

INTERIM GEOLOGIC MAP OF THE EAST PART OF THE TOOEELE 30' X 60' QUADRANGLE, TOOELE, SALT LAKE, AND DAVIS COUNTIES, UTAH, YEAR 1 OF 3

by

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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 G13AC00169. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.



OPEN-FILE REPORT 633
UTAH GEOLOGICAL SURVEY

a division of

Utah Department of Natural Resources

2014

INTRODUCTION

The Tooele 30' x 60' quadrangle is located west of Salt Lake City, in Tooele, Salt Lake, and Davis Counties, northwest Utah. The map area is located in the eastern Basin and Range Province, and includes several mainly north-south-trending mountain ranges and intervening valleys and the southern part of Great Salt Lake (plate 1, figure 1).

This geologic map updates the prior regional-scale geologic maps by Stokes (1963) and Moore and Sorensen (1979) at 1:250,000 scale. The primary sources of mapping are indicated in the map explanation. This map shows the progress in the first year of a three-year project to map the geology of the Tooele 30' x 60' quadrangle at intermediate scale (1:62,500). Additional updates to this part of the map could occur in subsequent years of the project.

GEOLOGIC UNIT DESCRIPTIONS

QUATERNARY-TERTIARY SURFICIAL DEPOSITS

Alluvial deposits

- Qal **Alluvium** (Holocene) – Primarily clay, silt, and sand with some gravel lenses deposited by streams in channels and broad drainages; sediment reflects local sources; locally includes alluvial-fan, colluvial, low-level terrace, lacustrine, and eolian deposits; thickness generally less than about 20 feet (6 m).
- Qam **Alluvial mud** (Holocene) – Mud (clay and silt) and sandy mud accumulated in low relief areas adjacent to Great Salt Lake in Tooele Valley; thickness probably less than 20 feet (6 m).
- Qai **Alluvial silt** (Holocene to upper Pleistocene?) – Silt, clay, some sand, and minor gravel deposited by streams and sheet wash within former lagoonal areas related to Great Salt Lake and Lake Bonneville shorelines; bottom of lagoonal basins may include some unexposed, thin, fine-grained lacustrine deposits; thickness less than about 20 feet (6 m).
- Qat **Terrace alluvium** (Holocene to upper Pleistocene) – Sand, silt, clay, and gravel in larger alluvial terraces of varying levels above floodplains; surfaces typically 10 feet (3 m) or more above adjacent drainages; thickness is 40 feet (12 m) or less.
- Qag **Alluvial gravel** (upper to middle? Pleistocene) – Poorly to moderately well-sorted sand, silt, clay, and pebble to boulder gravel that forms a thin veneer on gently sloping erosional surfaces; less than 100 feet (30 m) above modern drainages; overlies map units Qafo, Tslf, Tslg along the western margin of Salt Lake Valley; previously mapped as pediment-mantle alluvium (Biek and others, 2007; Solomon and others, 2007); thickness as much as 15 feet (5 m).

QTag Older alluvial gravel (middle? Pleistocene to Pliocene?) – Poorly to moderately well-sorted sand, silt, clay, and pebble to boulder gravel that forms a thin veneer on gently sloping erosional surfaces; as much as 300 feet (90 m) above modern drainages; overlies map units Tslf and Tslg along the western margin of Salt Lake Valley; previously mapped as pediment-mantle alluvium (Biek and others, 2007; Solomon and others, 2007); thickness as much as 15 feet (5 m).

Qafy Younger fan alluvium, post-Bonneville (Holocene) – Poorly sorted gravel with sand, silt, and clay; deposited by streams, debris flows, and flash floods on alluvial fans and in mountain valleys; includes alluvium and colluvium in canyon and mountain valleys; may include small areas of eolian deposits and lacustrine fine-grained deposits below the Bonneville shoreline; includes active and inactive fans younger than Lake Bonneville, but may also include some older deposits above the Bonneville shoreline; locally, unit Qafy spreads out on wave-cut lake terraces and, due to limitations of map scale, is shown to abut Lake Bonneville shorelines; Qafy also drapes over, but does not completely conceal shorelines; thickness variable, to 50 feet (15 m) or more.

Qafo Older fan alluvium, syn- and pre-Bonneville (upper to middle? Pleistocene) – Poorly sorted gravel with sand, silt, and clay; forms higher level deposits that are coeval with and predate Lake Bonneville and that are incised by younger alluvial deposits; may locally include small areas of lacustrine or eolian deposits; thickness variable, to 100 feet (30 m) or more.

QTaf Oldest fan alluvium (lower Pleistocene? to Pliocene?) – Poorly sorted gravel with sand, silt, and clay; unconsolidated to semiconsolidated with calcic soil development on upper surfaces; forms high-level deposits incised by younger alluvial deposits and locally etched by Lake Bonneville; may locally include small areas of lacustrine or younger alluvial deposits; mapped along western margin of Oquirrh Mountains; thickness variable, to 100 feet (30 m) or more.

Spring deposits

Qsm Spring and marsh deposits (Holocene) – Clay, silt, and sand that is variably organic-rich, calcareous, or saline; present in ephemeral or perennial saturated (marshy) areas near springs and seeps; form extensive areas mapped near Great Salt Lake; thickness 0 to 30 feet (0-10 m).

Eolian deposits

Qes Eolian silica sand (Holocene) – Windblown sand and silt deposited as dunes and sheets; generally thin with no distinct bedding; mostly silty, well-sorted, fine-grained quartz sand; less than 15 feet (5 m) thick.

Qeo Eolian oolitic sand (Holocene) – One deposit of windblown sand composed of oolites formed in Great Salt Lake; forms sparsely vegetated, active dunes above

beach of lacustrine oolitic sand on northern Antelope Island; less than 10 feet (3 m) thick.

- Qei **Eolian silt** (Holocene) – Windblown silt with minor clay and fine sand that is commonly oolitic; occurs as low-relief dunes that cap fine-grained lacustrine and alluvial deposits in lower Tooele Valley; thickness as much as 10 feet (3 m).

Lacustrine deposits (Great Salt Lake)

- Qpm **Playa mud** (Holocene) – Deposits of clay, silt, oolitic, and pelletal sand composing the bed of Great Salt Lake and some higher adjacent areas formed through a mix of lacustrine, alluvial, and eolian processes; locally mud is organic rich and contains carbonate chips; salts accumulate on playa surfaces as these deposits are locally and intermittently exposed depending on lake level; the extent of Great Salt Lake is indicated on the map by the historical average altitude of 4200 feet (1280 m); the historic highstand of Great Salt Lake was 4212 feet (1284 m) and Atwood (2006) reported on shoreline superelevation of 1986-1987; thickness is variable, generally less than 15 feet (5 m).
- Qly **Younger lacustrine deposits** (Holocene to upper Pleistocene?) – Silt, clay, and minor sand from higher levels of Great Salt Lake; form islands near Great Salt Lake wetlands and mudflats northeast of Magna; deposits are gradational upslope with fine-grained regressive Lake Bonneville deposits and downslope with units Qlmy and Qldy; near Magna unit Qly is incised by post-Bonneville alluvium; locally covered with a loess veneer; thickness generally less than 15 feet (5 m).
- Qdy **Younger deltaic deposits** (Holocene) – Silt, sand, and clay present in a lobate, paleo-Jordan River delta complex of the Baileys Lake and Browns Island area, lower Salt Lake Valley; locally includes distributary channel fill and deltaic fan deposits, and a loess veneer; deposits overlie units Qlmy and Qldy; exposed thickness less than 10 feet (3 m).
- Qlos **Younger lacustrine oolitic sand** (Holocene) – Oolitic sand, flat carbonate chips and pebbles, and minor silt and sand that is thin to medium bedded; locally present in barrier bars and islands fringing Great Salt Lake and some beaches of Antelope Island; exposed thickness as much as 6 feet (2 m).
- Qlmy **Younger lacustrine mud** (Holocene to upper Pleistocene?) – Mud composed of silt, clay, and minor sand; locally includes thin salt deposits and some organic materials; forms mudflats in lower Salt Lake Valley from the margin of Great Salt Lake extending upslope where it laterally interfingers with units Qly and Qldy; thickness probably less than 10 feet (3 m).
- Qldy **Younger lacustrine and deltaic deposits** (Holocene to upper Pleistocene?) – Clay, silt, sand, and minor pebble gravel deposited by the ancestral Jordan River delta where it entered Great Salt Lake; locally includes a loess mantle; form a

broad, gently sloping surface with some channel remnants; exposed thickness less than 10 feet (3 m).

Lacustrine deposits (Great Salt Lake and Lake Bonneville)

Qlb Lacustrine boulders (Holocene to upper Pleistocene) – Shore-zone boulders of Lake Bonneville and locally of Great Salt Lake; boulders are in areas where finer-grained sediments have been eroded, leaving large boulders on bedrock knobs and headlands; form boulder fields and strandlines on hillsides of Antelope Island; thickness is probably as much as 10 feet (3 m).

Qlg Lacustrine gravel (Holocene to upper Pleistocene) – Sandy gravel to boulders composed of locally derived rock fragments deposited in shorezones of Great Salt Lake and Lake Bonneville; clasts are typically well rounded and sorted; locally tufa-cemented (especially the Provo shoreline) and draped on bedrock; thickness variable, to 100 feet (30 m) or more.

Lacustrine and deltaic deposits (Lake Bonneville)

Qls Lacustrine sand (upper Pleistocene) – Sand and silt deposited by transgressive and regressive phases of Lake Bonneville; generally thick bedded and well sorted; typically grades downslope to finer-grained lacustrine deposits; thickness to 100 feet (30 m) or more.

Qlf Lacustrine fine-grained deposits (upper Pleistocene) – Sand, silt, marl, and calcareous clay of Lake Bonneville; thinly to very thick bedded; may include ostracode- and gastropod-rich layers; locally includes the white marl of Gilbert (1890); thickness to 100 feet (30 m) or more.

Glacial deposits

Qgt Glacial till (upper Pleistocene) – Poorly sorted gravel, sand, and mud in eroded morainal deposits within one cirque basin north of Nelson Peak, Oquirrh Mountains; locally includes associated glacial outwash, alluvium and colluvium; gravel is typically angular and poorly sorted; till is probably associated with the Pinedale/Angel Lake glaciation, ~12 to 24 ka (Pierce, 2004); Osborn and Bevis (2001) reported on Pinedale/Angel Lake and older glacial deposits farther south in the Oquirrh Mountains (older Bull Lake/Lamoille glaciation, ~ 130 to 190 ka; Pierce, 2004); probably as much as 50 feet (15 m) thick.

Mass-movement deposits

Qmct Colluvium and talus (Holocene to upper Pleistocene) – Local accumulations of mixed colluvium and talus present in the Oquirrh Mountains and Antelope Island; common near Lake Bonneville shorelines; thickness to 15 feet (5 m).

Qms Landslide deposits (Holocene to middle? Pleistocene) – Poorly sorted, clay- to boulder-size material; generally characterized by hummocky topography, main and internal scarps, and chaotic bedding in displaced bedrock; also includes several displaced bedrock blocks probably moved from Lake Bonneville wave

action along the north end of the Oquirrh Mountains (Tooker and Roberts, 1971a; Solomon, 1993); we did not map the massive April 10, 2013 landslide at the Kennecott/Rio Tinto Bingham Canyon mine (see Pankow and others, 2014); unit undivided as to inferred age because research shows that even landslides with subdued morphology (suggesting they are older and have not moved recently) may continue to creep or are capable of renewed movement (Ashland, 2003); age and stability determinations require detailed geotechnical investigations; thickness highly variable.

Mixed-environment deposits

Qla Lacustrine and alluvial deposits, undivided (Holocene to upper Pleistocene) – Unconsolidated deposits of sand, gravel, silt, and clay; consist of lacustrine deposits reworked by streams and slope wash, alluvial deposits reworked by lakes, and alluvial and lacustrine deposits that cannot be readily differentiated at map scale; thickness locally exceeds 30 feet (10 m).

Qac Alluvial and colluvial deposits, undivided (Holocene to upper Pleistocene) – Mixed alluvium and colluvium in upland valleys and along bases of slopes; variable grain sizes; locally grade into other deposits; thickness generally less than 20 feet (6 m).

Human-derived deposits

Qh Human disturbance (Historical) – Deposits and disturbed areas from human development; includes the Kennecott/Rio Tinto tailings ponds and some other operations, smaller gravel pits and quarries, salt evaporators, Trans-Jordan Sanitary Landfill, wastewater and storm water ponds, and thicker fill for Interstate Highway 80 and its overpasses; thickness generally less than about 20 feet (6 m). Additional unmapped disturbed areas and smaller fill deposits are common throughout the map area.

Qhm Mine dumps (Historical) – Unconsolidated mine waste at the Kennecott/Rio Tinto Barneys Canyon mine; mine dumps are principally coarse rock fragments with lesser sand- and silt-sized particles; most dumps are mapped as stacked units; mine dump thickness is highly variable, but locally exceeds 200 feet (60 m).

Stacked-unit deposits

Qh/unit (Qh/Tbx, Qh/Tsl, Qh/Tnf, Qh/Tw?, Qh/Tvu, Qh/Tipqm, Qh/Tvlo?, Qh/Tiqmp, Qh/Tim, Qh/Tilp, Qh/Tiqlp, Qh/Ppp, Qh/Pdk, Qh/Pofp, Qh/Pocp, Qh/IPobp, Qh/IPobmu, Qh/IPobml, Qh/IPobml?)

Human disturbance over unit (Historical over Tertiary, Permian, Pennsylvanian) – Disturbed areas and deposits from human development overlying various bedrock map units at Kennecott/Rio Tinto open-pit mines (Bingham Canyon, Barneys Canyon, Melco) and large gravel pit on southeast side of Antelope Island; at the Kennecott mines Qh is largely the open pits and bedrock geology is from Kennecott Utah Copper Corporation (2009) and Swensen and Kennecott staff (1991); thickness of upper disturbed areas is highly variable.

Qhm/unit (Qhm/Qal, Qhm/Tbx, Qhm/Tvu, Qhm/Tw?, Qhm/Tim, Qhm/Tilp, Qhm/Ppp, Qhm/Pdk, Qhm/Pofp, Qhm/Pocp, Qhm/IPobp, Qhm/IPobmu, Qhm/IPobml, Qhm/IPobml?)

Mine dumps over unit (Historical over Quaternary, Tertiary, Permian, Pennsylvanian) – Unconsolidated mine waste materials overlying various bedrock map units at the Kennecott/Rio Tinto mines; mine dumps are principally coarse rock fragments with lesser sand- and silt-sized particles; mine dumps were mapped from 2011 orthophotos and underlying geology is from KUCC (2009) and Swensen and Kennecott staff (1991); mine dump thickness is highly variable, but locally exceeds 200 feet (60 m).

TERTIARY ROCK UNITS

Tsl Salt Lake Formation, undivided (Miocene) – Tuffaceous sandstone, conglomerate, volcanic ash, conglomeratic limestone, and possibly poorly consolidated sandstone that locally crops out on eastern Antelope Island in small exposures and in a large sand and gravel pit (Doelling and others, 1990; Willis and Jensen, 2000); gray tuffaceous sandstone is very fine grained, moderately indurated, laminated to medium bedded, and locally cross bedded; pale gray conglomerate is crudely stratified, has clasts of quartzite and limestone cobbles that are subangular to subrounded, and a calcareous and sandy matrix; very light gray volcanic ash consisting of glass shards is present within poorly exposed fine-grained sediments; tephrochronology analyses from the east side of the island indicate ages from ~ 8 to 11 Ma (Willis and Jensen, 2000); a fission-track age of 6.1 Ma (Bryant and others, 1989) appears too young (Willis and Jensen, 2000); unit Tsl unconformably overlies older Tertiary rock units (units Tso, Tnf, Tw?); incomplete thickness is about 1800 feet (550 m) (Doelling and others, 1990), but the upper part is not exposed.

Salt Lake Formation, divided into two lithosomes in western Salt Lake Valley.

Tslf Salt Lake Formation, fine-grained lithosome (Pliocene? to Miocene?) – White to light-gray tuffaceous marlstone and micrite, lesser claystone, sandstone, unwelded rhyolitic tuff (volcanic ash), and minor limestone; appears to interfinger laterally with unit Tslg; typically poorly exposed with local exposures in cuts and pits near the Harkers Canyon-Clay Hollow area; previously called part of the Jordan Narrows unit (see Slentz, 1955; Biek and others, 2007; Solomon and others, 2007); further evaluation of unpublished and new tephrochronology data is ongoing; yielded fission-track age of 4.4 ± 1.0 Ma for a rhyolitic tuff from the reclaimed Pioneer pit (Bryant and others, 1989); exposed (incomplete) unit thickness is about 300 to 500 feet (90-150 m) (Biek and others, 2007; Solomon and others, 2007).

Tslg Salt Lake Formation, gravel lithosome (Pliocene? to Miocene?) – Poorly sorted, unconsolidated gravel with sand, silt, and clay that locally contains unwelded rhyolitic tuff (volcanic ash); clasts are locally sourced from sedimentary and volcanic rocks; appears to interfinger laterally with unit Tslf; occurs as piedmont gravel that is deeply dissected and capped by an erosional surface along

western Salt Lake Valley; previously called part of the Harkers fanglomerate (Slentz, 1955), and previously mapped as unit QTaf (oldest alluvial-fan deposits) (Biek and others, 2007; Solomon and others, 2007); further evaluation of unpublished and new tephrochronology data is ongoing; exposed (incomplete) thickness as much as 350 feet (100 m) (Biek and others, 2007; Solomon and others, 2007).

- Tso Older Tertiary strata, undivided** (Oligocene? to Paleocene?) – Conglomeratic strata on eastern Antelope Island where association with units Tnf or Tw? is currently unclear; pale-gray conglomerate with primarily carbonate and quartzite clasts that are very poorly sorted and range from pebble to boulder size (see unit 3, measured section S4, Willis and Jensen, 2000); located northwest of large gravel pit; previously part of lower member of unnamed conglomeratic unit (Doelling and others, 1990); unconformably overlies the Farmington Canyon Complex and underlies the Salt Lake Formation; complete thickness about 190 feet (60 m) (Doelling and others, 1990).
- Tnf Norwood Tuff and Fowkes Formation, undivided** (Oligocene? to Eocene?) – Gray conglomerate with volcanic, metamorphic, carbonate, quartzite, and chert clasts (pebbles to boulders) with sandy, gritty matrix and calcite cement, and interbedded purple and gray bentonitic mudstone; overlies unit Tw? within large gravel pit of eastern Antelope Island; yielded K-Ar ages of 38.8 Ma (claystone/bentonite), and 42.9 and 49.2 Ma on recycled volcanic clasts (Doelling and others, 1990; Willis and Jensen, 2000); thickness is about 300 feet (90 m) (measured sections S1, S2, Willis and Jensen, 2000).
- Tw? Wasatch Formation?** (Eocene? to Paleocene?) – On *Antelope Island*, grayish-red to dark-reddish-brown conglomerate and breccia; contains angular clasts of local metamorphic rocks (pebbles to boulders) in a gritty, densely cemented matrix; present within and adjacent to large gravel pit; unconformably overlies the Farmington Canyon Complex; queried since no direct age control, but lacks volcanic clasts; thickness is about 135 feet (40 m) (see lower parts of measured sections S1, S2, Willis and Jensen, 2000); the *Oquirrh Mountains* have three exposures of conglomerate with subangular to subrounded pebbles to boulders of quartzite, sandstone, some black chert, and rare limestone, with silica cement; U-Pb detrital zircon age pending from Harkers Canyon outcrop; unconformably overlies Permian and Pennsylvanian rock units; thickness about 30 to 500 feet (10-150 m) (Tooker and Roberts, 1971a; Biek and others, 2007; Solomon and others, 2007).

Volcanic Rocks of the Northern and Central Oquirrh Mountains

These volcanic rocks are present in the Bingham mining district. The rocks were divided into four informal compositional suites by Waite (1996) and Waite and others (1997): (1) younger volcanic suite, (2) older volcanic suite, (3) nepheline minette-shoshonite suite (within the older volcanic suite), and (4) Bingham intrusive suite. Biek and others (2005) and Biek (2006a) informally referred to the younger suite as the “volcanic and intrusive

rocks of the west Traverse Mountains,” and combined the latter three suites as the “volcanic and intrusive rocks of the Bingham Canyon suite.” We also group the igneous rocks into younger and older suites, and further separate the suites into extrusive and sedimentary rocks, and intrusive rocks. The terminology for the intrusive rocks of the Bingham district (after Lanier and others, 1978) is based on historic usage at Bingham mine (for the purpose of separating similar rock units); it is entrenched and does not necessarily reflect geochemical composition and newer geochemically-based rock classifications. Information on Bingham area geology and ore genesis is provided in several publications, including Moore (1973), Bray and Wilson (1975), Economic Geology (1978), Black and Babcock (1991), John and Ballantyne (1997), Gruen and others (2010), Kloppenburg and others (2010), Landtwing and others (2010), Redmond and Einaudi (2010), Porter and others (2013), and Pankow and others (2014). For geochemical and age data see Moore (1973), Moore and McKee (1983), Waite (1996), Deino and Keith (1997), Waite and others (1997), Pulsifer (2000), Maughan (2001), Parry and others (2001), Biek and others (2005), Biek (2006b), NMGRL & UGS (2006), and von Quadt and others (2011). Key geologic maps are indicated in the mapping sources.

Tbx Breccia pipes and bodies (lower Oligocene? to upper Eocene?) – Unit includes the Kilkinny breccia, located on west side of the Bear Gulch porphyry, and Dalton breccia at Bingham Canyon mine (Smith, 1975; Swensen and Kennecott staff, 1991; KUCC, 2009); Kilkinny breccia is composed of intrusive and sedimentary fragments and is locally cut by latite porphyry dikes; Bear Gulch breccia has an intrusive matrix with small quartzite fragments; Dalton breccia appears as a hole filled with coarse crushed sedimentary fragments with no matrix (Smith, 1975); age of pipes and bodies is likely post-mineralization (post ~37 Ma) (K.A. Krahulec, UGS, verbal communication to D.L. Clark, June 10, 2014); highly variable in diameter and depth.

Tvu Volcanic rocks, undivided (upper to middle Eocene) – Combined unit of various volcanic rocks located under the mine dumps on east side of Bingham mine, where prior mapping does not match existing schemes of KUCC (2009) or Biek and others (2007); map unit also includes small intrusion northwest of Copperton (unit Tiu of Biek and others, 2007) and volcanic boulder lag overlying unit Tw? near Harkers Canyon; probably associated with older volcanic and intrusive suite rocks at Bingham (see below).

Younger Volcanic and Intrusive Suite (lower Oligocene to upper Eocene, ~30-37 Ma) – Younger volcanic and intrusive rocks are present to the south in the western Traverse Mountains (Biek and others, 2005; Clark and others, in preparation).

Younger Intrusive Rocks

Tir Rhyolitic intrusion (early Oligocene? to late Eocene) – Shaggy Peak plug or dome is light- to medium-gray porphyritic rhyolite that contains a border phase with abundant plagioclase, quartz, and biotite phenocrysts and generally near-vertical flow foliations, and an interior phase with slightly larger phenocrysts and

little or no flow foliation (Biek, 2006a); present at the southern map boundary in the Butterfield-Rose Canyon area; yielded K-Ar age of 33.0 ± 1.0 Ma (Moore, 1973) and $^{40}\text{Ar}/^{39}\text{Ar}$ age of 35.49 ± 0.13 Ma (Biek and others, 2005). Other rhyolitic intrusions are present south of the map area in Tickville Gulch, Dry Mountain-Ophir, and Eagle Hill-Mercur (Laes and others, 1997; Clark and others, in preparation).

Older Volcanic and Intrusive Suite (middle Eocene, ~37-41 Ma) – Data indicate that the older suite rocks are largely comagmatic with the Bingham intrusive complex (Waite and others, 1997) and contain significantly higher chromium and barium concentrations and more magnetic minerals than the younger suite (Pulsifer, 2000).

Older Extrusive and Sedimentary Rocks

Tvfou Older intermediate lava flows (middle Eocene) – Dark-gray lava flows of intermediate composition derived from the Bingham intrusive complex; interlayered with and difficult to differentiate from the older lahars and debris flows (unit Tvlo); present along the east flank of the Oquirrh Mountains; $^{40}\text{Ar}/^{39}\text{Ar}$ age of 38.17 ± 0.09 Ma from recycled volcanic clast (Deino and Keith, 1997), and interlayered with Eocene lacustrine strata near Butterfield Canyon, south of map area (Biek and others, 2005); exposed thickness likely exceeds 1000 feet (300 m) (Biek and others, 2007).

Tvlo Older lahars and debris flows (middle Eocene) – Pebbles to boulders of intermediate-composition volcanic rocks in a matrix of lithic and crystal fragments; locally contains mostly mafic clasts; contains some thin discontinuous lava flows of intermediate composition (Pulsifer, 2000; Maughan, 2001; Biek and others, 2005); generally forms rubbly slopes along east flank of Oquirrh Mountains; Bingham area $^{40}\text{Ar}/^{39}\text{Ar}$ ages of 38.68 ± 0.13 Ma from waterlain tuff near top of unit (Maughan, 2001) and 39.18 ± 0.11 Ma from volcanic clast near base of unit (Deino and Keith, 1997); also interlayered with Eocene lacustrine strata near Butterfield Canyon, south of map area (Biek and others, 2005); thickness may exceed 4000 feet (1200 m) (Biek and others, 2007).

Older Intrusive Rocks

Tipqm

Porphyritic quartz monzonite intrusions (late to middle Eocene) – Intrusion at the former Lark townsite and the Ohio Copper dike in Bingham mine. Lark intrusion (plug) is light- to medium-gray dacite porphyry with abundant phenocrysts of plagioclase and biotite and lesser hornblende in a fine-grained groundmass; typically weathers to grussy or clayey soils; present near mouth of Butterfield Canyon near former Lark townsite (Laes and others, 1997; Biek and others, 2005; Biek and others, 2007); K-Ar ages from Bingham tunnel portal of 36.9 ± 0.9 Ma (hornblende) and 36.9 ± 1.0 Ma (biotite) (Moore and others, 1968), and Re-Os mineral age (molybdenum) is ~34 Ma (Russ Franklin, Kennecott Exploration, verbal communication to Ken Krahulec, UGS, March 14, 2013). Ohio Copper dike (east of Bingham stock) is medium-gray to greenish-gray, porphyritic amphibole-biotite quartz monzonite with orthoclase and plagioclase

- phenocrysts in a phaneritic groundmass; a distinct late phase of Bingham and Last Chance (quartz) monzonite (KUCC, 2009); no direct age data, but probably between 37 and 38.5 Ma; other similar intrusions are present in the Porphyry Hill/Knob area north of Mercur, Oquirrh Mountains (Laes and others, 1997).
- Tiqmp **Quartz monzonite porphyry intrusion** (middle Eocene) – Forms western part of the Bingham stock at Bingham mine; light-gray, amphibole-biotite quartz monzonite porphyry; amphibole is altered to phlogopite and quartz, and plagioclase is altered to sericite and clay; there are no exposures of unaltered rock; inferred source of Bingham mineralizing fluids (KUCC, 2009); southwestern part of unit Tiqmp is referred to as hybrid quartz monzonite porphyry by Kennecott (KUCC, 2009); K-Ar age of 37.6 ± 0.07 Ma (Moore, 1973), and U-Pb zircon age of 37.96 ± 0.09 Ma (von Quadt and others, 2011).
- Tim **Monzonite intrusions** (middle Eocene) – Forms Bingham and Last Chance stocks and associated intrusions at Bingham mine; medium- to dark-gray, augite-actinolite-phlogopite (quartz) monzonite; where altered, augite is replaced by actinolite, chlorite, phlogopite, and quartz, and some plagioclase is replaced by orthoclase; contains pyrite, chalcopyrite, bornite and molybdenite mineralization; original magnetite is replaced by sulfide minerals; main Bingham ore host (KUCC, 2009); Last Chance stock has a K-Ar age of 38.6 ± 0.18 Ma (Moore, 1973), U-Pb zircon age of 38.55 ± 0.19 Ma, and $^{40}\text{Ar}/^{39}\text{Ar}$ age of 38.40 ± 0.16 Ma (Parry and others, 2001); similar monzonite intrusions occur south of the map area in the Spring Gulch and Calument mine area (near Stockton), Soldier Canyon, and near axis of Long Ridge anticline (Lufkin, 1965; Laes and others, 1997; Krahulec, 2005).
- Tilp **Latite to dacite porphyry** (middle Eocene) – Light- to dark-gray, latite to dacite porphyry (hornblende-augite-biotite quartz latite porphyry) with abundant phenocrysts of plagioclase and hornblende and lesser biotite; at Bingham mine includes the Fortuna sill, Main Hill and Starless dikes, Bear Gulch porphyry, and apophyses (Laes and others, 1997; Biek and others, 2005; KUCC, 2009); K-Ar age of 37.1 ± 1.1 Ma (Moore, 1973), $^{40}\text{Ar}/^{39}\text{Ar}$ age of 38.84 ± 0.19 Ma (Deino and Keith, 1997), and U-Pb zircon age of 37.94 ± 0.13 Ma (von Quadt and others, 2011).
- Tiqlp **Quartz latite porphyry dikes** (middle Eocene) – Medium-brown and light-greenish-gray, hornblende-biotite quartz latite porphyry; hornblende is altered to phlogopite and/or chlorite within the pit area; distinguished from other latitic dikes by the presence of relatively large quartz phenocrysts and higher percentage of aphanitic groundmass; groundmass usually contains considerable hornblende (KUCC, 2009); includes Raddatz porphyry dikes with large K-feldspar phenocrysts (Settlement Canyon area) (see Krahulec, 2005), and the Andy Dike and apophyses at Bingham mine (KUCC, 2009); $^{40}\text{Ar}/^{39}\text{Ar}$ ages of 37.66 ± 0.08 and 37.72 ± 0.09 Ma (Deino and Keith, 1997), and U-Pb zircon age of 37.97 ± 0.11 Ma (von Quadt and others, 2011); also forms some small dikes (unmapped)

east of Pass Canyon and near North Oquirrh thrust (Swensen and Kennecott staff, 1991) with K-Ar age of 36.5 Ma (Moore, 1973); Raddatz dike has K-Ar age of 38.6 ± 1.1 Ma (Moore, 1973) and $^{40}\text{Ar}/^{39}\text{Ar}$ age of 39.4 ± 0.34 Ma (Kennecott, unpublished age in Krahulec, 2005).

PERMIAN TO MISSISSIPPIAN ROCK UNITS OF NORTHERN AND CENTRAL OQUIRRH MOUNTAINS

Tooker and Roberts (1970) divided Permian, Pennsylvanian, and Mississippian rocks in the Oquirrh Mountains into three sequences (from north to south: Rogers Canyon, Curry Peak, and Bingham, each interpreted to belong to a separate thrust sheet), and Tooker and Roberts (1998) and Tooker (1999) provided different formation nomenclature per thrust nappe. Conversely, Welsh (1976, 1983, 1998) and Welsh and James (1998) argued that there were no major lithologic facies changes between structural blocks of the Oquirrh Mountains, and applied Bingham area stratigraphic nomenclature to the northern Oquirrh Mountains. The Bingham sequence nomenclature was modified by Kennecott geologists to include Lower Permian formations (Swensen, 1975; Swensen and Kennecott staff, 1991; Laes and others, 1997). We apply Oquirrh Group and associated formation names from Bingham across a larger area based on similar lithofacies and age relations throughout this part of Utah (figure 3; see Constenius and others, 2011; Clark and others, in preparation). We suggest abandonment of the different nomenclature by thrust sheet (nappe) of Tooker (1999).

Ppp Park City Formation and Phosphoria Formation, undivided (Middle to Lower Permian, Guadalupian to Leonardian) – Contains the Franson and Grandeur Members of the Park City Formation separated by the Meade Peak Phosphatic Shale Tongue of the Phosphoria Formation (Solomon and others, 2007); upper part (Franson) contains gray dolomite and tan quartzite (261+ feet [80+ m]); middle part (Meade Peak) includes platy, shaley dolomite, quartzite, sandstone, shale, chert, and phosphorite (284 feet [87 m]); lower part (Grandeur) consists of gray to light-brown limestone that is bioclastic, sandy, and cherty (215 feet [65 m]) (Tooker and Roberts, 1970; Solomon and others, 2007); overall, unit is thin to thick bedded; present in the northeastern Oquirrh Mountains, Little Valley area southward to near Barneys Canyon; entire unit previously called Park City Formation (Welsh and James, 1961; Laes and others, 1997; Gunter, 1991), and Grandeur Member of Park City Formation (Tooker and Roberts, 1970, 1971a; Swensen, 1975); may be conformable or unconformable with underlying unit Pu (see Tooker and Roberts, 1970); several fossils from the lowermost limestone indicate a Leonardian to possible Wordian? age (Gordan and Duncan in Tooker and Roberts, 1970); top eroded, but incomplete thickness of 760 feet (230 m) was measured by Tooker and Roberts (1970) in Coon Canyon, and Kennecott cross section at Barneys Canyon (Gunter, 1991 and plate 4) indicates incomplete thickness of about 350 feet (110 m).

The Kessler Canyon Formation was included as the upper part of the Oquirrh Group of the Rogers Canyon sequence in the northern Oquirrh Mountains (Tooker and Roberts, 1970). Swensen (1975) and Welsh (1998) noted that east of the Garfield fault this unit is

roughly equivalent to several formations (Diamond Creek-Kirkman, Freeman Peak, and Curry Peak?) and therefore omitted it from the Oquirrh Group; we herein reassign the Kessler Canyon Formation south of the Arthur fault to unit Pu, while west of the Garfield fault and north of the Arthur fault, we reinterpret most of the Kessler Canyon Formation as the Oquirrh Group, Bingham Mine Formation.

Pu Permian strata, undivided (Lower Permian, Leonardian? to Wolfcampian?) – Combined unit due to structural disturbance, limited age control, and poor exposure that includes units Pdk, Pofp, Pocp?; present below unit Ppp in a fault-bounded structural block containing a series of NE-trending folds; unit contains interbedded light-brown to reddish-brown and light-gray quartzite, sandstone (calcareous, ferruginous, dolomitic), limestone, dolomite, dolomite breccia, and some thin chert beds; bedding is thin to medium; worm trails in ferruginous sandstone are common (Tooker and Roberts, 1970; Swensen, 1975); present east of the Garfield fault from near Harkers Canyon northward to the Arthur fault where it is poorly exposed and typically forms slopes and some ledges; fossil age data are very limited (see Tooker and Roberts, 1970); thickness is uncertain due to structural complications.

Pdk Diamond Creek Sandstone and Kirkman Formation, undivided (Lower Permian, Leonardian? to Wolfcampian?) – Combined unit due to structural disturbance that extends across the Oquirrh Mountains from Flood and Pass Canyons (west) to near Barneys Canyon (east); stratigraphically higher beds in Flood and Pass Canyons consist of interbedded light-gray sandstone, quartzitic sandstone, and local beds of light-brownish-gray dolomite or dolomitic limestone that are typically contorted, lenticular, and discontinuous; lower part is light-gray to tan, calcareous sandstone breccia; lenses and blocks of limestone and dolomite occur within the unit; lower part of unit in upper Dry Fork consists of light-gray to tan, calcareous sandstone that is locally brecciated, cross-bedded, and ripple marked and is underlain by dark-gray, weathering to light- to medium-bluish-gray limestone and arenaceous limestone that is thinly laminated and commonly contorted and brecciated (Welsh and James, 1961; Swensen, 1975); typically forms slopes; unit underwent both soft-sediment and tectonic deformation (Welsh and James, 1961; Schurer, 1979a, 1979b); Welsh (1998) reported the Diamond Creek Sandstone beds are in part brecciated because of collapse over the dissolution of anhydrite in the underlying Kirkman Formation in the Oquirrh Mountains and Wasatch Range; the unit has been structurally deformed between the North Oquirrh thrust fault (north) and Midas thrust and Bear fault (south), and also south of the Arthur fault where included as unit Pu; contact with underlying Freeman Peak Formation is locally faulted, but is otherwise conformable (Schurer, 1979a; Gunter, 1991; Gunter and Austin, 1997); limited age control in Oquirrh Mountains (Swensen, 1975); thickness is uncertain due to structural complexity, but Swensen (1975) estimated about 2000 feet (600 m).

Oquirrh Group, herein includes Lower Permian formations and Pennsylvanian formations of the Bingham sequence following Laes and others (1997), also see Constenius and others (2011) and Clark and others (in review).

PIPo **Oquirrh Group, undivided** (Lower Permian to Lower Pennsylvanian) – Three isolated outcrops of possible Oquirrh Group rocks in Tooele Valley (Tooele Army Depot) that Tooker (1980) mapped as the Bingham Mine Formation, Markham Peak Member, but stratigraphic context is difficult to determine; exposed thickness roughly 1100 feet (340 m).

Pofp **Oquirrh Group, Freeman Peak Formation** (Lower Permian, Wolfcampian) – Light-gray to tan to brownish-tan calcareous quartzite that is thick bedded and interbedded with some thin, calcareous sandstone and platy, argillaceous siltstone and shale (rarely exposed except in roadcuts or prospect tunnels); lacks worm tracks found in the Curry Peak Formation and fine banding of the Bingham Mine Formation; forms jointed blocks and distinctive talus-covered slopes; present along the nose of the Copperton anticline from Bingham Canyon north and west around to Freeman Peak and also to the west near Pass and Bates Canyons (Welsh and James, 1961; Swensen, 1975); previously referred to as the Clinker formation (Welsh and James, 1961); unconformable with underlying Curry Peak Formation; fusulinids *Schwagerina* and *Pseudoschwagerina* indicate a Wolfcampian age (Welsh and James, 1961); thickness is 2400 feet (730 m) on Freeman Peak, central Oquirrh Mountains (Swensen, 1975).

Pocp **Oquirrh Group, Curry Peak Formation** (Lower Permian, Wolfcampian) – Dark-gray, weathering to light gray and tan, very fine grained, calcareous sandstone and siltstone that is thin bedded (poorly), and includes some minor quartzite and limestone; sandstone and siltstone locally weathers with a darker brown, punky rind; sparsely fossiliferous, but worm tracks and trails are abundant on bedding planes; quartzite lacks fine color banding of Bingham Mine Formation (Welsh and James, 1961; Swensen, 1975); generally forms chippy slopes with few ledges; present on flanks of Copperton anticline north of the Midas thrust and west in the Markham Peak-Pole Canyon area; previously referred to as Curry formation (Welsh and James, 1961); unconformable on underlying Bingham Mine Formation (Welsh and James, 1961), but not observed west of the map area (Clark and others, in preparation); uppermost part of formation yielded fusulinids (*Triticites*, *Schwagerina*, *Pseudoschwagerina*) of Wolfcampian age (Welsh and James, 1961); thickness is 2450 feet (750 m) in section on south flank of Curry Peak, central Oquirrh Mountains (Swensen, 1975).

IPobm **Oquirrh Group, Bingham Mine Formation** (Upper Pennsylvanian, Virgilian-Missourian) – Previously mapped as the Kessler Canyon Formation of the northern Oquirrh Mountains (Tooker and Roberts, 1970); brown-weathering, fine-grained quartzitic sandstone, quartzite, and calcareous sandstone with lesser interbeds of medium- to dark-gray, fine-grained, sandy and cherty limestone; light-brown to pale-red sandstone is very fine grained, feldspathic, and cross-

laminated; bedding is medium to thick, but can be poor; forms talus-covered slopes with some intervening ledges; no Commercial and Jordan Limestone marker beds at base of formation in this thrust sheet; fossil age data from the northern Oquirrh Mountains exposures is limited (Tooker and Roberts, 1970; Welsh, 1998); queried in structural block between the Garfield and Arthur faults where age control is poor; west of Garfield fault, incomplete lower part of formation is about 1000 to 2000 feet (300-600 m) thick (Tooker and Roberts, 1970, 1971a), and incomplete section between Garfield and Arthur faults is about 3400 feet (1040 m) thick.

Tooker and Roberts (1970) divided the Bingham Mine Formation of the Bingham sequence into the Markham Peak and Clipper Ridge Members, and later Kennecott maps (Swensen and others, 1991; Laes and others, 1997; KUCC, 2009) also used the names Markham and Clipper Members. However, Swensen (1975) reported the type section of Tooker and Roberts (1970) is invalid, as it is inappropriately located, and used informal upper and lower members.

IPobmu

Oquirrh Group, Bingham Mine Formation, upper member (Upper Pennsylvanian, Virgilian-Missourian) – Light-gray to tan, thinly color-banded and locally cross-bedded, quartzite and calcareous quartzite with interbedded thin, light- to medium-gray, calcareous, fine-grained sandstone, limestone, and siltstone; several of the thin calcareous units are locally important as marker beds; upper-lower member contact is placed at base of the Manefay limestone marker bed; unit is very similar to the lower member above the Commercial Limestone (Swensen, 1975); Virgilian and Missourian fusulinids (*Triticites*) are reported from the Markham Peak section (R.C. Douglass in Tooker and Roberts, 1970), and Welsh and James (1961) reported a Virgilian and Missourian age for the entire formation; 2200 feet (670 m) thick in the Bingham district (Swensen, 1975).

IPobml

Oquirrh Group, Bingham Mine Formation, lower member (Upper Pennsylvanian, Missourian) – Most of the unit consists of light-gray to tan, color-banded quartzite and calcareous quartzite with thin, interbedded, light- to medium-gray, calcareous, fine-grained sandstone, limestone, siltstone, and minor shale; unit includes several limestone marker beds including the Commercial and basal Jordan Limestone beds (important Bingham ore hosts, but not mapped separately here due to scale limitations); the Commercial (100 feet [30 m] thick) consists of dark-gray to black, argillaceous, thin bedded, silty and cherty limestone, whereas the Jordan (308 feet [94 m] thick) is thin-bedded, dark-gray, argillaceous and silty, cherty limestone and arenaceous limestone (Swensen, 1975); Missourian-age conodont fauna were recovered from the Jordan Limestone east of Tooele (S.R. Ritter, Brigham Young University, written communication to D.L. Clark, October 27, 2009) and Missourian fusulinids also reported from this member (Welsh and James, 1961; R.C. Douglass in Tooker and Roberts, 1970);

thickness is about 3100 feet (945 m) near Middle Canyon, Bingham district (Swensen, 1975).

IPobp Oquirrh Group, Butterfield Peaks Formation (Middle to Lower Pennsylvanian, Desmoinesian-Atokan-Morrowan) – Generally characterized by cyclically interbedded limestone and clastic intervals; limestone is medium gray and locally fossiliferous, arenaceous, cherty, and argillaceous in thin to thick beds and contains locally abundant brachiopod, bryozoan, coral, and fusulinid fauna; diagnostic black chert weathers brown and locally occurs as spherical nodules and laterally linked masses; light-brown calcareous quartzite, quartzite, and calcareous sandstone is thin to medium bedded and locally cross-bedded; includes some poorly exposed light-gray siltstone and mudstone interbeds; overall, limestone predominates over quartzite and sandstone, with clastic percentages increasing upsection; unit forms ledges and cliffs with regularly intervening slopes; subdivided in the Bingham district into upper and lower members (Swensen, 1975; Laes and others, 1997) but not differentiated here; includes the Erda Formation of the northern Oquirrh Mountains based on similar lithofacies and age relations (see Welsh, 1976, 1983, 1998); fossil age data in Welsh and James (1961), Tooker and Roberts (1970), Douglass and others (1974), Swensen (1975), Welsh (1998), Konopka (1999), Davis and others (1989, 1994); conodont data in the northern Oquirrh Mountains indicates the base of unit IPobp is Atokan, but in the southern Oquirrh Mountains the base is Morrowan (Davis and others, 1994); complete thickness is 9072 feet (2766 m) on Butterfield Peaks, central Oquirrh Mountains (Tooker and Roberts, 1970), and 3606 feet (1099 m) measured by Tooker and Roberts (1970; their Erda Formation) and 3690 feet (1125 m) measured by Konopka (1999) near Rogers Canyon, northern Oquirrh Mountains.

IPMwm

Oquirrh Group, West Canyon Limestone and Manning Canyon Formation, undivided (Middle Pennsylvanian, Atokan to Upper Mississippian, Chesterian) – Combined unit along the North Oquirrh thrust fault where separation of formations is difficult due to poor exposure and map scale.

IPowc Oquirrh Group, West Canyon Limestone (Middle-Lower Pennsylvanian, Atokan-Morrowan to Upper Mississippian, Chesterian) – Light- to medium-gray limestone, fossiliferous limestone, arenaceous limestone, with subordinate light-brown to light-gray calcareous sandstone and quartzite and minor dark-gray carbonaceous shale; limestone is medium to very thick bedded, and locally very fossiliferous, cherty, arenaceous, bioclastic, or bioturbated; fossils include crinoids, bryozoans, brachiopods, trilobites, foraminifera, corals, gastropods, sponges, calcareous algae, and pellets (Tooker and Roberts, 1970; Swensen, 1975; Davis and others, 1989); present in ledgy and cliffy exposures in the Kessler anticline, in the core of unnamed anticline near Lake Point, and along North Oquirrh thrust (Bates Canyon-Nelson Peak area); includes the upper 2/3 of the Lake Point Limestone of Tooker and Roberts (1970) in the northern Oquirrh Mountains based on lithofacies and age relations; conodont data indicates Middle Pennsylvanian (Atokan) through Mississippian (Chesterian) ages, while the

southern Oquirrh are reportedly Morrowan through Chesterian age (Davis and others, 1989, 1994); additional macrofossil data from northern and southern Oquirrh Mountains is available from Gordon and Duncan in Tooker and Roberts (1970) and Welsh (1976); complete thickness of 1050 feet (320 m) (Green Ravine area, measured section units 109 to 10, northern Oquirrh Mountains, Davis and others, 1989, 1994); type and reference sections south of map area range from 1456 to 1007 feet (444-307 m) (Nygreen, 1958; Tooker and Roberts, 1970; Davis and others, 1994).

Mmc Manning Canyon Formation (Upper Mississippian, Chesterian) – Light-gray to dark-gray limestone, sandy limestone, fossiliferous limestone and some thin shaley partings; limestone is thin to thick bedded with local black chert nodules, wispy sand layers, and intraformational conglomerate; macrofossils include brachiopods, crinoids, bryozoans, gastropods, corals, and trilobites (Tooker and Roberts, 1970; Davis and others, 1989); forms slopes and ledges on flanks of the Kessler anticline; includes the lower 1/3 of the Lakepoint Limestone of Tooker and Roberts (1970), which has similar age relations, but differing lithofacies compared to the typical Manning Canyon Shale; upper contact placed at top of the prominent double-cliff limestone unit (units 9 and 8 of measured section by Davis and others, 1989, 1994; see also Tooker and Roberts, 1970, figure 8; Welsh, 1976); conodont and macrofossil data indicate a Chesterian age (Davis and others, 1989, 1994; Gordon and Duncan in Tooker and Roberts, 1970); the Manning Canyon is an interval of regional decollement, commonly exhibiting substantial deformation; thickness is 477 feet (145 m) (units 9 through 1 of measured section by Davis and others, 1989, 1994); regional thicknesses can vary, but more reliable thicknesses of the Manning Canyon are 1140 to 1559 feet (320-475 m) in Soldier Canyon, Oquirrh Mountains (Gillully, 1932; Moyle, 1959) and 1176 feet (359 m) in the Lake Mountains (Biek and others, 2009).

Mgb Great Blue Limestone (Upper Mississippian, Chesterian to Meramecian?) – Upper part is bluish-gray to medium- and dark-gray limestone that is locally fossiliferous, cherty, and argillaceous; bedding is medium to very thick; black chert occurs as nodules; fossils include brachiopods, corals, bryozoans, and crinoids; lower part is not well exposed, but is limestone interbedded with dark-gray to olive-gray shale; limestone is similar to the upper part, but bedding is medium; present in the core of the Kessler anticline as ledge and cliffy exposures; previously mapped as the Green Ravine Formation of Tooker and Roberts (1970); macrofossil age data from Gordon and Duncan in Tooker and Roberts (1970); incomplete thickness is about 1400 feet (430 m) (Tooker and Roberts, 1970).

CRETACEOUS TO PALEOPROTEROZOIC ROCK UNITS OF ANTELOPE ISLAND

KXa Altered and deformed rocks (Cretaceous, Paleoproterozoic) – Older rocks (Farmington Canyon Complex) that were altered in the Cretaceous to dark-green to greenish-black chloritic to dark-reddish-brown hematitic gneiss, mylonite, and

phyllonite; locally silicified and cut by quartz veins and pods (includes Kq unit of Doelling and others, 1990); found along shear zones, including a major shear zone in the central part of Antelope Island and near the contact with the overlying sedimentary cover; retrograde alteration and deformation of Farmington Canyon Complex protoliths is mostly Cretaceous in age (W.A. Yonkee, Weber State University, verbal communication to D.L. Clark, Dec. 19, 2013), however, Bryant (1988) indicated some quartz veins and pods may be related to Precambrian alteration; in chloritic gneiss the original minerals are altered to sericite, fine-grained chlorite, biotite, stilpnomelane, epidote, and albite; phyllonite and mylonite contain sericite (6-35%), chlorite (21-31%), quartz (29-51%), and feldspar (0-30%) (Yonkee and others, 2000a); previously mapped as units XWfg and XWfs by Doelling and others (1990); unit KXa thickness is highly variable, and quartz veins and pods are <10 feet (3 m) to 400 feet (120 m) across (Doelling and others, 1990; Yonkee and others, 2000a).

- Ct Tintic Quartzite** (Middle? to Lower? Cambrian) – Tan to pale-gray to greenish-gray metaquartzite with interbeds of quartz pebble conglomerate; quartzite (60%) is dense, fine- to medium-grained; pebbly quartzite (20%) and conglomerate (20%) contain moderately well sorted clasts of tan, white and red polycrystalline quartz from 0.5 to 4 inches (1-10 cm) in diameter; bedding is medium to thick, and the unit commonly forms ledge slopes and small blocky cliffs; quartzite is variably deformed with locally well developed cleavage (stretched pebbles and micaceous partings), quartz-filled veins, and minor folds; unconformably overlies unit Zsd (Doelling and others, 1990; Yonkee and others, 2000b); detrital zircon (DZ) data has not constrained the maximum depositional age (Link, 2011; Yonkee and others, in press); incomplete thickness is at least 800 feet (245 m), top not exposed (Doelling and others, 1990; Yonkee and others, 2000b).
- Zsm Slate and dolomite unit and Mineral Fork Formation, undivided** (Neoproterozoic) – Combined unit in small exposures due to map scale.
- Zsd Slate and dolomite** (Neoproterozoic) – Consists of an upper slate member and thin lower dolomite member (Christie-Blick, 1983; Doelling and others, 1990; Yonkee and others, 2000b); the slate member consists of purple, greenish-gray, and reddish-brown slate, argillite, silty dolomite, and fine-grained metaquartzite that is thin bedded; the upper half consists mostly of purplish to reddish slate and fine-grained metaquartzite, and the lower half consists of multi-colored slate with interbedded calcareous slate and silty dolomite; commonly forms smooth, covered slopes, but is locally well exposed; generally displays well-developed slaty cleavage, widespread minor folds, and locally complex quartz-filled veins developed during Mesozoic thrusting; slate grades downward to underlying light-gray to pink dolomite; the dolomite is finely crystalline to marbled; bedding is finely laminated to thick bedded, partly reflecting recrystallization; the dolomite forms resistance cliffs; dolomite is generally weakly deformed and from 20 to 30 feet (6-10 m) thick; unit Zsd unconformably overlies the Mineral Fork Formation; previously called Kelley Canyon Formation (Doelling and others, 1990, Yonkee

and others, 2000b; Willis and others, 2010), but the strata on Antelope Island may not be correlative with the Kelley Canyon Formation (W.A. Yonkee, Weber State University, written communication to D.L. Clark, February 24, 2014; Yonkee and others, in press) and the nomenclature may not be appropriate for the eastern (cratonic) section rock units; DZ data was obtained from the unit on Antelope Island, but the maximum depositional age and correlation are unclear (Yonkee and others, in press); DZ ages from the underlying Mineral Fork Formation are <700 Ma in the central Wasatch Range (Richey and others, 2011); unit thickness is variable from 70 to 280 feet (20-85 m) due to structural deformation (Doelling and others, 1990; Yonkee and others, 2000b).

Zmf Mineral Fork Formation (Neoproterozoic) – Dark-brownish-black, very poorly sorted, matrix-supported diamictite with minor interbedded argillite, metaquartzite, and conglomerate locally present near the top of the unit; clasts compose 20 to 60% of the diamictite and lie within a micaceous, gritty matrix; clast size is highly variable from pebbles to boulders 7 feet (2 m) across, but cobble-sized clasts are abundant; clasts vary from angular to rounded, but many were altered and flattened during Mesozoic deformation; clast types include quartzo-feldspathic gneiss and granite, metaquartzite (including rare, but distinctive, chrome-green quartzite), schist, and amphibolite, with relative abundances varying between outcrops; diamictite has a well-developed cleavage formed during Mesozoic thrusting and is defined by subparallel partings in the matrix and flattened clasts; unit generally forms slopes, but cliffs are locally present; usually not bedded; locally chloritized and structurally deformed; unconformably overlies the Farmington Canyon Complex (Doelling and others, 1990; Yonkee and others, 2000b); a DZ maximum depositional age of <700 Ma is given for the formation in the central Wasatch Range (Richey and others, 2011) where it overlies the Big Cottonwood Formation (<766 Ma) (Dehler and others, 2010); unit Zmf (eastern section/cratonic) is correlative to part of Perry Canyon Formation (western section/passive margin) in the northern Wasatch Range (Balgord and others, 2013); thickness is 0 to 200 feet (0-60 m) (Christie-Blick, 1983; Doelling and others, 1990; Yonkee and others, 2000b; Willis and others, 2010).

Farmington Canyon Complex, divided into eight informal units after Yonkee and others (2000a); also see Willis and others (2010). Now considered Paleoproterozoic in age from about 1.6 to 1.7 Ga (Nelson and others, 2011 and references therein; also see Willis and others, 2010). Correlation with units of the Wasatch Range is presently unclear (Bryant, 1988; Yonkee and Lowe, 2004; King and Coogan, in preparation). Map unit descriptions are modified from Yonkee and others (2000a) and Willis and others (2010).

Xfcp Granite and pegmatite (Paleoproterozoic) – Mostly weakly to non-foliated, coarse-grained granite and pegmatite; only larger bodies mapped separately; unit includes pegmatitic granite that forms large bodies on the eastern part of the island, garnet-muscovite-bearing granite in small pods within and near layered

gneiss, red granite that forms small plutons on the southern end of the island, and pegmatite in widespread dikes and pods within other units; larger outcrops of granite and pegmatite are generally white to gray to pink, variably fractured, and have a knobby appearance; contains quartz (25-40%), plagioclase (20-35%), K-feldspar (30-50%) with minor muscovite, garnet, biotite, and accessory minerals, and is compositionally granite based on mineral modes; grain sizes variable from <1 to 10 mm in granite and locally >1 cm in pegmatite.

Xfcgr, Xfcg

Granitic gneiss (Paleoproterozoic) – Light- to pinkish-gray, weakly to strongly foliated, hornblende-bearing, quartz-feldspar gneiss with lenses of hornblende-plagioclase gneiss; intruded by widespread pegmatite dikes; unit includes a central body of weakly to moderately foliated, red granitic gneiss (unit Xfcgr) and a surrounding body of moderately to strongly foliated migmatitic granitic gneiss (Xfcg) that are mineralogically indistinguishable (Yonkee and others, 2000a); widely spaced, generally planar fractures produce a blocky appearance in most outcrops; exposed in a large elliptical area on the west-central part of the island and in a smaller area to the northeast; contains quartz (31-36%), plagioclase (18-32%), K-feldspar (27-39%), hornblende and rare pyroxene (4-8%), and accessory minerals, and has granitic compositions based on mineral modes; grain sizes from 0.1 to 10 mm.

Xfcb **Banded gneiss** (Paleoproterozoic) – Light- to pinkish-gray, strongly foliated and banded, locally migmatitic, hornblende-bearing, quartz-feldspar gneiss with lenses of hornblende-plagioclase gneiss; intruded by widespread pegmatite dikes; dominant rock type within the central and eastern parts of the island and surrounds the granitic gneiss unit; contains quartz (31-34%), plagioclase (28-38%), K-feldspar (16-27%), hornblende (6-12%), possible pyroxene and biotite, accessory minerals, and is granitic to granodioritic in composition based on mineral modes; grain sizes from 0.1 to 3 mm.

Xfch **Hornblende-plagioclase gneiss** (Paleoproterozoic) – Dark-gray to black elongate pods of hornblende-plagioclase gneiss incorporated into granitic gneiss and banded gneiss, and light-gray to black plagioclase- to hornblende-rich gneiss that forms a large mafic body in the central part of the island; intruded by pegmatite dikes; contains hornblende (20-60%), plagioclase (30-60%), quartz (0-15%), minor pyroxene, accessory minerals, and varies compositionally from gabbro to diorite to tonalite based on mineral modes; grain sizes from 0.1 to 4 mm.

Xfcu **Metamorphosed ultramafic rock** (Paleoproterozoic) – Dark-green to black meta-ultramafic rock with amphibole, pyroxene, and rare olivine that are variably altered to chlorite, serpentine, and talc, and commonly with some surrounding hornblende-rich gneiss; forms small isolated pods within layered gneiss at the southern end of the island; contains anthophyllite and tremolite (~30%), orthopyroxene and clinopyroxene (15%), minor olivine, alteration minerals, and accessory minerals; grain size up to 3 mm.

- Xfcq **Quartz-rich gneiss** (Paleoproterozoic) – White to pale-gray, quartz-plagioclase gneiss with minor layered gneiss and biotite schist; forms concordant lenses from 3 to 100 feet (1-30 m) wide within the layered gneiss; weathers to form vitreous, milky to greenish-gray, fractured and resistant outcrops; consists dominantly of quartz (79-94%), with lesser amounts of plagioclase (5-12%), biotite, muscovite, and accessory minerals; grain sizes from 0.2-5 mm.
- Xfcl **Layered gneiss** (Paleoproterozoic) – Light- to dark-gray outcrops of biotite- and garnet-bearing, migmatitic, quartz-feldspar gneiss with well-developed compositional layering (quartzo-feldspathic, biotite-rich, quartz-rich, amphibolite layers from 0.2 to 6 feet [0.05-2m] thick); contains lenses of biotite schist and quartz-rich gneiss and rare pods of metamorphosed ultramafic and mafic rock; cut by widespread amphibolitic dikes; intruded by pegmatite dikes and granitic pods; forms heterogeneous, gray to brown to pink outcrops of variable erosional resistance in elongate regions within the southern and central parts of the island; layered gneiss mineral abundances are variable and contain quartz (18-46%), plagioclase (27-43%), K-feldspar (3-16%), biotite (4-32%), locally garnet, sillimanite, cordierite, and accessory minerals; grain sizes from 0.1-5 mm; U-Pb zircon age of 1691 ± 26 Ma from layered gneiss in southern Antelope Island (Nelson and others, 2011); **biotite schist** forms lenses up to 6 feet (2 m) wide; present locally with intercalated thin layers and pods of granitic material; relatively non-resistant, weathering to form brown slopes and subdued ledges; schist consists of biotite (38-55%), quartz (1-16%), coarser-grained muscovite (4-7%), garnet (1-4%), and lesser sillimanite and highly altered cordierite?, alteration (sericite, 33%); grain sizes from 0.1-5 mm.

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ACKNOWLEDGMENTS

We thank Kim Schroeder and Gerry Austin (Kennecott Utah Copper/Rio Tinto) for technical assistance, and Jeff Lachowski and Jeff Huber (Kennecott Utah Copper/Rio Tinto – Land, Water, and Energy) with logistical assistance. Adolph Yonkee (Weber State University) helped to update the geology on Antelope Island. Robert Baskin (USGS) provided Great Salt Lake bathymetry and shoreline data. The late John Welsh contributed to the understanding of Permian-Pennsylvanian strata of this region and shared much of his unpublished data. Barbara Nash (University of Utah) is conducting tephrochronology analyses, and Michael Perkins (formerly University of Utah) provided some tephrochronology data. Geochemical analyses are by ALS Chemex. We also thank UGS staff including Robert Biek, Grant Willis, and Stephanie Carney for reviews and improvements to this map and explanation; Ken Krahulec, Rich Giraud, and Jon King provided technical assistance on geologic issues; Basia Matyjasik compiled the GIS data, and Jay Hill helped prepare the explanatory materials.

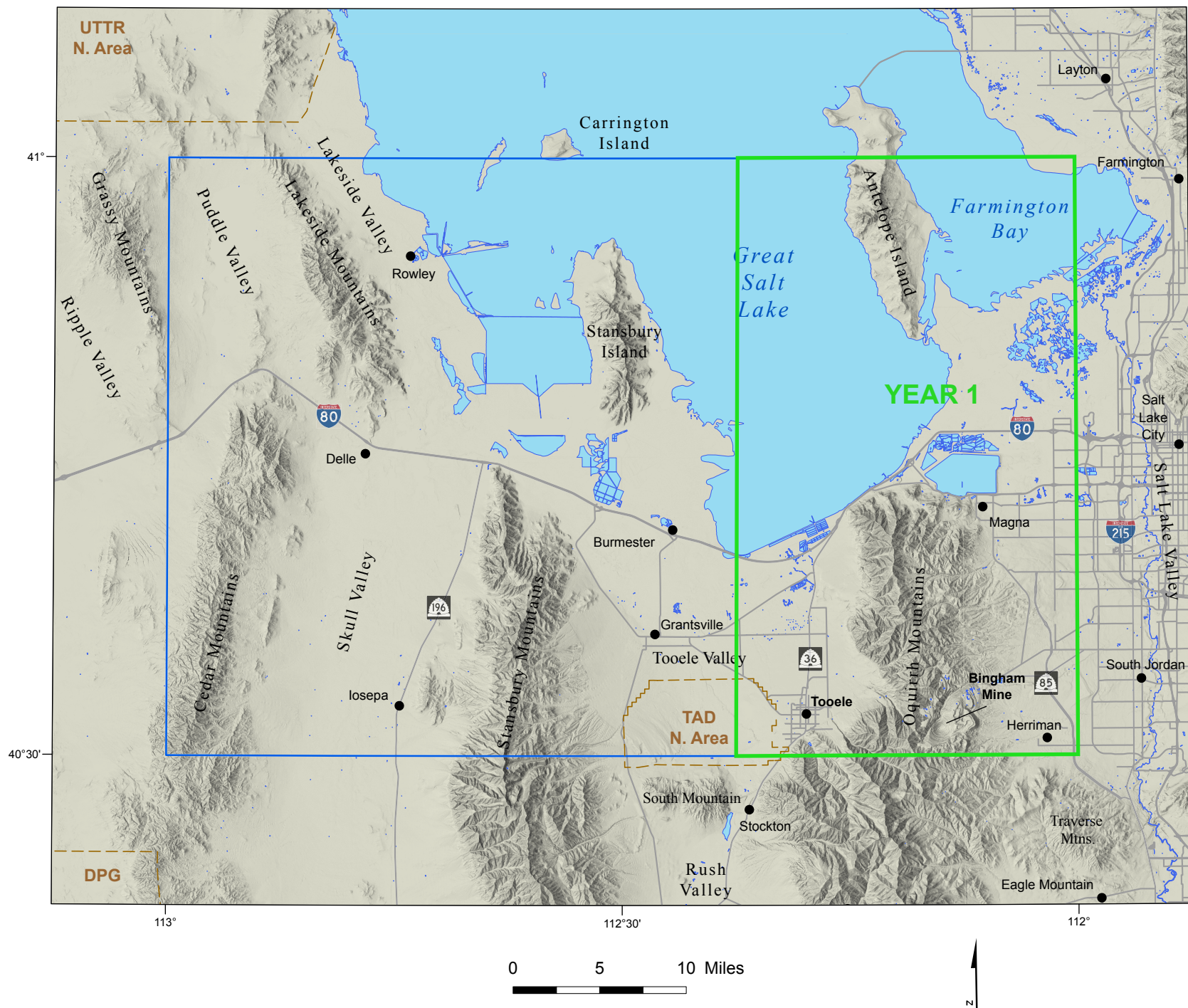


Figure 1. Location map showing primary geographic features in the Tooele 30' x 60' quadrangle. TAD is Tooele Army Depot. DPG is Dugway Proving Ground. UTTR is Utah Test and Training Range. The Great Salt Lake historic average elevation of 4200 feet (1280m) is depicted on this map.

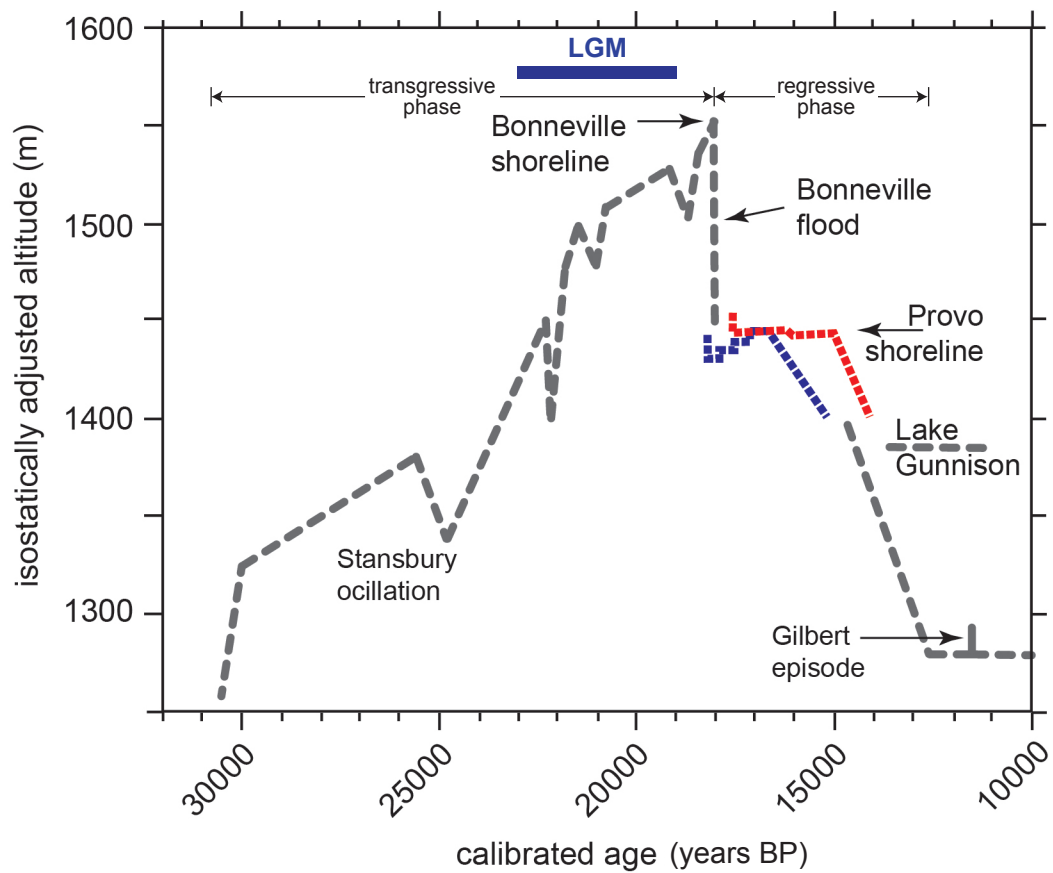


Figure 2. Simplified Lake Bonneville hydrograph and chronology. LGM is Last Glacial Maximum. The two alternatives for the Provo-shoreline level and chronology (red and blue lines) are from Miller and others (2013). Modified from Reheis and others (2014).

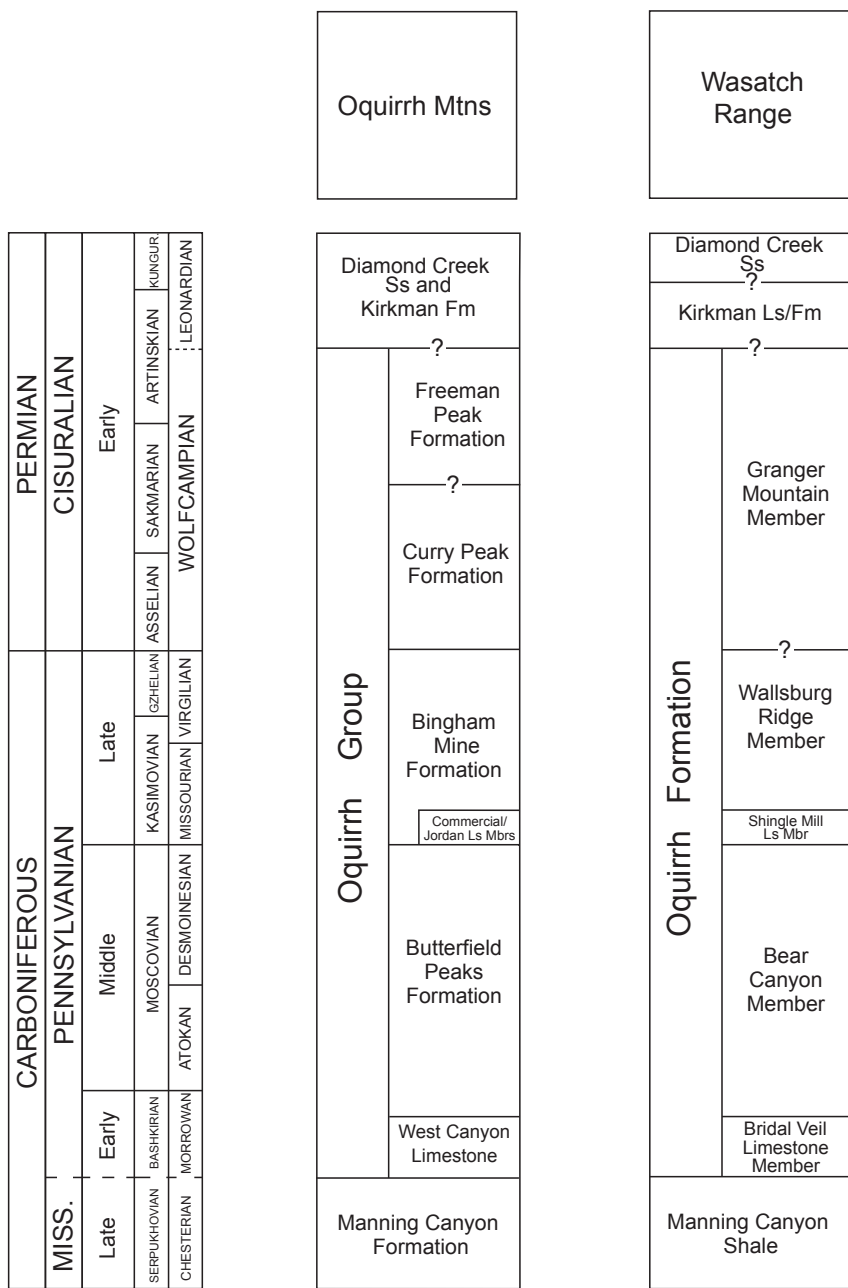
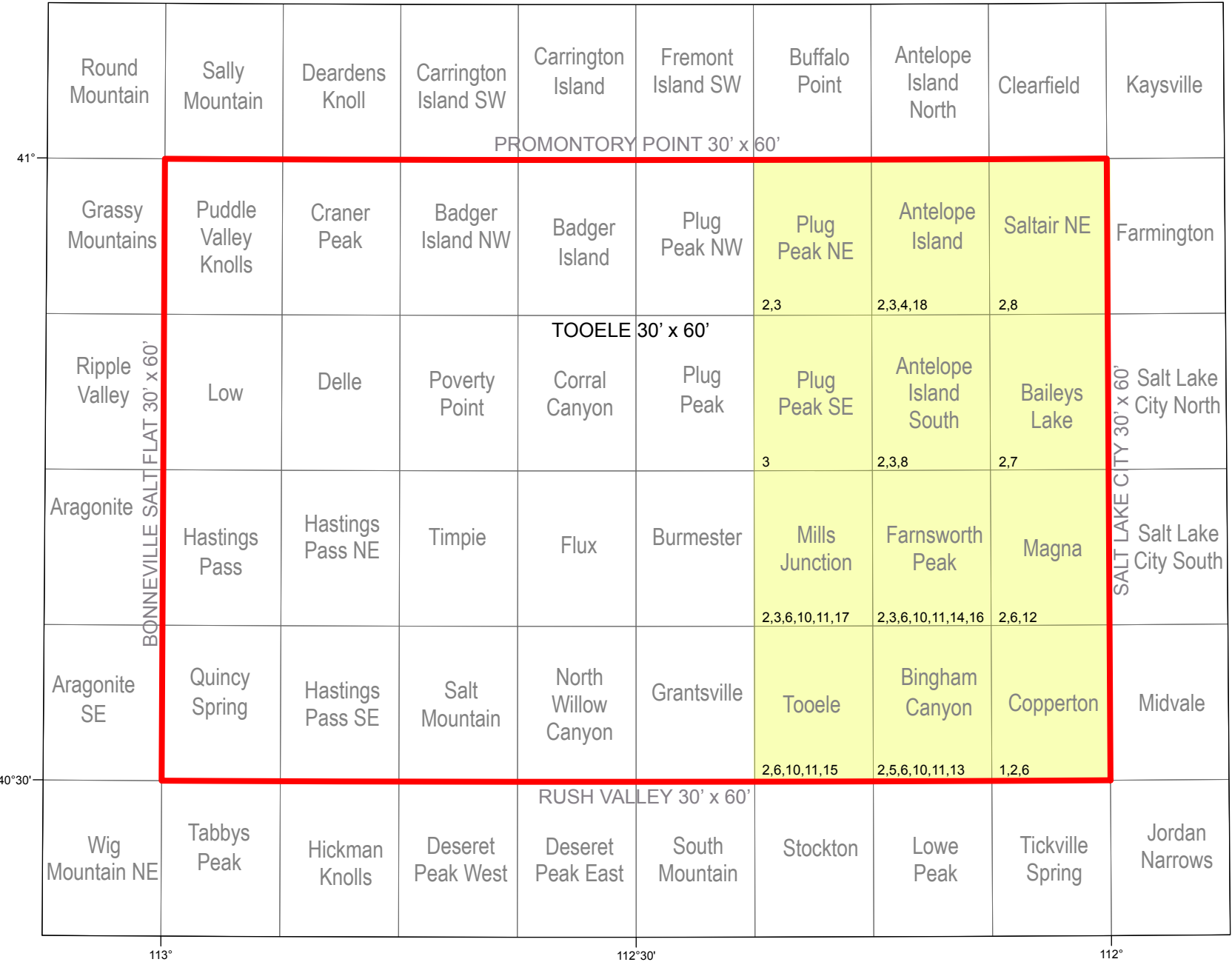


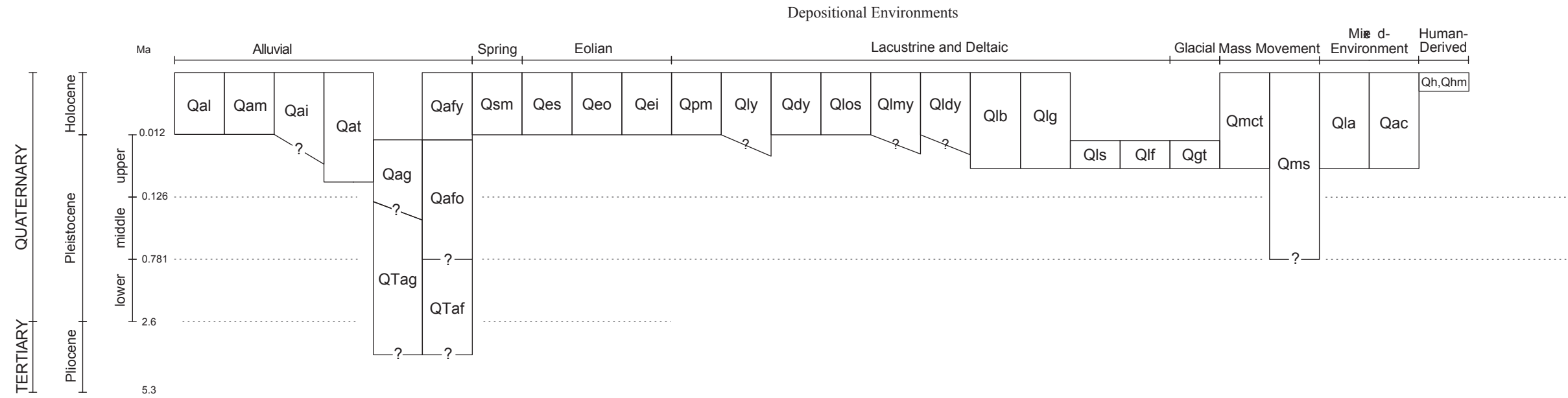
Figure 3. Comparison of Permian-Pennsylvanian nomenclature of the Oquirrh Group/Formation and other units used in this map and adjacent areas.



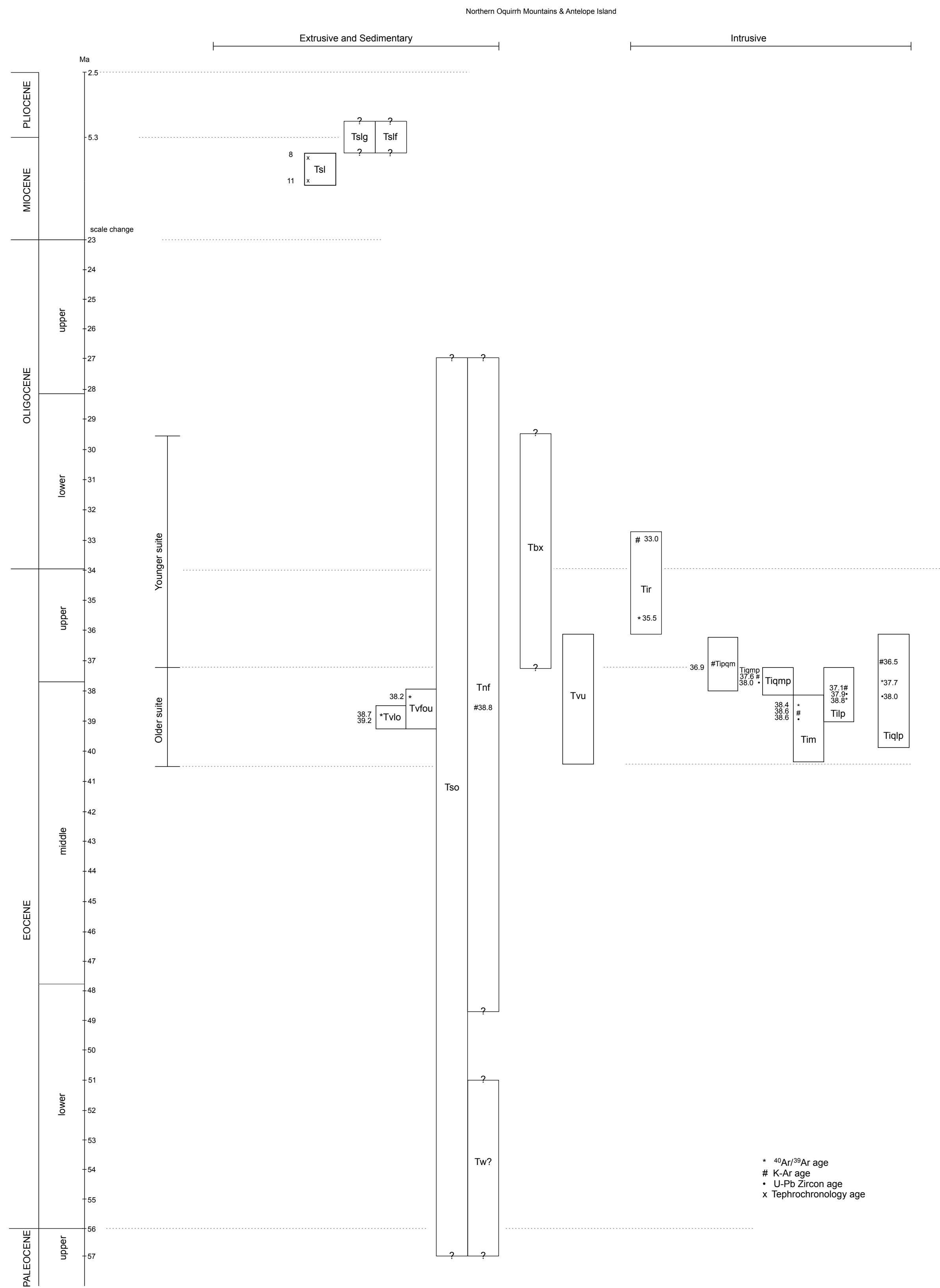
Primary Sources of Geological Mapping

- 1B iek and others (0)
- 2C lark,D .L. (UGS) and Oviatt,C .G. (KSU),0 Phot ogeologic and limited field mapping
- 3D inter (00)
- 4D oelling and others (9)
- 6L aes and others (9)
- 7M cKean and Hylland (0)
- 8M cKean (0)
- 9S churer (9)
- 0S olomon (9)
- 11S olomon (9)
- 2S olomon and others (0)
- 3S wensen and Kennecott staff (9)
- 4 Thomas (9)
- 5 Tooker (0)
- 6 Tooker and Roberts (9)
- 7 Tooker and Roberts (0)
- 8 Yonkee and others (0)

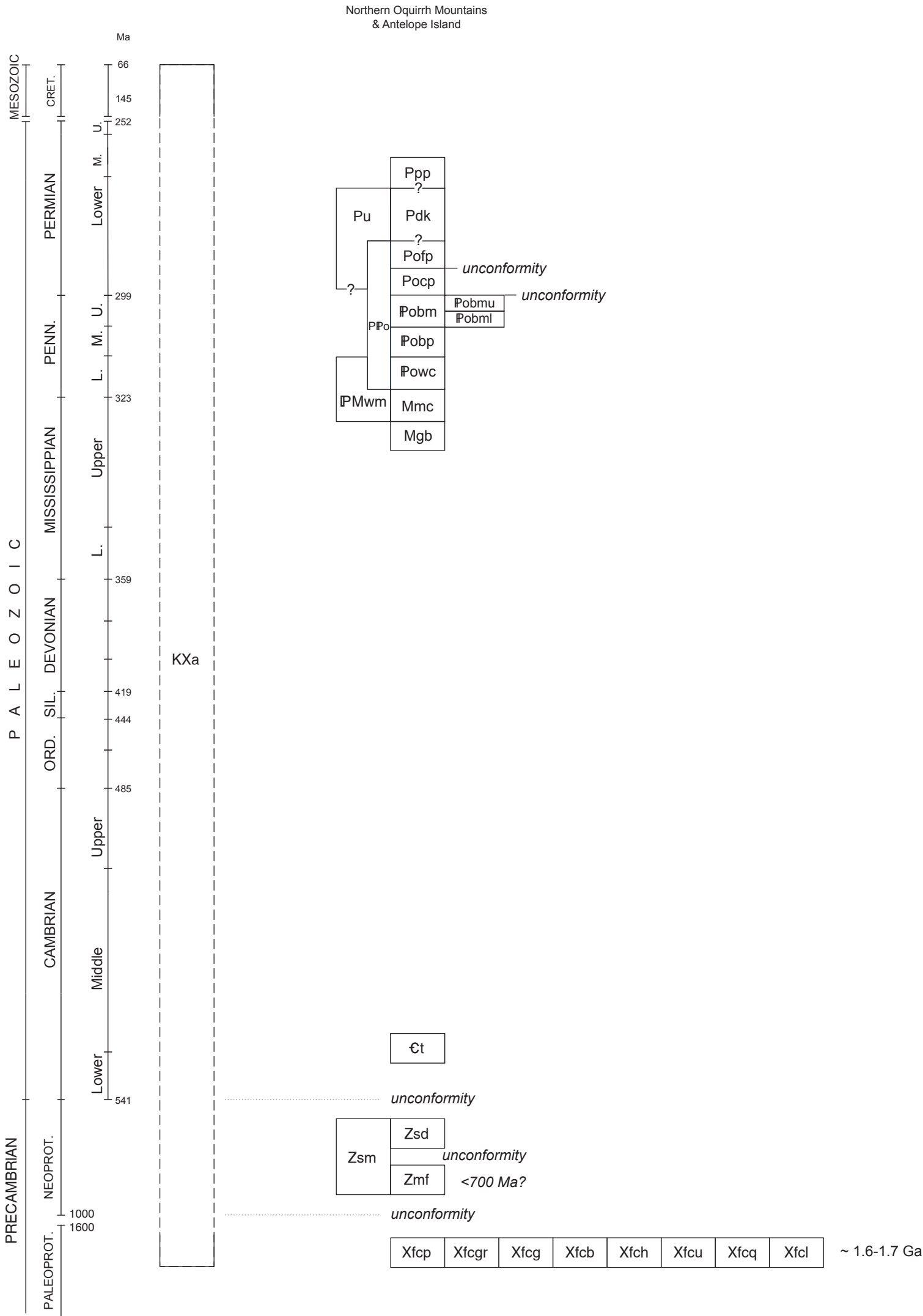
CORRELATION OF QUATERNARY-TERTIARY GEOLOGIC UNITS

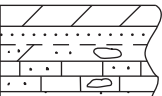
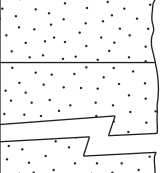
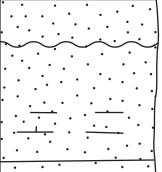
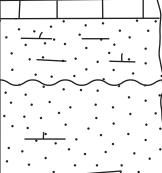
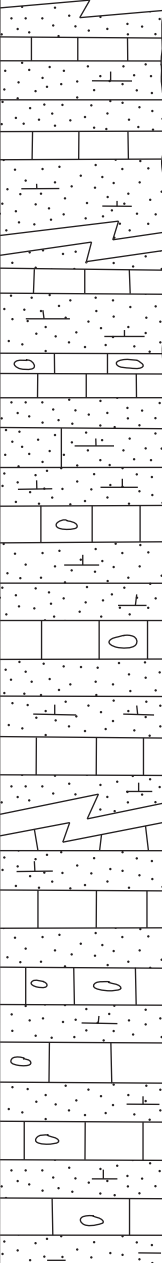
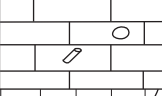
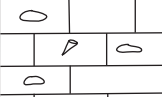
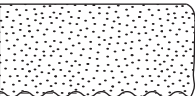
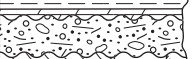
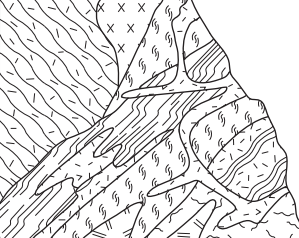


CORRELATION OF TERTIARY GEOLOGIC UNITS



CORRELATION OF MESOZOIC,P ALEOZOIC, AND PRECAMBRIAN GEOLOGIC UNITS



LITHOLOGIC COLUMN											
Northern Oquirrh Mountains and Antelope Island											
TIME-STRATI-GRAPHIC UNIT		GEOLOGIC UNIT		MAP SYMBOL	THICKNESS Feet (Meters)	LITHOLOGY					
Tertiary	Miocene-Eocene	Igneous and sedimentary rocks		see correlation chart	various		Salt Lake Fm. ~6–11Ma Older Tertiary strata ~27?–57? Ma Younger volcanic and intrusive suite ~30-37 Ma Older volcanic and intrusive suite ~37-40 Ma				
PERMIAN	Lower	Wolfcampian	Park City and Phosphoria Formations		Ppp	760+ (230+)		Contorted, folded, brecciated			
			Permian strata	Diamond Creek Sandstone and Kirkman Formation	Pu	Pdk	2000? (600?)				
			Freeman Peak Formation		Pofp		2400 (730)				
	Curry Peak Formation		Pocp		2450 (750)		Unconformity	worm trails			
	Upper	Missourian - Virgilian	Bingham Mine Formation		Pobm	Pobml	5300 (1615)	2200 (670)	3100 (945)		Unconformity
PENNSYLVANIAN	Middle	Atokan - Desmoinesian	Oquirrh Group		Butterfield Peaks Formation	Pobp	9072 (2766)		Cyclic lithologic character		
	Lower	Morrowan	West Canyon Limestone		Pmwm	Powc	1050 (320)		Commercial and Jordan Limestones		
MISSISSIPPIAN	Upper	Mera. ?-Chest.	Manning Canyon Formation			Mmc	477 (145)				
			Great Blue Limestone			Mgb	1400+ (430+)				
CAMBRIAN	L. - M.	Tintic Quartzite			€t	800+ (245+)		Unconformity Unconformity Major unconformity			
		Slate and Dolomite		Zsm	Zsd	70–280 (20–85)					
Neoprot.		Mineral Fork Fm.				Zmf	0–200 (0–60)				
Paleoproterozoic		Farmington Canyon Complex			Xfc_	----		Altered and deformed in Cretaceous (KXa) ~1.6–1.7 Ga			

GEOLOGIC SYMBOLS

	Contact – Dashed where gradational
	High-angle normal fault – Dashed where approximately located, dotted where concealed; bar and ball on down-thrown side
	Normal fault, geophysical – Located from shallow seismic data; dashed and dotted for Great Salt Lake fault; dotted for subsidiary faults; bar and ball on down-thrown side
	Strike-slip or oblique-slip fault – Dashed where approximately located, dotted where concealed; arrows and bar and ball indicate relative displacement
	Fault of unknown geometry – Dashed where approximately located, dotted where concealed
	Thrust fault – Dashed where approximately located, dotted where concealed; teeth on hanging wall
	Reverse fault – Dashed where approximately located; teeth on hanging wall
	Attenuation fault – Dotted where concealed; boxes on hanging wall
	Low-angle normal fault – Dotted where concealed; boxes on hanging wall
	Lineament – From air photo interpretation
	Extent of mine dumps
	Quartz vein
	Axial trace of anticline – Dashed where approximately located, dotted where concealed; arrow shows plunge
	Axial trace of overturned anticline – Dashed where approximately located, dotted where concealed; arrow shows plunge
	Axial trace of syncline – Dashed where approximately located, dotted where concealed; arrow shows plunge
	Axial trace of overturned syncline – Dashed where approximately located, dotted where concealed; arrow shows plunge
	Axial trace of monocline – Dotted where concealed
Lake Bonneville Shorelines –	
	Bonneville shoreline
	Provo shoreline
	Stansbury shoreline
	Great Salt Lake shoreline (historic average 4200 feet [1280 m])
	Glacial cirque headwall
	Landslide scarp – Hachures on down-dropped side
	Pit/Open pit mine extent – SE Antelope Island gravel pit, Bingham Canyon, Barneys Canyon, Melco mines
Sedimentary bedding attitude –	
	Inclined
	Vertical
	Overtured
Volcanic and metamorphic foliation attitude –	
	Inclined
	Vertical
	Mine or quarry
	Adit
	Shaft
	Sand and gravel pit
	Drill hole – Oil/Gas exploration
	Sediment core – Great Salt Lake and vicinity
	Ground water monitoring well
	Geochronology sample
	Geochemical sample
	Tephrochronology sample
	Fossil sample
	Paleoseismic trench
	Shear zone – Hatched area where part of unit KXa

