades downslope from sandy nearshore deposits to finer grained offshore deposits; locally concealed by loess veneer; intermediate shorelines typically poorly developed on this facies; Qlsb deposited at and below highest Bonneville shoreline but above the Provo shoreline, and Qlsp deposited at and below the Provo shoreline; exposed thickness less than 40 feet (12 m).*

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 concealed by loess veneer; Qlmb deposited below Bonneville shoreline and Qlmp deposited below the Provo shoreline; grades upslope into lacustrine sand and silt; exposed thickness less than about 40 feet (12 m).*

Qldp, Qldb Deltaic deposits (Upper Pleistocene) – *Moderately to well-sorted, moderately to well-rounded, clast-supported, pebbly sand and pebbly gravel; thin to thick bedded; locally partly cemented with calcium carbonate; foreset beds commonly dip 30º-35º; mapped as eroded remnants at the leading edge of large deltas deposited by the American Fork River and Dry Creek; Provo-level deposits are overlain by up to 15 feet (5 m) of topset alluvium (Qalp); Bonneville-level deposits are less well exposed and are in part mapped simply as lacustrine gravel and sand (Qlgb); intermediate shorelines are locally well developed on the Provo-level deposits; exposed thickness from 0 to about 150 feet (0-45 m).*

Mass-movement deposits

Qmf Debris-flow deposits (Holocene) − *Very poorly sorted, subangular, cobble- to boulder-size gravel in a matrix of silt, sand, clay, and pebbles; mapped on younger undifferentiated alluvial-fan deposits east of Alpine; although all alluvial fans consist principally of debris-flow deposits, these debris flows are mapped separately due to their relatively fresh morphology and well-developed levee deposits of angular rubble; includes debris flows that occurred at the mouth of Preston Canyon in November 2001 and September 2002; typically less than 10 feet (3 m) thick.*

Qmsh, Qmsy, Qmso Landslide deposits (Historical to Pleistocene) − *Very poorly sorted, clay- to boulder-size, locally derived material deposited by rotational and translational movement; characterized by hummocky topography, numerous internal scarps, and chaotic bedding attitudes; basal slip surfaces most commonly form in the volcanic rocks of the east Traverse Mountains (Tv) and Tertiary alluvial-fan deposits (Taf), but are also in lacustrine deposits and regolithic and colluvial sediment derived from Oquirrh Group and altered Little Cottonwood stock; Qmsh denotes small slides with historical movement in Corner Canyon and northeast of Cedar Hills in the Timpanogos Cave quadrangle; younger landslides (Qmsy) may have historical movement, but typically are characterized by slightly to moderately subdued landslide features indicative of middle or late Holocene to Late Pleistocene age; older landslides (Qmso) are deeply incised and head scarps and hummocky topography have been extensively modified by erosion and so most are likely Late Pleistocene in age; many of these landslides show evidence for complex, multiple episodes of movement; query indicates uncertain designation; the northwest-facing slope of Steep Mountain is covered by colluvium that, in low light, shows evidence of creep as wavy, subhorizontal ridges and swales (shown by hachure pattern on plate 1); additional unmapped landslide deposits may be present in the east Traverse Mountains, but subdued features, poor exposures, and altered and faulted nature of Tv and Taf deposits make positive identification impossible without 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; locally grades downslope into colluvial deposits, and may include colluvial deposits where impractical to differentiate the two; generally less than 20 feet (6 m) thick.*

Mixed-environment deposits

Qac, Qaco 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, small drainages, and the upper reaches of larger ephemeral streams by fluvial, slope-wash, and creep processes; older deposits (Qaco) form isolated remnants deeply incised by adjacent streams; Qaco deposit in upper reaches of Fort Canyon contains several poorly developed soil horizons and may represent deposition in a sag pond adjacent to Fort Canyon fault; generally less than 30 feet (9 m) thick.*

Qatc Alluvial terrace and colluvial deposits (Holocene to Upper Pleistocene) − *Mapped along Dry Creek where it is impractical to differentiate deposits of two or more terrace levels and colluvium derived from adjacent slopes; may include small areas of fine-grained lacustrine deposits; up to a few tens of feet thick.*

Qmtc, Qmtco Talus and colluvium (Holocene to Upper Pleistocene) − *Very poorly sorted, angular to subangular cobbles and boulders and finer grained interstitial sediment deposited principally by rock fall and slope wash at the base of steep washes in the Traverse Mountains; includes minor alluvial sediment at the bottom of the washes; older deposits (Qmtco) mapped at the head of Oak Hollow grade downslope into older alluvial-fan deposits; generally less than 30 feet (9 m) thick.*

Qlay Lacustrine and alluvial deposits (Holocene to Upper Pleistocene) − *Moderately to well-sorted, fine-grained sand, silt, and clay deposited in the Mill Pond area at the mouth of Mitchells Hollow; probably less than 15 feet (5 m) thick.*

Qlag Lacustrine and alluvial coarse-grained deposits (Pleistocene) − *Poorly to moderately sorted, clay- to boulder-size sediment; mapped at the mouth of Fort Canyon where it is impractical to differentiate alluvial-fan, alluvial, and nearshore lacustrine deposits; 0 to about 30 feet (0-9 m) thick.*

Stacked-unit deposits

Qlsb/Qafo Lacustrine sand and silt deposits over older alluvial-fan deposits (Upper Pleistocene) − *Older alluvial-fan deposits planated by wave action and partly concealed by a discontinuous veneer of lacustrine sand and silt; mapped along the southwest side of the east Traverse Mountains; where lacustrine deposits are thin or absent, fan surfaces are commonly covered by a lag of angular to subangular boulders.*

Qlgb/₱obm? Lacustrine gravel and sand over Bingham Mine Formation(?) (Upper Pleistocene/Upper Pennsylvanian) − *Discontinuous veneer of Bonneville-level gravel and sand that partly conceals orthoquartzite of the Oquirrh Group; mapped along the southwest side of the east Traverse Mountains.*

Qc/Qmso Colluvial deposits over older mass-movement deposits (Holocene to Upper Pleistocene) − *Interpreted to be older landslide deposits concealed by a thick cover of colluvium, both derived from highly fractured Oquirrh Group orthoquartzite and both of which are believed to consist of angular pebbles to boulders of orthoquartzite in a sandy to silty matrix; main scarp is deeply eroded; forms distinctive surface that blocks lower part of Little Valley; lower reaches of deposit may be underlain by and involve volcanic rocks of the east Traverse Mountains (Tv); colluvial veneer may be in excess of 15 feet (5 m) thick and the entire mass may be 80 to 100 feet (25-30 m) thick.*

unconformity

QUATERNARY-TERTIARY

QTa Old alluvial deposits (Lower Pleistocene to Pliocene) – *Moderately well sorted, sand, silt, and pebble- to boulder gravel deposited by ancestral Dry Creek; locally moderately cemented; clasts consist of grussified granitic boulders and uncommon grussified volcanic clasts, and orthquartzite, limestone, and marble; southernmost deposit contains abundant, large orthoquartzite blocks; forms remnants overlying marble breccia north of Alpine; 0 to about 100 feet (0-30 m) thick.*

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TERTIARY

Taf Alluvial-fan deposits (Miocene[?] to Oligocene[?]) – *Unconsolidated, pebble- to boulder-size, subangular to subrounded orthoquartzite and calcareous sandstone clasts and, especially near the base and top of the deposits, minor volcanic clasts; limestone clasts are rare and appear to be restricted to the upper part of the deposits; clasts of monzogranite or granodiorite of the Little Cottonwood stock are conspicuously absent, probably because the intrusion had not yet been unroofed when these sediments were being deposited; includes 300-foot-long (100 m) block of brecciated orthquartzite near the center of section 11, T. 4 S., R. 1 E. that I interpret to be a slide block derived from former nearby mountain front; a single good exposure of the lower part of the deposits in Hog Hollow that dips 20º east reveals subangular to subrounded, pebble- to cobble-size clasts with fewer boulders, medium to thick beds, and clasts that are about 60% sandstone and orthoquartzite and about 40% grussified volcanic clasts of the east Traverse Mountains; appears to lack tuffaceous sediments and so is likely older than the Salt Lake Formation; may correlate with the Tibble Formation (late Eocene to Oligocene), and if so the deposits in the east Traverse Mountains probably have undergone about 4 miles (7 km) of southwestward tectonic transport along the Deer Creek detachment fault (see Constenius and others, 2003), with orthoquartzite clasts derived principally from footwall exposures of the Weber Sandstone; first mapped as undifferentiated Oquirrh Group by Bullock (1958) and later reinterpreted as Neogene-age alluvial-fan deposits by Machette (1992); mapped south of the Fort Canyon fault at the east end of the Traverse Mountains where it unconformably overlies volcanic rocks of the east Traverse Mountains (Tv); age poorly constrained between middle Oligocene(?) and Miocene(?); lineaments visible on aerial photographs suggest that these deposits may be cut by additional, unmapped normal or oblique-slip faults that are difficult to identify due to poor exposures and lack of marker beds; similarly, aerial photo interpretation indicates that additional landslide deposits may be present on this unit, but subdued features and poor exposures make positive identification impossible without detailed geotechnical investigations; thickness uncertain but likely in excess of 1000 feet (330 m).*

unconformity

Tipd Pebble dikes (Oligocene) – *Gray to brown silicified breccia that forms small dikes or plug-like masses intruded into volcanic rocks of the east Traverse Mountains (Tv) southwest of Corner Canyon; consists principally of angular pebbles of Oquirrh Group orthoquartzite and volcanic rocks of the east Traverse Mountains (Tv) and less common, rounded orthoquartzite, black chert, and granitic pebbles; clast composition varies widely between exposures; Marsell (1932) reported that the matrix consists of finely comminuted quartzite and granite cemented by cryptocrystalline quartz and opal; includes thin veinlets of chalcedony; probably about 30 million years old, emplaced by pressurized fluids from intrusion of Little Cottonwood stock that picked up and milled and pulverized rock through which it passed; width and length uncertain due to poor exposures, but likely varies from a few inches to several feet wide by up to 200 feet (60 m) long.*

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Ti Monzogranite and granodiorite of Little Cottonwood stock (Oligocene) – *Medium to coarse-grained, porphyritic biotite monzogranite and biotite-hornblende granodiorite (Hanson, 1995; Marsh and Smith, 1997; Vogel and others, 2001); potassium feldspar crystals up to 1.5 inches (4 cm) are common; accessory minerals include magnetite, sphene, zircon, apatite, and allanite (Lawton, 1980); includes minor aplite dikes; fractures commonly coated with thin slickensided surfaces of epidote; grades upward into increasingly altered rock of the transition zone; Parry and Bruhn (1986) and John (1989) reported an emplacement depth of about 7 miles (11 km) for the western part of the stock; John and others (1997) discussed the age of the Little Cottonwood stock and reported numerous K-Ar and $^{40}Ar/^{39}Ar$ ages that suggest an emplacement age of about 31 to 30 million years ago; Vogel and others (1997) reported a U-Pb age on zircon of 30.5 ± 0.5 Ma; forms the largest and westernmost intrusion of the Wasatch igneous belt.*

Altered monzogranite and granodiorite of Little Cottonwood stock (Miocene[?] alteration of Oligocene rocks) – *Hydrothermally altered and mechanically deformed monzogranite and granodiorite of the Little Cottonwood stock (see map unit Ti); grades from greenish, highly altered rocks near the Wasatch and Fort Canyon faults to brownish, less altered rocks toward the interior of the pluton; fracture surfaces, even in less altered rocks, are commonly coated with epidote; forms partly preserved footwall carapace up to about 650 feet (200 m) thick that grades downward into little altered or unaltered monzogranite and granodiorite; age of alteration uncertain, but Parry and Bruhn (1986) reported a K-Ar age of 17.6 ± 0.7 Ma on hydrothermal sericite and estimated depths of formation between 4.5 and 7.1 miles (7.2-11.4 km); units and contacts adapted from Evans and others (1997):*

Tia1 Fault slip zone – *Consists of cataclasite and phyllonite that each contain two syndeformational mineral assemblages, including an early, higher temperature epidote-chlorite-sericite-magnetite assemblage and a later, lower temperature laumontite-prehnite-hematite and clay mineral assemblage locally found in cross-cutting veins (Parry and Bruhn, 1986); includes pseudotachylyte veins; preserved thickness generally less than 30 feet (10 m).*

Tia2 Transition zone – *Hydrothermally altered and fractured monzogranite and granodiorite of Little Cottonwood stock; grades upward into heterogeneous and increasingly deformed and altered rock of fault slip zone, and downward into unaltered Little Cottonwood stock; weathers to grussified soils; about 65 to 650 feet (20-200 m) thick.*

unconformity

Tv Volcanic rocks of the east Traverse Mountains, undivided (Oligocene-Eocene) − *Complexly interbedded block and ash-flow tuffs, volcanic mudflow breccia, minor lava flows, and minor fluvial volcaniclastic deposits in the east Traverse Mountains that are impractical to map separately due to poor exposures and extensive alteration; classified as borderline latite, trachyte, dacite, and andesite on the TAS diagram of LeBas and others (1986) (see table 1 for analytical data); block and ash-flow tuffs likely comprise the bulk of these deposits and are typically gray, brownish-gray, or pinkish-gray, massive, coarse-grained, crystal lithic tuff with sparse to abundant volcanic clasts up to 6 feet (2 m) or more in diameter; matrix contains abundant sand- to pebble-size volcanic fragments, feldspar, and typically uncommon euhedral biotite and hornblende; a trench in the NE1/4NW1/4 section 15, T. 4 S., R. 1 E. (sample L12103-4) exposed a weathered tuff bed at least 25 feet (8 m) thick that lacks volcanic clasts; volcanic rocks of the east Traverse Mountains show some similarity with Keetley Volcanics and some of the eastern group of stocks of the Wasatch igneous belt based on minor and trace element variation diagrams; Crittenden and others (1973) reported a K-Ar age of 37.3 ± 1.1 Ma for volcanic rocks near Corner Canyon, and sample L33103-9 from Maple Hollow yielded an $^{40}Ar/^{39}Ar$ age of 35.25 ± 0.13 on biotite, which is consistent with the older rocks of the Wasatch igneous belt; volcanic rocks of the east Traverse Mountains thus appear to be older than those of the west Traverse Mountains (east of Rose Canyon), which belong to the younger volcanic suite (about 33 to 31 million years old) of Waite (1996; see also Waite and others, 1997; Biek and others, 2004; Biek, 2005); undifferentiated volcanic rocks of the east Traverse Mountains are probably about 1000 feet (300 m) thick.*

The volcanic rocks are locally extensively hydrothermally altered in the east Traverse Mountains, including fracture-controlled silicified zones up to 400 feet (120 m) wide that grade outward to kaolinitized and oxidized volcanic rock; much of the rock is so weathered that blasting is seldom required for large excavations; alteration and weathering of these volcanic rocks resulted in widespread landslides, and additional, unmapped landslides may be present on this map unit; silicified zones are marked by complete replacement of volcanic rock by opal and cryptocrystalline and microcrystalline quartz that forms red, pink, yellow, and white jasper and opalite with local preservation of relict porphyritic texture (Marsell, 1932); silicified masses are locally vuggy with drusy quartz crystals and cross-cutting chalcedony veins; two large areas of opalite are mapped separately, but opalite is also common in the east-central part of section 16, T. 4 S., R. 1 E.

unconformity

PENNSYLVANIAN and MISSISSIPPIAN

Oquirrh Group

₱obm(?) Bingham Mine Formation(?) (Upper Pennsylvanian) − *Light-brown, fine-grained orthoquartzite and calcareous sandstone; typically highly fractured, intensely brecciated, or locally pulverized; very poorly exposed and overall structure uncertain; best exposed along or just below ridge crests, but elsewhere slopes are commonly covered by a veneer of colluvium and talus not practical to map at a scale of 1:24,000; correlation uncertain, but probably part of the middle and upper 7300-foot-thick (2200 m) Bingham Mine Formation (Upper Pennsylvanian [Gordon and Duncan, 1970]), part of the Bingham sequence of Tooker and Roberts (1970), and may include Permian strata of the Curry Peak and Freeman Formations; may be the Weber Quartzite (Lower Permian to Middle Pennsylvanian), which may exceed 2000 feet (600 m) in thickness in American Fork Canyon (Baker, 1964; Bryant, 1992); total exposed thickness in the Lehi quadrangle is unknown, but likely exceeds 1000 feet (300 m); the Oquirrh Group is in excess of 17,800 feet (5400 m) thick in the Oquirrh Mountains (Tooker and Roberts, 1970) and about 25,000 feet (7600 m) thick near Mt. Timpanogos (Baker, 1964).*

₱obp Butterfield Peaks Formation (Middle Pennsylvanian [Desmoinesian – Atokan]) − *Not exposed in quadrangle; Tooker and Roberts (1970) reported the formation is 9070 feet (2765 m) thick in the Oquirrh Mountains.*

₱Mowc West Canyon Limestone (Lower Pennsylvanian [Morrowan] to Upper Mississippian) − *Not exposed in quadrangle; age from Davis and others (1994), who reported a thickness of 1007 feet (307 m) in the southern Oquirrh Mountains.*

MISSISSIPPIAN

Mmc Manning Canyon Shale (Upper Mississippian) − *Not exposed in quadrangle; about 1650 feet (500 m) thick in the Wasatch Range (Baker, 1972; Bryant, 1992).*

Mdo Doughnut Formation (Upper Mississippian) − *Mostly white to light-gray, medium- to coarse-grained marble, marble breccia, and lesser white, fine-grained quartzite; appears to grade northward such that northernmost 1500 feet (500 m) of outcrop, exposed at hill 5889 near Alpine, is medium-gray brecciated limestone and marble overlain by similarly brecciated calcareous sandstone and orthoquartzite; highly fractured; likely equivalent to metamorphosed Doughnut Formation exposed in the Silver Lake area on the footwall of the Deer Creek detachment fault, about 5 miles (8 km) to the northeast in the Dromedary Peak quadrangle, but fractured clastic strata of northern exposures could be a fault block of the Oquirrh Formation, or possibly a very well lithified colluvial or talus facies of the Tibble Formation; likely displaced about 4 miles (7 km) or more laterally and vertically along the Deer Creek detachment fault (Constenius and others, 2003); marble strata represent metamorphosed shallow-water (shelf) facies likely equivalent to upper part of Great Blue Limestone and lower part of Manning Canyon Shale; incomplete section present in Lehi quadrangle, but formation is 300 to 1200 feet (90-365 m) thick (Baker and Crittenden, 1961).*

Mgb Great Blue Limestone, undivided (Upper Mississippian) − *Medium- to very thick bedded, light- to dark-gray but typically bluish-gray limestone; locally cherty and fossiliferous with brachiopods, corals, and bryozoans; commonly laminated and platy weathering; "curly" limestone exposed on north side of American Fork Canyon; upper contact not exposed, but regionally marks a prominent change from cliff-forming limestone to slope-forming shale; incompletely exposed south of American Fork Canyon; age from Gordon and others (2000); thickness uncertain, but regionally the formation is about 2500 feet (750 m) thick (Gordon and others, 2000).*

Mh Humbug Formation (Upper Mississippian) − *Interbedded calcareous quartz sandstone, orthoquartzite, limestone, and dolomite; gray to pale-purple shale may mark the top of the formation at American Fork Canyon; upper contact is conformable and gradational and regionally represents a change from predominantly sandstone of the Humbug to limestone of the Great Blue; incomplete section mapped near the mouth of American Fork Canyon and also exposed north of Box Elder Canyon; age from Morris and Lovering (1961); about 800 feet (245 m) thick (Baker and Crittenden, 1961) in the Wasatch Range.*

Md Deseret Limestone (Upper Mississippian) − *Thick- to very thick bedded, light- to medium-gray dolomite with irregularly shaped black chert nodules; lower part has thin- to medium-bedded, platy weathering limestone with sparse crinoid stems and rugose corals; upper contact is conformable and gradational and corresponds to the base of the first thick sandstone bed; age from Morris and Lovering (1961); 420 feet (128 m) thick (Baker and Crittenden, 1961) in the Wasatch Range.*

Mg Gardison Limestone (Lower Mississippian) − *Mostly dark-gray, thick- to very thick bedded limestone and dolomite; upper contact not exposed in the Lehi quadrangle, but regionally appears conformable and gradational; also exposed in the Timpanogos Cave quadrangle; about 600 feet (185 m) thick (Baker and Crittenden, 1961).*

MISSISSIPPIAN and DEVONIAN

MDf Fitchville Formation (Lower Mississippian – *Upper Devonian*) − *Upper part: massive, dark-gray dolomite, thin white beds at top; lower part: medium-bedded, pale-gray vuggy dolomite; 100 to 175 feet (30-53 m) thick (Baker and Crittenden, 1961).*

unconformity

CAMBRIAN

Ꞓm Maxfield Limestone (Middle Cambrian) – *Thin- to thick-bedded, gray mottled, dolomitic limestone and dolomite; oolitic or pisolitic near the base; about 200 feet (60 m) thick (Baker and Crittenden, 1961).*

Ꞓo Ophir Formation (Middle – Lower? Cambrian) – *Upper unit: blocky, brown calcareous sandstone; middle unit: massive, wavy-bedded gray limestone; lower unit: olive-green shale; 510 feet (155 m) thick (Baker and Crittenden, 1961).*

Ꞓt Tintic Quartzite (Lower Cambrian) – *Medium- to coarse-grained, white to pale-pink quartzite; includes pale-purple pebbly quartz conglomerate near the base; about 1300 feet (400 m) thick (Baker and Crittenden, 1961).*

unconformity

PRECAMBRIAN

Zm Mutual Formation – *Rusty to red-purple quartzite, gritstone, and conglomerate with minor red-purple or greenish shale; 100 to 1300 feet (30-400 m) thick (Baker and Crittenden, 1961).*

unconformity

Zmf Mineral Fork Tillite – *Black conglomeratic quartzite or sandstone, with some thin layers of rhythmically bedded siltstone; 250 to 1000 feet or more (75-400+ m) thick; (Baker and Crittenden, 1961).*

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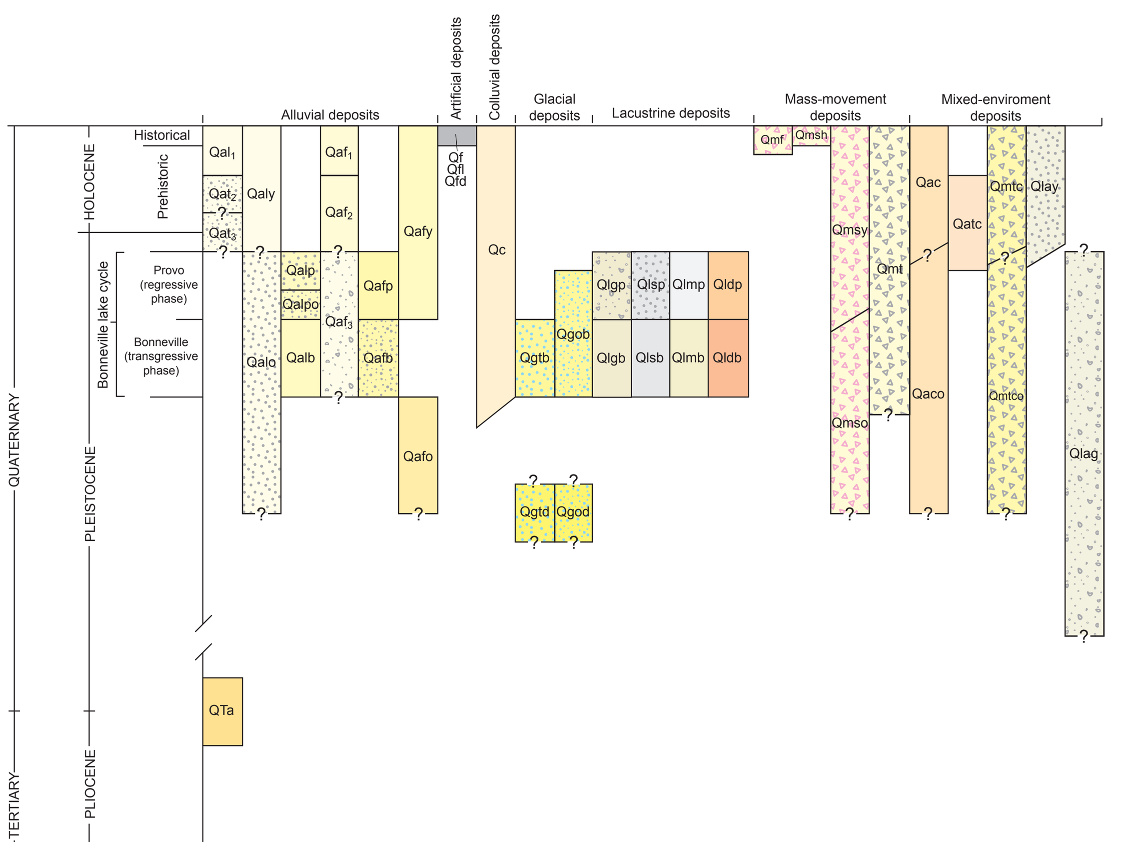
ACKNOWLEDGMENTS

A great many individuals have expressed interest in, and opinions about, the geology of the Lehi quadrangle, and to all of you I am grateful. Special thanks to Adolph Yonkee (Weber State University), Craig Forster (University of Utah), and Kurt Constenius (Independent) for technical reviews of this map and plate 2 materials and for discussions in the field and office. Adolph also shared his mapping and knowledge of the Fort Canyon fault rocks; Craig made me think carefully about inferred range-bounding faults; and Kurt helped to clarify my understanding of the Tertiary history of the region. Bedrock geology and unit descriptions in the Timpanogos Cave quadrangle are taken largely from Baker and Crittenden (1961), whereas the Quaternary geology in that same quadrangle was modified from Machette (1992) and includes my own mapping. Kent Brown (Utah Geological Survey [UGS]) set up photogrammetry for this project and cleaned my digital files. Tim Thompson (Intermountain GeoEnvironmental Service) graciously allowed access to trenches excavated in landslide deposits at Little Valley and near Potato Hill. A special thanks to SunCrest Development Corp. for allowing access to their property, and to Jim McCalpin (Geo-Haz Consulting, Inc.) and Dave Simon (Simon-Bymaster, Inc.) for discussions in the trenches. Thanks, too, to Francis Ashland, Mike Hylland, and Chris DuRoss (UGS) for sharing their knowledge about landslides and faults in the east Traverse Mountains. Greg McDonald and Rich Giraud (UGS) shared data they collected on debris-flow deposits in the Preston Canyon area east of Alpine. Max Pitcher graciously facilitated access to the Fort Canyon area. Thanks to UGS colleagues Mike Hylland, Doug Sprinkel, and Grant Willis for their careful review of the map and accompanying materials; Tom Chidsey, Sandy Eldredge, Mike Lowe, and Barry Solomon (UGS) also reviewed parts of this report. Finally, I thank the numerous city officials working in this area for their interest in this mapping project.

MAP SYMBOLS

- Contact, dashed where approximately located, queried where uncertain
- Normal fault, dashed where approximately located, dotted where concealed and approximately located; query indicates uncertain presence; bar and ball on down-dropped side where known; minus sign on cross section indicates movement away from viewer, plus sign indicates movement towards viewer
- Normal fault inferred principally from gravity data; very approximately located; bar and ball on down-dropped side
- Thrust fault, dashed where approximately located, dotted where concealed and approximately located; teeth on upper plate
- Axial trace of syncline
- Lake Bonneville shorelines - Major shorelines of the Bonneville lake cycle. Mapped at the top of the wave-cut platform, dashed where approximately located
  - B — Highest shoreline of the Bonneville (transgressive) phase
  - b — Other shorelines of the Bonneville phase – mostly transgressive
  - P — Highest shoreline of the Provo (regressive) phase
  - p — Other shorelines of the Provo phase – mostly regressive shorelines of the Provo phase, but may include some shorelines of the Bonneville (transgressive) phase
- 4800● Elevation (in feet) of selected Lake Bonneville shoreline feature; elevation determined photogrammetrically
- Crest of Lake Bonneville offshore bar or spit
- Crest of lateral glacial moraine
- Landslide scarp, hachures on down-dropped side
- Erosional scarp within terraces along American Fork River
- 35 Strike and dip of inclined bedding (red symbols in the east Traverse Mountains indicate attitudes from J.E. Welsh, unpublished map, 1965 and in the Wasatch Range red symbols indicate attitudes from Baker and Crittenden, 1961)
- 30 Approximate strike and dip of inclined bedding
- Approximate strike and dip direction of inclined bedding
- Strike of vertical bedding
- 30 Strike and dip of overturned bedding (red symbol near Dry Creek indicates attitude from Baker and Crittenden, 1961)
- Horizontal bedding (from J.E. Welsh, unpublished map, 1965)
- Sand and gravel pit
- Quarry (crushed rock)
- X Prospect
- Adit
- Spring
- L32103-2 Sample location and number (see table 1 for analytical data)
- Area of colluvium (unmapped over shallow bedrock) locally exhibiting evidence of soil creep, northwest slope of Steep Mountain

CORRELATION OF QUATERNARY UNITS



CORRELATION OF BEDROCK UNITS

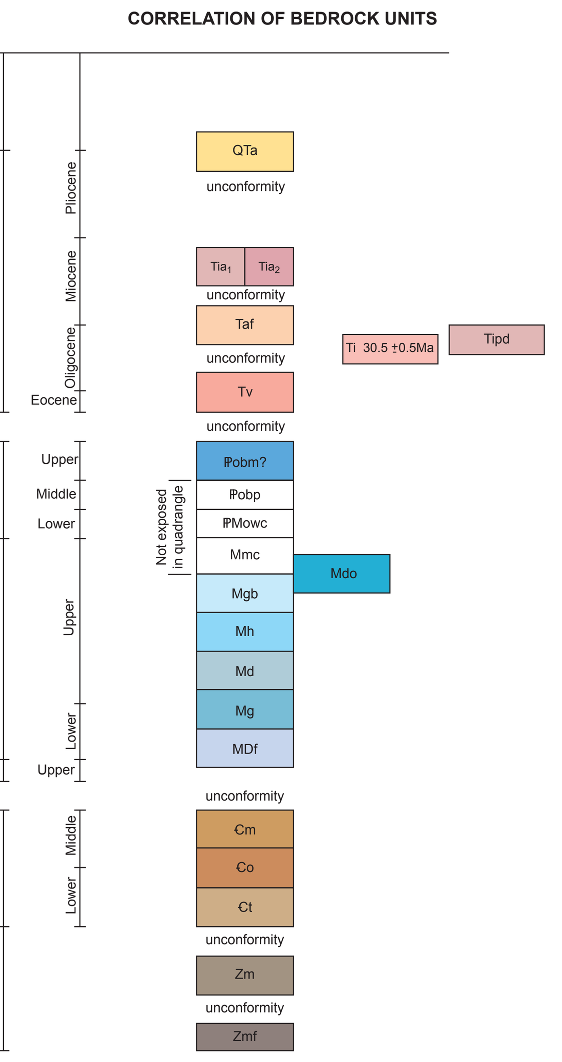
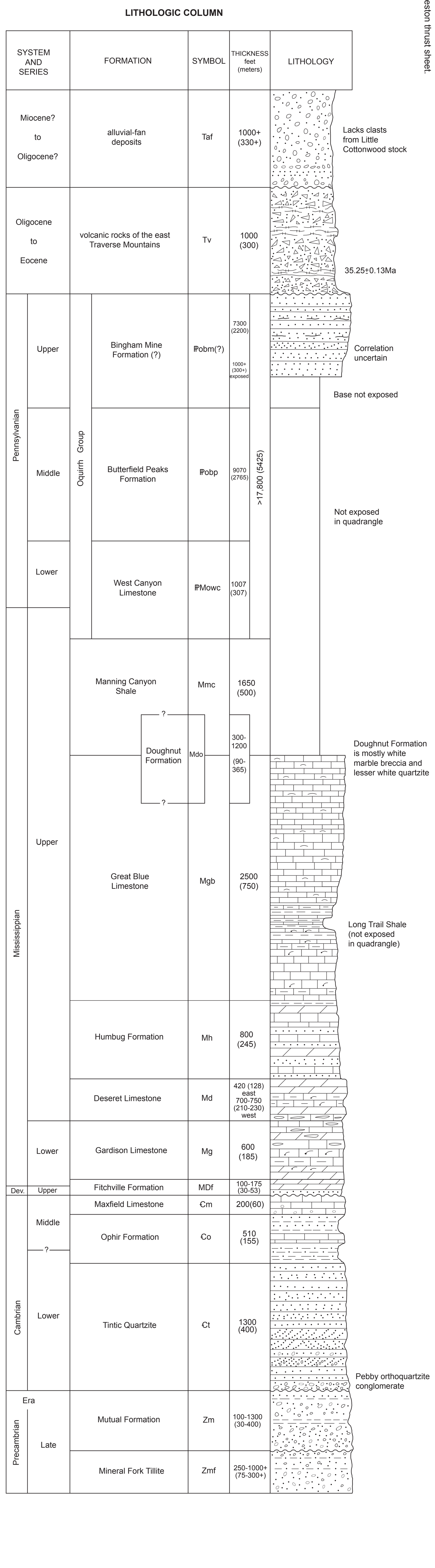
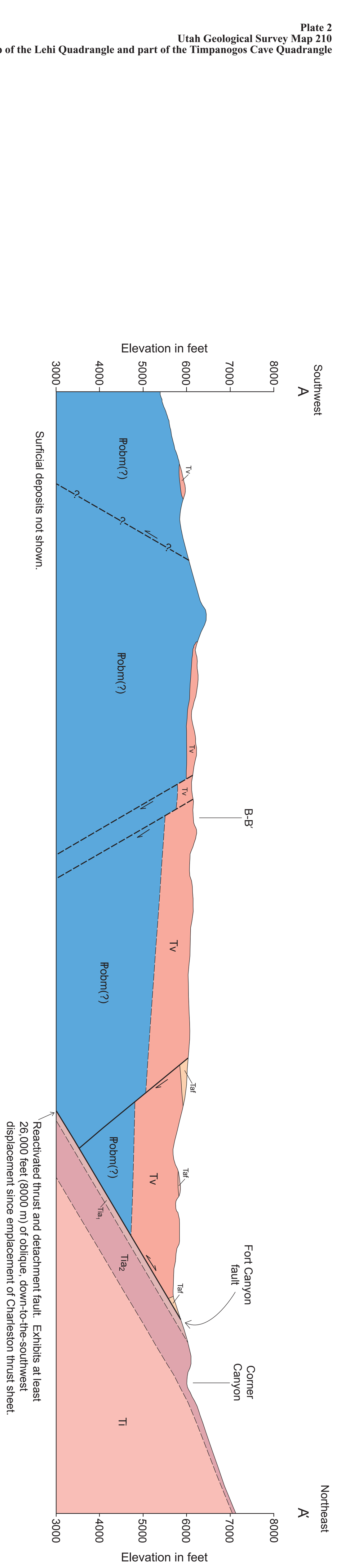
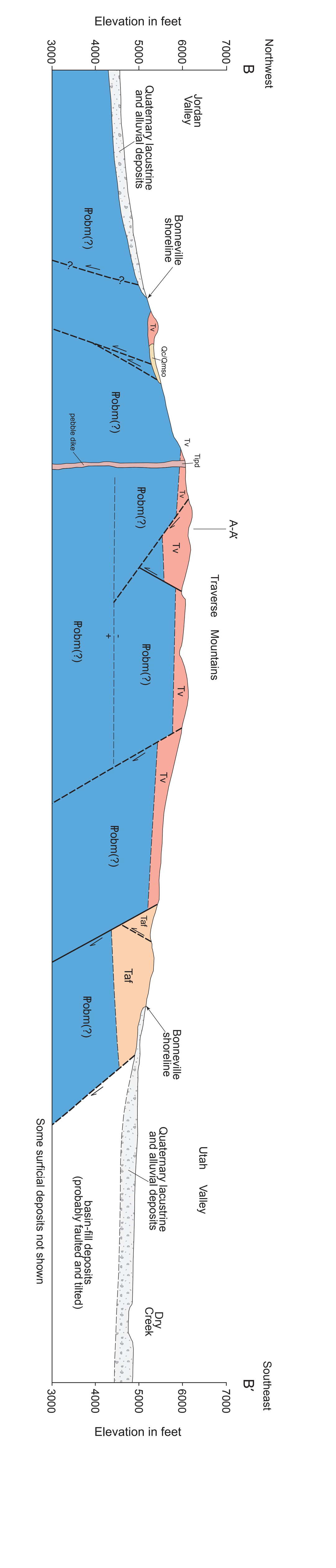


Table 1. Major and trace element whole-rock analyses

SAMPLE	Unit	Rock Type	Rock Name	Latitude	Longitude	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	Cr_2O_3	TiO_2	MnO	P_2O_5	SrO	BaO	LOI	Total
L12104-1	Tv	tuff	dacite	40° 28' 31.5"	111° 49' 28.0"	57.44	17.63	5.60	4.07	3.10	2.15	0.86	0.01	0.72	0.06	0.24	0.08	0.09	7.82	99.87
L12104-3	Tv	tuff	dacite	40° 28' 24.5"	111° 49' 19.0"	60.00	17.74	4.96	4.27	1.89	2.70	2.24	<0.01	0.72	0.06	0.28	0.09	0.16	4.77	99.88
L12104-4	Tv	tuff	dacite	40° 28' 39.0"	111° 49' 21.0"	59.22	17.65	4.94	4.41	2.61	2.65	0.99	<0.01	0.67	0.04	0.27	0.09	0.10	6.08	99.73
L31403-6	Tv	tuff?	trachyte	40° 28' 05.5"	111° 51' 32.6"	61.22	16.71	5.86	3.65	1.14	3.67	3.46	<0.01	0.77	0.08	0.35	0.10	0.19	2.22	99.41
L31403-7	Tv	tuff?	trachyte	40° 28' 17.4"	111° 51' 02.1"	59.87	16.72	6.24	3.74	0.86	3.88	3.39	<0.01	0.85	0.07	0.42	0.12	0.20	3.47	99.83
L32103-1	Tv	flow?	latite	40° 28' 20.6"	111° 52' 06.7"	60.01	16.53	6.23	4.60	1.56	3.83	3.37	<0.01	0.82	0.05	0.39	0.10	0.17	1.93	99.61
L32103-2	Tv	flow?	latite	40° 28' 05.6"	111° 52' 03.9"	59.74	15.97	6.10	4.35	2.10	3.60	3.19	<0.01	0.85	0.04	0.39	0.11	0.17	3.25	99.86
L33103-2	Tv	tuff	dacite	40° 29' 22.9"	111° 50' 29.1"	59.14	15.04	5.20	4.15	2.80	2.70	2.78	<0.01	0.69	0.06	0.34	0.10	0.20	6.55	99.76
L33103-8	Tv	flow?	latite	40° 28' 04.2"	111° 50' 23.5"	57.47	16.81	6.82	4.41	2.38	3.34	3.02	0.01	0.78	0.07	0.30	0.12	0.40	3.67	99.60
L33103-9	Tv	flow?	latite	40° 27' 59.4"	111° 50' 28.5"	58.11	16.32	6.48	5.23	3.18	3.31	3.20	0.01	0.77	0.10	0.43	0.10	0.21	1.66	99.11
L61703-2	Tv	tuff?	latite	40° 28' 48.5"	111° 45' 58.5"	60.00	16.44	6.73	5.03	2.34	3.18	3.33	<0.01	0.75	0.07	0.42	0.09	0.20	1.31	99.90
L6403-1	Tv	tuff	dacite	40° 26' 39.3"	111° 51' 50.2"	61.07	15.80	4.98	1.95	0.85	0.91	2.56	<0.01	0.81	0.02	0.10	0.04	0.07	10.30	99.46
L91902-6	Tv	flow?	dacite	40° 29' 31.0"	111° 49' 30.0"	60.40	15.53	6.07	3.82	2.44	3.15	3.41	0.01	0.79	0.06	0.35	0.09	0.17	3.35	99.62
L92002-1	Tv	tuff?	dacite	40° 29' 20.0"	111° 49' 22.0"	61.12	17.74	4.76	3.24	0.48	3.16	2.98	0.01	0.83	0.02	0.35	0.11	0.18	4.76	99.74
L92002-2	Tia2	altered stock	dacite	40° 29' 41.5"	111° 48' 58.5"	59.17	15.09	5.77	3.03	3.06	2.79	3.39	0.01	0.77	0.06	0.33	0.08	0.16	5.81	99.53

SAMPLE	Ag	Ba	Ce	Co	Cr	Cs	Cu	Dy	Er	Eu	Ga	Gd	Hf	Ho	La	Lu	Mo	Nb
L12104-1	<1	806	126	12.3	80	11.2	32	2.9	1.6	1.7	25	6.5	7	0.5	70.0	0.2	<2	15
L12104-3	<1	1380	127.5	13.2	60	2.8	22	3.3	1.8	1.7	26	7.0	7	0.6	70.0	0.2	2	14
L12104-4	<1	879	140	11.5	110	6.5	28	2.9	1.4	1.7	25	6.7	6	0.5	72.4	0.2	<2	15
L31403-6	<1	1785	137	18.2	80	3.0	46	4.2	2.3	2.1	22	7.7	6	0.7	76.9	0.3	6	13
L31403-7	<1	1765	131	18.7	120	2.9	50	4.4	2.4	2.1	23	7.9	7	0.8	77.3	0.3	6	13
L32103-1	<1	1600	127.5	17.1	90	1.9	44	3.9	2.1	2.1	23	7.1	6	0.7	70.4	0.2	5	13
L32103-2	<1	1575	125.5	19.1	110	2.5	49	3.9	2.0	2.1	22	7.6	7	0.7	70.6	0.3	5	13
L33103-2	<1	1755	113.5	14.9	90	2.4	38	3.6	1.9	1.7	20	5.9	7	0.6	62.0	0.3	8	12
L33103-8	<1	3520	119	16.6	110	2.2	39	4.3	2.2	2.1	23	6.8	7	0.8	66.7	0.3	8	12
L33103-9	<1	1910	127.5	17.5	100	2.1	37	4.3	2.3	2.0	22	6.9	7	0.8	67.2	0.4	8	12
L61703-2	<1	1865	137.5	18.2	30	2.2	32	4.2	2.4	2.2	22	8.2	7	0.8	79.7	0.3	2	12
L6403-1	<1	642	84.1	10.3	40	21.3	11	4.6	2.5	1.5	22	6.3	6	0.9	47.4	0.4	2	19
L91902-6	<1	1750	132	19.1	60	2.3	35	3.6	2.1	1.9	23	6.7	7	0.7	71.5	0.3	3	13
L92002-1	<1	1905	152	15.2	60	1.0	52	14.7	9.2	4.2	24	17.3	8	3.3	82.6	1.3	2	13
L92002-2	<1	1660	120	18.5	50	2.4	34	3.8	2.2	1.9	21	6.9	7	0.8	67.9	0.3	2	12

SAMPLE	Nd	Ni	Pb	Pr	Rb	Sm	Sn	Sr	Ta	Tb	Th	Tl	Tm	U	V	W	Y	Yb	Zn	Zr
L12104-1	51.7	25	30	14.8	75.2	6.6	2	796	0.9	0.6	14	<0.5	0.2	1.2	90	1	17.6	1.2	187	232
L12104-3	53.2	18	25	15.0	69.9	7.0	2	902	0.9	0.7	14	0.6	0.2	2.6	110	3	19.8	1.4	142	241
L12104-4	52.9	14	30	15.4	60.8	6.9	2	913	0.9	0.7	13	<0.5	0.2	1.2	86	1	16.0	1.1	122	215
L31403-6	56.6	29	23	16.0	116.0	8.9	3	886	0.9	0.9	19	<1	<0.5	4.9	135	2	21.5	2.0	77	216
L31403-7	59.6	33	23	16.5	110.0	9.3	3	983	0.8	1.0	16	<1	<0.5	3.7	128	2	21.8	1.9	121	226
L32103-1	53.8	28	20	15.0	103.5	8.9	2	980	0.8	0.9	17	<1	<0.5	3.5	92	1	20.0	1.6	73	220
L32103-2	56.3	31	19	15.5	106.0	8.8	3	977	0.8	0.9	16	<1	<0.5	3.8	145	1	19.2	1.6	85	222
L33103-2	44.1	28	21	12.8	105.0	6.9	2	847	0.8	0.7	17	<1	<0.5	4.7	116	1	19.0	1.8	80	235
L33103-8	51.7	18	21	14.1	95.3	8.5	2	1110	0.7	0.8	13	<1	<0.5	3.1	140	1	20.7	2.0	79	249
L33103-9	53.5	19	22	14.5	88.4	8.2	2	1015	0.7	0.9	13	<1	<0.5	3.0	134	1	21.5	2.0	84	234
L61703-2	57.0	12	22	16.6	100.5	8.7	2	986	0.8	1.0	17	0.6	0.3	4.0	171	3	22.4	2.0	84	247
L6403-1	37.2	13	34	10.2	194	6.8	2	251	1.2	0.9	13	1	<0.5	3.0	73	3	25.4	2.1	100	225
L91902-6	48.6	25	25	14.2	110.0	7.5	2	823	0.8	0.8	17	<1	<0.5	3.6	165	2	19.4	1.9	89	252
L92002-1	73.6	21	21	18.6	65.5	15.5	1	977	0.9	2.6	17	<1	1.3	6.6	139	2	109.5	7.8	46	260
L92002-2	47.9	24	23	13.5	107.5	7.6	2	724	0.8	0.8	16	<1	<0.5	3.5	149	1	20.5	2.0	82	239

NOTE: Major oxides reported in weight percent by X-Ray Fluorescence; minor and trace elements reported in ppm by Inductively Coupled Plasma-Mass Spectrometry.
All analyses performed by ALS Chemex, Inc., Sparks, NV.
Latitude and longitude based on NAD83.

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