UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources

Plate 1
Utah Geological Survey Open-File Report 656
Interim Geologic Map of Parts
of the Tooele 30' x 60' Quadrangle, Year 3

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

2016

by

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SCALE 1:62,500

1 0.5 0 1 2 3 4 MILES

1 0.5 0 1 2 3 4 5 6 KILOMETERS

CONTOUR INTERVAL 20 METERS

GREAT SALT LAKE BATHYMETRIC CONTOUR INTERVAL 1 FOOT

UTAH

MAP LOCATION

TRUE MAGNETIC

APPROXIMATE MEAN DECLINATION, 2016

Disclaimer

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This map is a plot of geographic information system (GIS) files created to visually represent the content of the GIS data files. It is not a published map and it contains many features that do not meet UGS cartographic standards, such as automatically generated labels that may overlap other labels and lines.

Base from USGS Tooele 30' x 60' Quadrangle (1980)
Projection: UTM Zone 12
Datum: NAD 1927
Spheroid: Clarke 1866

Mapping by authors: 2013-2016
Project Manager: Robert F. Biek
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Interim Geologic Map of Parts of the Tooele 30′ x 60′ Quadrangle, Tooele, Salt Lake, and Davis Counties, Utah, Year 3

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UTAH DNR GEOLOGICAL SURVEY

OPEN-FILE REPORT 656
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
2016

INTRODUCTION

The Tooele 30′ x 60′ quadrangle straddles urban and rural areas and is west of Salt Lake City, in Tooele, Salt Lake, and Davis Counties, northwest Utah. The map area is 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 is part of an ongoing effort to map the geology of the state of Utah at an intermediate scale. This map shows the progress in the third year of a multi-year project to map the geology of the Tooele 30′ x 60′ quadrangle at 1:62,500 scale. Revisions to the map may occur in subsequent years of the project. Map data were compiled from several prior sources and updated where needed (see Primary Sources of Geologic Mapping). Clark revised the bedrock and surficial deposit geology, Oviatt revised the Quaternary-Tertiary geology (see also scientific updates to Lake Bonneville in Oviatt and Shroder, in preparation), and Dinter mapped the Great Salt Lake fault zone and Carrington fault (see also Dinter and Pechmann, 2014). Additional geologic and geotechnical data for the year 3 area are by Dames & Moore and others (1987). This map updates the prior regional-scale (1:250,000) geologic maps by Stokes (1963) and Moore and Sorensen (1979).

Locations of prior subsurface data (drill holes, sediment cores, monitoring wells), and new and prior surface samples for geochronology, fossils, and geochemistry are indicated on the map. These data will be tabulated in the fourth and final year of this multi-year project. The final map publication will also include geologic cross sections, gravity data, and GIS data.

We updated and made the stratigraphic nomenclature more consistent across the map area. In the description of bedrock geologic units we indicate various prior mapping/stratigraphic designations to show how the nomenclature has evolved over time.

GEOLOGIC UNIT DESCRIPTIONS

QUATERNARY-TERTIARY SURFICIAL DEPOSITS

Alluvial deposits

Qal **Alluvium, undivided** (Holocene) – Primarily clay, silt, and sand with some gravel lenses deposited by streams in channels and broad drainages; sediment reflects local sources; locally merges with alluvial-fan deposits; locally includes alluvial-fan, colluvial, low-level terrace, lacustrine, and eolian deposits; thickness generally less than about 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).

Qafy **Younger fan alluvium, post-Lake Bonneville** (Holocene to uppermost Pleistocene) – Poorly sorted gravel with sand, silt, and clay; deposited by streams, debris flows, and flash floods on alluvial fans and in mountain valleys; merges with unit Qal; 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 lake terraces and, due to limitations of map scale, is shown to abut Lake Bonneville shorelines, even though it is not cut by these shorelines; Qafy also locally drapes over, but does not completely conceal shorelines; thickness variable, to 50 feet (15 m) or more.

Qafo **Older fan alluvium, syn- and pre-Lake 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; includes fan surfaces of different levels; fans are incised by younger alluvial deposits and locally etched by Lake Bonneville; may locally include small areas of lacustrine or eolian deposits, and younger alluvium; thickness variable, to 100 feet (30 m) or more.

QTaf **Oldest fan alluvium, pre-Lake Bonneville** (lower Pleistocene? to Pliocene?) – Poorly sorted gravel with sand, silt, and clay; unconsolidated to semi-consolidated with calcic soil development on upper surfaces; forms high-level deposits incised by younger alluvial deposits and locally etched by Lake Bonneville; may overlap in age with unit Tslc; may locally include small areas of lacustrine or younger alluvial deposits; only a few deposits mapped at northern Cedar and Stansbury Mountains; thickness variable, as much as 100 feet (30 m).

Spring deposits

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

Eolian deposits

Qes **Eolian 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; only thicker deposits mapped; also mapped in stacked units; less than 15 feet (5 m) thick.

Qeo **Eolian oolitic sand** (Holocene) – Deposits of windblown sand composed of oolites formed in Great Salt Lake; forms sparsely vegetated, active dunes on shores of Stansbury Island and northern Antelope Island and in Lakeside Valley; 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 sand, and pelletal sand composing the bed of Great Salt Lake and some higher adjacent areas, and much of the floor of Skull Valley; 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; gradational with units Qal, Qlf, Qlk; the extent of Great Salt Lake is indicated on the map by the historic average altitude of 4200 feet (1280 m) (Baskin and Allen, 2005; U.S. Geological Survey, 2016); the historic highstand of Great Salt Lake was 4212 feet (1284 m) in 1873, 1986, and 1987 (U.S. Geological Survey, 2016), and Atwood (2006) reported on shoreline superelevation in 1986–1987 that locally exceeded 4212 feet (1284 m) due to prevailing wind fetch; the historic lowstand was 4191 feet (1278 m) in 1963 (U.S. Geological Survey, 2016); 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-Lake 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).

Qlk **Younger lacustrine carbonate-chip sand and gravel** (Holocene) – Lacustrine sand and gravel primarily composed of calcium-carbonate clasts, including ooids, pellets, and rounded, irregularly shaped flakes and chips, with some pebbles of local rocks; formed on the floor of Great Salt Lake when the mudflats (unit Qpm) were submerged, or were precipitated from pore waters in mud, and later reworked by waves; locally present in barrier bars and islands fringing Great Salt Lake and some beaches of Antelope Island; locally grades into units Qla and Qpm; 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 where it entered Great Salt Lake; locally include 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 were winnowed out by waves, 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 shore zones of Great Salt Lake and Lake Bonneville; clasts are typically well rounded and sorted; locally tufa-cemented (especially the Provo shoreline, figure 2) 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); can include thin eolian sand deposits at surface; thickness to 100 feet (30 m) or more.

Qlt **Lacustrine tufa** (upper Pleistocene) – Light-gray tufa with laminated and vuggy appearance; locally caps small hills in six small exposures located just below Provo shoreline near Redlam Spring, northern Cedar Mountains; other unmapped deposits in northern Oquirrh Mountains; thickness as much as 10 feet (3 m).

Glacial deposits

Qgt **Glacial till** (upper Pleistocene) – Poorly sorted gravel, sand, and mud in eroded moraines within cirque basins in northern Stansbury and Oquirrh Mountains; locally includes glacial outwash, and some small areas of younger alluvium and colluvium; gravel is typically angular and poorly sorted; till is probably associated with the younger Pinedale/Angel Lake glaciation, ~12 to 24 ka, and the older Bull Lake/Lamoille glaciation, ~130 to 190 ka (Pierce, 2004); Osborn and Bevis (2001) reported on glacial deposits in the Stansbury and Oquirrh Mountains, older till may be present downslope of the younger till; 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 located across the map area; common near Lake Bonneville shorelines; thickness up to 15 feet (5 m).

Qms **Landslide deposits** (Holocene to middle? Pleistocene) – Poorly sorted, clay- to boulder-size material, and large, displaced blocks; generally characterized by hummocky topography, main and internal scarps, and chaotic bedding in displaced bedrock; also includes several displaced bedrock blocks 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), which was subsequently altered to allow access to the mine operations; 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 alluvial deposits reworked by lakes, lacustrine deposits reworked by streams and slopewash, and alluvial and lacustrine deposits that cannot be readily differentiated at map scale; can grade into other lacustrine and alluvial deposits; thickness locally exceeds 30 feet (10 m).

Qac **Alluvial and colluvial deposits, undivided** (Holocene to upper Pleistocene) – Mixed alluvium and colluvium locally in upland valleys and along bases of slopes; clay- to boulder-size materials; 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 some Kennecott/Rio Tinto and former mining operations, gravel pits and quarries, landfills, wastewater and storm water ponds, the Grantsville reservoir, motor sports area, and thicker fill for Interstate Highway 80 and its overpasses; also mapped in several stacked units; laterally extensive mine dumps, and tailings and evaporation ponds are mapped separately (see below); additional unmapped disturbed areas and smaller fill deposits are common throughout the map area; thickness generally less than about 20 feet (6 m).

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).

Qht **Tailings impoundment** (Historical) – Large mine tailings disposal area of Kennecott/Rio Tinto located at the north end of the Oquirrh Mountains; aboveground diked area contains unconsolidated, fine-grained mine tailings that have been slurried and pumped to this location; also includes some areas of human disturbance; maximum thickness planned to be as much as 247 feet (75 m); maximum permitted elevation of the active north tailings pond is 4462 feet (1360 m), and the average elevation of the inactive south pond is 4430 feet (1350 m), with an original ground surface elevation in this area of ~4215 feet (~1285 m) (Leslie Heppler, Utah Division of Oil, Gas and Mining, verbal communication, June 21, 2016).

Qhe **Evaporation ponds** (Historical) – Laterally extensive salt evaporation ponds (both active and inactive) operated by various companies near the southern margin of Great Salt Lake; lake water is pumped to a series of diked areas that contain brine of varying concentrations and evaporates to form salt deposits; thickness is typically less than 10 feet (<3 m).

Stacked-unit deposits

Qh/unit (Qh/Tbx, Qh/Tsl, Qh/Tnf, Qh/Tso, 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 unit 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/Tso, 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 surficial deposit and 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).

Qes/unit (Qes/Qafy, Qes/Qla, Qes/Qlg, Qes/Qafo, Qes/TKs)

Eolian sand over unit (Holocene over Holocene, Pleistocene, Tertiary?, Cretaceous?) – Eolian sand forming a mantle on other surficial deposits and rock units, particularly along the flanks of the northern Cedar Mountains and southern Lakeside Mountains; thickness is highly variable, but possibly as much as 60 feet (20 m).

QTaf/Tslc

Oldest fan alluvium over Salt Lake Formation, conglomerate lithosome (lower Pleistocene? to Pliocene? over Pliocene? to Miocene) – Quartzite-clast gravel overlying conglomerate unit along east flank of northern Stansbury Mountains; thickness of QTaf is from 0 to about 350 feet (105 m).

TERTIARY (NEOGENE-PALEOGENE) ROCK UNITS

Tsl **Salt Lake Formation, undivided** (Pliocene? to 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) and in Hastings Canyon area, northern Cedar Mountains (Maurer, 1970, his "Tertiary unnamed unit"; this study); 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 Antelope Island indicate ages from ~8 to 11 Ma (Willis and Jensen, 2000), and a fission-track age of 6.1 Ma (Bryant and others, 1989) appears too young (Willis and Jensen, 2000); no direct age data from Hastings Canyon, but interbedded with unit Tb; unit Tsl unconformably overlies older rock units; incomplete thicknesses are about 1800 feet (550 m) at Antelope Island (Doelling and others, 1990), and 300 feet (90 m) at Hastings Pass/Redlam Spring area in northern Cedar Mountains.

Tslc **Salt Lake Formation, conglomerate lithosome** (Pliocene? to Miocene) – Conglomerate, tuffaceous sandstone and gritstone, minor limestone and volcanic ash; clast composition includes volcanic, quartzite, and carbonate rock types; mapped on east and west flanks of northern Stansbury Mountains; east flank exposures are mapped as unit QTaf/Tslc since overlying quartzite-clast fan gravels cannot be readily separated at map scale; tephrochronology age from South Willow Canyon is about 11 Ma (Cougar Point Tuff XIII) (Perkins and others, 1998; Clark and others, 2012); underlying basalt from Muskrat Canyon area is 12.1 Ma (K-Ar age) (Moore and McKee, 1983); may overlap in age with unit QTaf; Rigby (1958) reported on conglomerate composition in South Willow Canyon, but did not map the formation; Slentz (1955) measured sections in South Willow and Davenport Canyons; exposed (incomplete) thickness as much as 3500 feet (1065 m).

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

Tslf **Salt Lake Formation, fine-grained lithosome** (Pliocene? to upper 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); new tephrochronology data indicate deposits contain Blacktail Creek ash (6.62 Ma), Walcott ash (6.4 Ma), and Wolverine Creek ash (5.6 Ma?) (UGS and others, 2015); yielded anomalously young 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 upper 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); new tephrochronology data indicate the deposits contain Blacktail Creek ash (6.62 Ma) (UGS and others, 2015); 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?) – ***Antelope Island,*** conglomeratic strata on eastern Antelope Island where relationship to units Tnf or Tw? is 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); exposed northwest of large gravel pit; Doelling and others (1990) previously mapped as part of lower member of unnamed conglomeratic unit; unconformably overlies the Farmington Canyon Complex and underlies the Salt Lake Formation; complete thickness about 190 feet (60 m) (Doelling and others, 1990); ***northern 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 maximum depositional age of 40 Ma from Harkers Canyon (unpublished data, 2015, GeoSep Services), and regionally the unit could extend into the Oligocene; 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); ***northern Stansbury Mountains,*** outcrops near Davenport Canyon of pale-reddish-orange conglomerate with primarily subrounded limestone and dolomite clasts and lesser sandstone and quartzite clasts; clasts typically less than 4 inches (10 cm) in a gritty, calcareous matrix; poorly bedded and exposed; previously called North Horn? Formation (Rigby, 1958); no direct age data, but underlies volcanic rocks (unit Tvs, 39–42 Ma); thickness as much as 400 feet (120 m) (Rigby, 1958).

Tnf **Norwood Formation 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 42.9 Ma (claystone/bentonite), and 38.8 and 49.2 Ma on recycled volcanic clasts (Doelling and others, 1990), and regionally the unit could extend into the Oligocene; thickness is about 300 feet (90 m) (measured sections S1, S2, Willis and Jensen, 2000).

Tw? **Wasatch Formation?** (Eocene? to Paleocene?) – 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 at Antelope Island; 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).

Volcanic Rocks of the Northern Stansbury Mountains and Northern Cedar Mountains

Tb **Trachybasalt** (Miocene?) – Dark-gray, locally vesicular, aphanitic, potassic trachybasaltic lava flows; locally vesicular; forms ledges and cliffs in northern Cedar Mountains (Hastings Canyon), northern Stansbury Mountains (Muskrat Canyon), and Salt Mountain area; Hogg (1972) provided some geochemical data, and new data were obtained; prior K-Ar ages (whole rock) of 12.1 ± 0.3 Ma (northern Stansbury Mountains) and 13.8 ± 0.4 Ma (northern Cedar Mountains) (Moore and McKee, 1983), but Nevada Isotope Geochronology Laboratory reports that the groundmass on a sample we submitted is too altered for a reliable $^{40}Ar/^{39}Ar$ age (northern Stansbury Mountains); thickness from 0 to 115 feet (0–35 m) (Davis, 1959; Maurer, 1970).

Ts **Shoshonite** (Miocene? or Oligocene?) – Moderate-gray aphanitic, shoshonitic lava flows; forms cliffs, ledges, and slopes in Mack Canyon-Miners Canyon area; Hogg (1972) provided some geochemical data, and we obtained some new data; previously called basalt (Rigby, 1958; Davis, 1959); prior K-Ar age of 12.7 ± 0.2 Ma (Moore and McKee, 1983), but Nevada Isotope Geochronology Laboratory reports that the groundmass on a sample we submitted is too altered for a reliable $^{40}Ar/^{39}Ar$ age; thickness from 0 to about 125 feet (0–40 m) (Rigby, 1958).

Tvs, Tvls

Rhyolitic to andesitic volcanic rocks of Stansbury Mountains (Eocene) – Interlayered extrusive volcanic and volcanosedimentary rocks in eastern Stansbury Mountains and Salt Mountain area; includes gray to red to brown lava flows, tuffs, lahars, debris avalanches, and tuffaceous sandstone; lahars and debris avalanches contain clasts of intermediate volcanic rocks; previously called latite volcanic series (Rigby, 1958) and andesites and associated rocks (Davis, 1959); in Davenport Canyon within unit Tvs is a pod of lacustrine limestone (unit Tvls), up to about 200 feet (60 m) thick, that was previously mapped as Great Blue Limestone (Rigby, 1958); unit Tvs and Tvls form slopes, ledges, and cliffs; new geochemical data show compositional range from rhyolite to dacite, trachydacite, and andesite (UGS, 2015, unpublished data); prior K-Ar ages of 39.4 ± 0.5, 40.6 ± 1.7, and 41.8 ± 0.5 Ma (Moore and McKee, 1983), and new $^{40}Ar/^{39}Ar$ plateau ages on biotite of 39.68 ± 0.50 and 41.30 ± 0.60 Ma (Nevada Isotope Geochronology Laboratory, 2015, unpublished data); thickness of unit Tvs is 740 feet (225 m) (Salt Mountain) and 1630 feet (500 m) (eastern Stansbury Mountains) (Rigby, 1958; Davis, 1959).

Tirs **Rhyolite and trachydacite porphyry intrusions of Stansbury Mountains** (Eocene) – Light-gray to light-greenish-gray porphyritic rhyolite and trachydacite plugs, dikes, and sills; phenocrysts include plagioclase, hornblende, and biotite; present along axis of Deseret anticline and near North Willow and Mack Canyons; new geochemical data were obtained; mapped as monzonite porphyry (Rigby, 1958) and andesite and trachyandesite porphyry (Davis, 1959); Rigby's small monzonite? plug was not located; K-Ar ages of 39.0 ± 0.6 and 40.3 ± 0.5 Ma (Moore and McKee, 1983).

Volcanic Rocks of the Northern and Central Oquirrh Mountains

Volcanic rocks in the Bingham mining district 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 historical usage at Bingham mine (for the purpose of separating similar rock units); it is entrenched and does not necessarily reflect geochemical composition and newer geochemistry-based rock classifications. Information on Bingham area geology and ore genesis is provided in numerous publications, including Moore (1973), Bray and Wilson (1975), Economic Geology (1978), Black and Babcock (1991), Chesley and Ruiz (1997), 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 and others (1968), Moore and Lanphere (1971), Moore (1973), Warnaars and others (1978), 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); uncertain age of pipes and bodies, but 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 (latite) overlying unit Tw? near Harkers Canyon; probably associated with older volcanic and intrusive suite rocks at Bingham (see below).

Younger Volcanic and Intrusive Suite (early Oligocene to late Eocene, ~30–37 Ma) – Younger volcanic and intrusive rocks are present in the western Traverse Mountains (Biek and others, 2005; Clark and others, 2012, in preparation).

<u>Younger Intrusive Rocks</u>

Tir **Rhyolitic intrusion** (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; $^{40}Ar/^{39}Ar$ 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, 2012, in preparation).

Older Volcanic and Intrusive Suite (upper to middle Eocene, ~37–41 Ma) – 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).

<u>Older Extrusive and Sedimentary Rocks</u>

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 avalanches (unit Tvlo); present along the east flank of the Oquirrh Mountains; $^{40}Ar/^{39}Ar$ 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 avalanches** (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 $^{40}Ar/^{39}Ar$ ages of 38.68 ± 0.13 Ma from waterlain tuff near top of unit (Maughan, 2001) and 39.18 ± 0.11 Ma from a 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).

<u>Older Intrusive Rocks</u>

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). 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 (K. Krahulec, UGS, verbal communication, July 2015); 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); U-Pb zircon age of 37.94 ± 0.08 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 U-Pb zircon age of 38.55 ± 0.19 Ma, and $^{40}Ar/^{39}Ar$ 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 Calumet 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); $^{40}Ar/^{39}Ar$ 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 and sills** (late to 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 and sills 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; new geochemical data obtained), and the Andy Dike and apophyses at Bingham mine (KUCC, 2009); $^{40}Ar/^{39}Ar$ 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 ± 1.1 Ma (Moore, 1973); Raddatz dike has $^{40}Ar/^{39}Ar$ age of 39.4 ± 0.34 Ma (Kennecott, unpublished age in Krahulec, 2005).

TERTIARY (PALEOGENE)-CRETACEOUS ROCK UNIT

TKs Tertiary-Cretaceous strata (lower Eocene? to Upper Cretaceous?) – Predominantly moderate-reddish-orange mudstone with lesser red and gray conglomerate, sandstone, and siltstone; conglomerate clasts include sandstone, limestone and chert (likely derived from Permian formations) as much as 18 inches (46 cm) in diameter; bedding is laminated to very thick; crops out as slopes and few ledges in western foothills between Hastings Canyon and Quincy Spring, northern Cedar Mountains; present in footwall of the Cedar thrust fault near Quincy Spring; gastropod fossils include *Gyraulus* sp. and other fauna, reportedly late Paleocene or Eocene (LaRoque in Maurer, 1970), but no detrital zircon age analyses yet; previously called the North Horn? Formation (Maurer, 1970); thickness from 0 to 1100+ feet (0–335+ m) (Maurer, 1970; this study).

TRIASSIC TO NEOPROTEROZOIC ROCK UNITS

T̶Rd **Dinwoody Formation** (Lower Triassic) – Moderate-brown limestone and lesser light-brown shale; laminated to thinly bedded forming slopes and ledges; mapped in two small outcrops located 2 miles (3 km) west-southwest of

Hastings Pass, northern Cedar Mountains; not recognized by Maurer (1970); no age data obtained; disconformably overlies unit Pgp; incomplete thickness is about 100 feet (30 m) or less.

Pgp **Gerster Formation and Plympton Formation?** (Middle Permian, Guadalupian) – Light-brown and light-gray limestone, cherty limestone, and dolomite; locally common chert nodules (gray, tan, pink) (Maurer, 1970); Wardlaw and others (1979) reported different lithologies [they provided no details on measured section and fossil locations]; locally fossiliferous with brachiopods, pelecypods, gastropods (Maurer, 1970); bedding is medium and thin forming steep, rough slopes; crops out near the crest of the northern Cedar Mountains and south of Hastings Pass; Maurer (1970) considered the unit all Gerster Formation, while Wardlaw and others (1979) indicated the top part is Gerster Limestone (*Kuvelousia* biostratigraphic zone) and underlying part is the Plympton Formation (*Thamnosia* biostratigraphic zone, but no fossil data there) [note that the Permian time scale has changed over time]; we do not apply the Park City Group nomenclature of Wardlaw and others (1979) pending further study; the Gerster is considered correlative to the upper Franson Member of the Park City Formation (east), while the Plympton is considered correlative to the Murdock Mountain Formation (west) and Rex Chert and lower Franson Member (east) (Wardlaw and others, 1979); complete thickness is about 1000 feet (305 m) (this study), whereas Maurer (1970) and Wardlaw and others (1979) [note incorrect scale bar] reported incomplete thicknesses of 511 to 870 feet (156–265 m).

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 these updated 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, 2012, 2016). Clark and others (2016) revised the Oquirrh Group stratigraphy in the Cedar Mountains from that of Maurer (1970). The Oquirrh Group facies and nomenclature changes from the Cedar Mountains to the Grassy Mountains.

We do not use the term Kessler Canyon Formation in this map area. 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). However, Swensen (1975) and Welsh (1998) noted that east of the Garfield fault (located near Kessler Canyon) 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 strata formerly mapped as the Kessler Canyon Formation south of the Arthur fault (located near Little Valley Wash) to Permian strata, undivided (Pu), while west of the Garfield fault and north of the Arthur fault we reinterpret most of the former Kessler Canyon Formation as the Oquirrh Group, Bingham Mine Formation.

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 (faulted), and used informal upper and lower members. The informal members are not mapped outside of the Bingham district due to map scale considerations.

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 Member of the Phosphoria Formation (Biek in Solomon and others, 2007); upper part (Franson) contains gray dolomite and tan quartzite (261+ feet [80+ m] thick); middle part (Meade Peak) includes platy, shaley dolomite, quartzite, sandstone, shale, chert, and phosphorite (284 feet [87 m] thick); lower part (Grandeur) consists of gray to light-brown limestone that is bioclastic, sandy, and cherty (215 feet [65 m] thick) (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, undivided (Welsh and James, 1961; Gunter, 1991; Laes and others, 1997), 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); limestone from the Meade Peak part recently yielded conodont *Neostreptognathodus sulcoplicatus* of late Leonardian (Kungurian) age (S.M. Ritter, BYU, written communication to D.L. Clark, Dec. 3, 2014); several fossils from the lowermost limestone (Grandeur) indicate a Leonardian to possible Wordian? age (Gordan and Duncan in Tooker and Roberts, 1970), and this limestone recently yielded conodont *Neostreptognathodus* sp. of

Leonardian age (S.M. Ritter, Brigham Young University, written communication to D.L. Clark, Dec. 3, 2014); top eroded, but incomplete thickness of 760 feet (230 m) was measured by Tooker and Roberts (1970) at Coon Canyon, and Kennecott cross section at Barneys Canyon (Gunter, 1991 and plate 4) indicates incomplete thickness of about 350 feet (110 m).

Ppm **Phosphoria Formation, Meade Peak Member** (Lower Permian, Leonardian) – Black and gray shaley phosphatic rock with interbedded chert and dolomite; contains oolitic phosphatic layers, and layers rich in brachiopods, vertebrate teeth, and skeletal fragments; forms covered slopes and few ledges at northern Cedar Mountains; contains fossil *Helicoprion* sp. (shark-like fish) and lingulid brachiopod molds (Maurer, 1970); Wardlaw and others (1979) included Meade Peak strata in their *Penicularis* (brachiopod) biostratigraphic zone; thickness is 75 to 141 feet (23–43 m) (Maurer, 1970; Wardlaw and others, 1979).

Ppg **Park City Formation, Grandeur Member** (Lower Permian, Leonardian) – Moderate-gray and light-brownish-gray limestone, dolomitic limestone, and dolomite that is finely crystalline and bioclastic; light-brown and gray chert is locally abundant and minor amounts occur throughout the member; can form two cliffs separated by a thin slope-forming unit; crops out south of Hastings Pass, northern Cedar Mountains; Maurer (1970) stated that brachiopod fossils suggest a Leonardian age, while Wardlaw and others (1979) reported *Quadrochonetes*, *Echinauris*, and *Peniculauris* (brachiopods) of the *Penicularis* biostratigraphic zone; we do not apply the Park City Group nomenclature of Wardlaw and others (1979) pending further study; thickness is 419 to 575 feet (128–175 m) (Maurer, 1970; Wardlaw and others, 1979).

Psl **Sandstone, limestone and dolomite** (Lower Permian, Leonardian) – Gray to light-brown sandstone, limestone, and lesser dolomite; sandstone is fine to medium grained with calcareous cement and tabular cross beds; carbonate rocks are finely crystalline, locally with chert and calcite nodules, and locally with brachiopods and gastropods; medium to thick bedded forming steep, ledgey slopes at northern Cedar Mountains; base of formation yielded fusulinids *Parafusulina* of Leonardian age (Clark and others, 2016); previously mapped as "Permian unnamed formation" (Maurer, 1970); may correlate with the Pequop Formation (west) and Diamond Creek Sandstone (east); complete thickness is 3953 feet (1205 m) (Maurer, 1970).

Pu **Permian strata, undivided** (Lower Permian, Leonardian? to Wolfcampian?) – Combined unit at northern Oquirrh Mountains 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 northern 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 slump 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 (located near Nelson Peak) and Midas thrust (located in Bingham mine) and Bear fault (located west of Freeman Peak), 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).

Pℙo **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).

Pofc **Oquirrh Group, Freeman Peak Formation and Curry Peak Formation, undivided** (Lower Permian, Wolfcampian) – Combined unit in the northern Cedar Mountains and southern Lakeside Mountains; medium- to dark-gray, weathering to yellowish-gray, calcareous, fine-grained sandstone and siltstone with lesser interbedded very pale orange, medium-gray and pale-red quartz sandstone and orthoquartzite (particularly in upper part) and uncommon gray sandy limestone; laminated to thick-bedded unit typically breaks into chips and plates forming rounded hills and slopes with occasional ledges; "worm trail" markings common on bedding planes in lower part of unit; fusulinids reported by Maurer (1970) and Clark and others (2016); appears to be conformable with underlying Bingham Mine Formation; corresponds to most of Maurer's (1970) Oquirrh Formation Unit 4 and Unit 5, and Young (1953) mapped as Oquirrh Formation, undivided; Clark and others (2016) reported 3500 feet (1065 m) in Cedar Mountains; incomplete thickness in southern Lakeside Mountains possibly 2600 feet (790 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, northern Oquirrh Mountains (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) at 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 weather 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, northern Oquirrh Mountains; previously referred to as Curry formation (Welsh and James, 1961); unconformable on underlying Bingham Mine Formation (Welsh and James, 1961), but not observed south or west of the map area (Clark and others, 2012, 2016); 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).

ℙo **Oquirrh Group, Pennsylvanian formations, undivided** (Pennsylvanian) – Combined unit likely of Bingham Mine Formation?, Butterfield Peaks Formation, and West Canyon Limestone where backthrusted and structurally deformed along the east side of the northern Cedar Mountains; locally may include small outcrops of Manning Canyon Formation; also mapped in the Cedar thrust sheet (west side) where there is no biostratigraphic control, but Clark and others (2016) assumed the Cedar Mountains Oquirrh Group stratigraphy remained valid there based on lithofacies; largely corresponds to Maurer's (1970) Oquirrh Formation Units 1, 2, and 3.

ℙobm **Oquirrh Group, Bingham Mine Formation** (Upper Pennsylvanian, Virgilian-Missourian) – 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; Commercial and Jordan Limestone marker beds present at base of formation only in the central Oquirrh Mountains; previously mapped as the Kessler Canyon Formation of the northern Oquirrh Mountains (Tooker and Roberts, 1970); fossil age data from the northern Oquirrh Mountains exposures are limited (Tooker and Roberts, 1970; Welsh, 1998), but recently yielded conodont *Streptognathodus pawkuskaensis* of Virgilian (Gzhelian) age (S.M. Ritter, BYU, written communication to D.L. Clark, Dec. 3, 2014); fusulinids reported from Cedar Mountains by Maurer (1970) and Clark and others (2016), and southern Lakeside Mountains yielded *Triticites* sp. (S.M. Ritter, BYU, written communication to D.L. Clark, July 1, 2016); corresponds to upper part of Maurer's (1970) Unit 3 and lower part of Unit 4; in northern Oquirrh Mountains, 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 (this study); complete thickness is 2700 feet (825 m) in Cedar Mountains (Clark and others, 2016), and possibly that thick in southern Lakeside Mountains.

IPobmu

Oquirrh Group, Bingham Mine Formation, upper member (Upper Pennsylvanian, Virgilian-Missourian) – Light-gray to tan, thinly color-banded and locally cross-bedded 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 at 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 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 were 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).

IPobw **Oquirrh Group, Butterfield Peaks Formation and West Canyon Limestone, undivided** (Middle to Lower Pennsylvanian) – Mapped as combined unit in eastern Stansbury Mountains and southern Lakeside Mountains, where unclear separation of formations due to sandy intervals in West Canyon Limestone; limited conodont data indicated Pennsylvanian age in southern Lakeside Mountains (S.R. Ritter, Brigham Young University, written communication to D.L. Clark, March 1, 2016); incomplete thickness about 550 feet (170 m) in northern Stansbury Mountains, and possibly 4000 feet (1220 m) thick in southern Lakeside Mountains.

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 quartzite and calcareous sandstone are 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, and clastic percentages increase 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); in Cedar Mountains corresponds to Maurer's (1970) Oquirrh Formation Unit 2 and most of Unit 3; fossil age data in Welsh and James (1961), Maurer (1970), Tooker and Roberts (1970), Douglass and others (1974), Swensen (1975), Davis and others (1989, 1994), Welsh (1998), Konopka (1999), Clark and others (2016); conodont data in the northern Oquirrh Mountains indicate 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) at 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; 4150 feet (1265 m) thick in Cedar Mountains (Clark and others, 2016).

IPMwm

Oquirrh Group, West Canyon Limestone and Manning Canyon Formation, undivided (Lower Pennsylvanian, Morrowan 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** (Lower Pennsylvanian, Morrowan) – 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, along North Oquirrh thrust (Bates Canyon-Nelson Peak area), and in a few small exposures south of Henry Spring, northern Cedar Mountains; includes the upper two-thirds of the Lake Point Limestone of Tooker and Roberts (1970) in the northern Oquirrh Mountains based on lithofacies and age relations; there are uncertainties about picking consistent lithologic and fossil datum associated with the formation contacts (see Davis and others, 1989, 1994); microfossil and macrofossil data from northern and southern Oquirrh Mountains are available from Gordon and Duncan in Tooker and Roberts (1970), Welsh (1976), Davis and others (1989, 1994); 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) – ***Northern Stansbury Mountains*** includes dark-gray to light-brown and pale-red shale and dark-gray carbonaceous limestone, and lesser sandstone and quartzite; bedding is very thinly laminated to medium; forms slopes and ledges on east flank from Broad to West Canyons; no fossil age data; thickness is about 1000 feet (305 m), greater than mapped by Rigby (1958). ***Northern Oquirrh Mountains*** includes 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 one-third of the Lakepoint Limestone of Tooker and Roberts (1970), which has similar age relations, but differing lithofacies compared to the typical Manning Canyon; 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); thickness in northern Oquirrh Mountains is 477 feet (145 m) (units 9 through 1 of measured section by Davis and others, 1989, 1994); the Manning Canyon Formation is an interval of regional decollement, commonly exhibiting substantial deformation, so regional thicknesses can vary, but more reliable thicknesses of the formation are 1140 to 1559 feet (320–475 m) at Soldier Canyon, Oquirrh Mountains (Gilluly, 1932; Moyle, 1959) and 1176 feet (359 m) at the Lake Mountains (Biek and others, 2009). ***Southern Lakeside Mountains and Northern Cedar Mountains*** include few exposures west of the Lakeside fault and associated with thrust faults in the Hastings Pass and Henry Spring areas; incomplete thickness as much as 500 feet (150 m) (Young, 1953; Doelling, 1964; Maurer, 1970).

Mgb **Great Blue Limestone** (Upper Mississippian) – Primarily limestone with minor shale and sandstone; bluish-gray to medium- and dark-gray limestone is locally fossiliferous, cherty, and argillaceous; bedding is medium to very thick; locally black chert occurs as nodules, particularly near the top; macrofossils include brachiopods, corals, bryozoans, and crinoids (see Davis, 1956; M.K. Elias in Arnold, 1956; Gordon and Douglas in Tooker and Roberts, 1970); dark-gray to olive-gray shale occurs in middle part of section just south of the map area and in the lower part of the northern Oquirrh Mountains section; uncommon yellowish-brown sandstone beds locally occur; forms ledgey and cliffy exposures; in northern Oquirrh Mountains previously mapped as the Green Ravine Formation of Tooker and Roberts (1970); complete thickness is from 650 to 1000 feet (200–305 m) at eastern Stansbury Mountains (Arnold, 1956; Rigby, 1958; this study), incomplete thickness at northern Oquirrh Mountains is about 1400 feet (430 m) (Tooker and Roberts, 1970), and incomplete thickness at southern Lakeside Mountains is 1537 feet (469 m) (Young, 1953).

Mh **Humbug Formation** (Upper Mississippian) – Light-brown and medium-blue-gray interbedded sandstone, quartzite, fossiliferous limestone, and sandy limestone; bedding is thin to thick; fossils include bryozoans, corals, brachiopods, crinoid columnals (Davis, 1956; Rigby, 1958); forms slopes and ledges; thickness is 950 to 1300 feet (290–400 m) at northern Stansbury Mountains (Rigby, 1958; this study), 850 feet (260 m) in southern Lakeside Mountains (this study), and Palmer (1970) reported 350 feet (105 m) (where incomplete and structurally disturbed) at Stansbury Island, near Cedar Canyon.

Mdf **Deseret Limestone, Gardison Limestone, Fitchville Formation?, undivided** (Upper to Lower Mississippian) – Combined unit in northern Stansbury Mountains and west side of Stansbury Island where difficult to separate formations at this map scale as Delle Phosphatic Member of Deseret is poorly exposed or thin (attenuated?) and because the contact of Gardison and Fitchville? is unclear; see descriptions for units Md and Mgf; in Stansbury Mountains locally silicified near major unconformity; unit may conformably overlie Stansbury Formation; lower part of unit contains late Kinderhookian conodonts (Sandberg and Gutschick, 1979; Nichols and others, 1992; Stamm in Silberling and Nichols, 1992a; Trexler, 1992); thickness is from 800 to 2200 feet (245–670 m).

Md **Deseret Limestone** (Upper and Lower Mississippian) – Mapped as separate unit in eastern Stansbury Island (where folded) and in isolated exposures near Skull Valley; medium- to dark-gray cherty limestone, limestone, fossiliferous limestone, cherty dolomite, minor medial light-olive-gray, weathering to light-brown, quartz sandstone; lower Delle Phosphatic Member includes dark phosphatic shale (poorly exposed) and medial cherty limestone (Delle not mapped separately, see Sandberg and Gutschick, 1984); bedding is thin to very thick; forms ledges and slopes; fossils locally include rugose corals, spiriferid brachiopods, and crinoids (Rigby, 1958), and Petersen (1969) reported ammonoids of early Meramecian age from the Delle Member in the northern Stansbury Mountains; Deseret was previously mapped as the upper part of the Pine Canyon Formation in Stansbury Mountains (Rigby, 1958); thickness of 1150 feet (350 m) reported by Palmer (1970), may be excessive due to folding.

Mw **Woodman Formation** (Upper? and Lower Mississippian) – Upper part is pale-red, light-brown, moderate-gray dolomitic calcareous siltstone and fine-grained sandstone; lower part (Delle Phosphatic Member) is gray, black, and pale-red, phosphatic and cherty siltstone and mudstone with lesser nodular limestone and cherty limestone; formation is laminated to thinly bedded forming slopes with few ledges in southern Lakeside Mountains (Sandberg and Gutschick, 1984; Poole and Sandberg, 1991; Silberling and Nichols, 1992a, 1992b); yielded Osagean fossil data (Sandberg and Gutschick, 1984; Poole and Sandberg, 1991; Silberling and Nichols, 1992b); previously mapped as part of the Humbug Formation and Deseret Limestone (Young, 1953); correlates to the Deseret Limestone to the east (Poole and Sandberg, 1991); thickness is 445 feet (135 m) (Silberling and Nichols, 1992b).

MDgp **Gardison Limestone, Fitchville Formation?, Pinyon Peak Limestone** (Lower Mississippian, Osagean to Upper Devonian, Famennian) – Combined unit in the southern Lakeside Mountains following Silberling and Nichols (1992a); upper part (Gardison) is moderate- to dark-gray silty limestone and limestone that is commonly cherty and fossiliferous; middle part (Fitchville?) is moderate- to dark-gray limestone that is locally fossiliferous and cherty; lower part (Pinyon Peak) is greenish-gray nodular silty limestone that is poorly exposed; bedding is thin to very thick forming ledges, cliffs, and few slopes; megafossils include corals, gastropods, brachiopods, bryozoa, crinoid columnals, while conodonts from upper part (Gardison) range from Osagean to late Kinderhookian, and from the lower part (Pinyon Peak) are late Fammenian; unconformably overlies Devonian dolomite; previously mapped as the Madison Limestone and part of the Deseret Limestone (Young, 1953); 640 to 1000 feet (195–305 m) thick in the southern Lakeside Mountains (Silberling, Nichols, 1992a; this study).

Mgf **Gardison Limestone and Fitchville Formation?** (Lower Mississippian, Osagean? to Kinderhookian) – Combined unit where difficult to separate formations and presence of Fitchville is unclear; upper part is light- to dark-gray limestone and minor dolomite that is locally cherty and fossiliferous; bedding is thin to thick; fossils include brachiopods, gastropods, and corals (Arnold, 1956; Rigby, 1958; Palmer, 1970); lower part is medium-gray dolomite and cherty dolomite with thin limestone interval at base; thin to very thick bedded; fossils locally include corals and brachiopods (Arnold, 1956; Rigby, 1958; Palmer, 1970; Howell, 1978); combined unit forms ledges, cliffs and slopes; Chapusa (1969), Palmer (1970), and Howell (1978) called lower part Fitchville Formation, however, an interval in lower part contains possible Osagean brachiopods (Howell, 1978) suggesting it is Gardison; in Broad Canyon, Stansbury Island, lower limestone contains upper Kinderhookian conodonts (Howell, 1978; Sandberg and Gutschick, 1979); lowermost shale interval of Howell (1978) and Sandberg and Gutschick (1979) placed in unit Dst herein; unit may conformably overlie Stansbury Formation; previously mapped/studied at Stansbury Island as the Gardison/Madison Limestone and Fitchville Formation (Chapusa, 1969; Palmer, 1970; Howell, 1978), but Sandberg and Gutschick (1979) used different nomenclature; the Fitchville was previously mapped as the lower part of the Gardner Dolomite (Rigby, 1958); queried in isolated exposures; thickness is 1000 to 1200 feet (305–365 m) in eastern Stansbury Island and western Stansbury Mountains (Chapusa, 1969; Palmer, 1970; Howell, 1978; this study).

Dst **Stansbury Formation** (Lower Mississippian, Kinderhookian to Upper Devonian, Famennian) – Enigmatic rock unit with complicated lithofacies relationships due to the Stansbury uplift (see Arnold, 1956; Stokes and Arnold, 1958; Rigby, 1958; Rigby, 1959; Nichols and others, 1992; Trexler, 1992). Our mapping follows Trexler (1992) and the uppermost part (commonly covered) likely includes strata equivalent to the Pinyon Peak Limestone, and possibly other units (see Howell, 1978; Sandberg and Gutschick, 1979). In northern Stansbury Mountains (type section at Flux), the formation includes conglomerate with lesser sandstone (quartz-arenite) or quartzite, dolomite, limestone, and shale; the distinctive conglomerate is gray dolomite-clast type in a dolomite matrix, and varies from matrix to clast supported; clasts are subrounded to subangular and up to 5 feet (2 m) in diameter; light-colored sandstone/quartzite has small-scale cross-lamination and can be laterally discontinuous; some dolomite and limestone is present near the lower and upper contacts, is locally fossiliferous, and may contain carbonate rock fragments; Stansbury Island section is different from the type section—it does not have conglomerate and it has roughly four times as much sandstone/quartz-arenite compared to Flux (Trexler, 1992); yellowish-orange and pale-red shale was observed at the top of the section at Stansbury Island (Howell, 1978; Sandberg and Gutschick, 1979; Clark, this study); bedding is thin to very thick, forming mostly ledges and slopes; unit Dst also includes three large slide blocks of Laketown-Ely Springs Dolomite, unit Dst(SOu), near Flux and Miners Canyon, Stansbury Mountains (Stokes and Arnold, 1958; Rigby, 1958; Trexler, 1992); major unconformity at base of formation (Rigby, 1958, 1959; Trexler, 1992); various fossil data indicate the formation ranges from early Kinderhookian to late Famennian in age (Sandberg and Gutschick, 1979; Nichols and others, 1992; Stamm in Silberling and Nichols, 1992a; Mamet in Trexler, 1992; Silberling? in Trexler, 1992); fossil brachiopod *Paurorhyncha endlichi* reported by Arnold (1956) and Rigby (1958) from the formation; Hollis (2015) reported U-Pb detrital zircon provenance data, but no maximum depositional age; upper part was previously mapped as Pinyon Peak Limestone in Stansbury Mountains by Rigby (1958); the formation is limited in lateral extent (Trexler, 1992); thickness from 0 to 1770 feet (0–540 m) at northern Stansbury Mountains and 925 feet (282 m) at Stansbury Island (Trexler, 1992).

Dgs **Guilmette Formation and Simonson Dolomite, undivided** (Middle Devonian) – Combined unit in the southern Lakeside Mountains where not readily separable for mapping purposes; predominantly gray color-banded dolomite and minor light-brown sandstone (Doelling, 1964); mapped as Jefferson Dolomite by Young (1953); complete thickness is 1469 to 1850 feet (448–565 m) (Young, 1953; this study).

Dss **Simonson Dolomite and Sevy Dolomite, undivided** (Middle to Lower Devonian) – Combined unit of dark- and light-gray dolomite that is medium to coarsely crystalline (Simonson) and light-gray dolomite that is finely crystalline with laminated surface appearance (Sevy); bedding is thin to very thick; occurs as ledges and slopes at Salt Mountain; no fossils or other age data; unconformable on unit SOu; combined unit thickness is 375 feet (115 m) at Salt Mountain, but removed elsewhere by Devonian unconformity (Rigby, 1958, 1959).

Dsy **Sevy Dolomite** (Lower Devonian) – Light- to moderate-gray dolomite that is finely to coarsely crystalline with laminated surface appearance; bedding is medium to thick; lighter colored and less resistant than surrounding formations; contains fossil fish fragments (Young, 1953); mapped separately in the southern Lakeside Mountains; previously called the Water Canyon Dolomite (Young, 1953; Doelling, 1964); complete thickness is 220 to 242 feet (67–74 m) (Young, 1953; Petersen, 1956).

SOu **Laketown Dolomite, Ely Springs Dolomite, Eureka Quartzite, undivided** (Silurian to Upper Ordovician) – Combined unit of medium- to light-gray dolomite that is medium to coarsely crystalline (Laketown) and underlying banded dark- and medium-gray dolomite that is fine to medium crystalline (Ely Springs); in southern Lakeside Mountains also includes thin interval of Eureka Quartzite at base 15 to 35 feet (5–10 m) thick; bedding is medium to very thick; primarily forms ledges and cliffs; fossils include primarily brachiopods and corals (Rigby, 1958; Young, 1953; Doelling, 1964); three slide blocks of SOu are included in unit Dst near Flux and Miners Canyon, Stansbury Mountains; at Stansbury Island, dark- to light-gray dolomite (likely Ely Springs) was previously mapped as Laketown (Chapusa, 1969) and Fish Haven (Palmer, 1970); in the Stansbury Mountains, Ely Springs previously mapped as Fish Haven Dolomite (Rigby, 1958); in the Lakeside Mountains was previously mapped as Laketown Dolomite, Fish Haven Dolomite, and upper unit of Swan Peak Formation (Young, 1953; Doelling, 1964); complete thickness is 1075 feet (328 m) in southern Lakeside Mountains (Young, 1953), 925 feet (280 m) at Salt Mountain and northern Stansbury Mountains (Rigby, 1958), and 425 feet (130 m) at Stansbury Island where it is locally unconformable with overlying Stansbury Formation and younger rocks and with the underlying Pogonip Group (Chapusa, 1969; Palmer, 1970).

Op **Pogonip Group** (Middle to Lower Ordovician) – Medium-gray limestone and lesser dolomite (variably sandy and cherty) with yellowish-orange argillaceous partings and laminae interbedded with siltstone, shale, and intraformational pebble conglomerate; bedding is thin to medium, and soft-sediment deformation exists as wavy bedding, slump folds, and intraformational breccia; forms ledges and slopes; fossils include trilobites, brachiopods, cephalopods, graptolites, echinoderms, ostracodes, bryozoans, and algae (Young, 1953; Arnold, 1956; Rigby, 1958; Doelling, 1964); the thin upper formation (Kanosh Shale) is only locally present at Salt Mountain and southern Lakeside Mountains, but elsewhere the upper Pogonip Group (including the Kanosh) was removed on the Ordovician unconformity (Tooele arch) (Rigby, 1958; Hintze, 1959); previously mapped as the Kanosh Shale and Garden City Formation (Rigby, 1958; Chapusa, 1969; Palmer, 1970; Helm, 1994, 1995), and Swan Peak Formation (lower unit) and Garden City Limestone/Formation (Young, 1953; Doelling, 1964); thickness as much as 1900 feet (580 m) at Stansbury Island (this study), 1200 feet (365 m) at northern Stansbury Mountains and Salt Mountain (Rigby, 1958), and 1037 to 1186 feet (315–360 m) at southern Lakeside Mountains (Young, 1953; Doelling, 1964).

Opk **Pogonip Group, Kanosh Shale** (Middle Ordovician) – Local marker unit that is an upper formation of the Pogonip Group; olive-green and black shale with minor argillaceous sandstone, limestone, and dolomite; forms slopes in Salt Mountain area; present but not mapped separately in southern Lakeside Mountains; fossils include graptolites and brachiopods (Rigby, 1958); thickness from 0 to about 100 feet (0–30 m) near Salt Mountain (Rigby, 1958; this study).

Cambrian stratigraphic nomenclature for the Stansbury Mountains was revised by Clark and Kirby (2009) from that of Rigby (1958) and Teichert (1959). These strata correspond to the thicker, deeper water/passive margin facies (western Utah section), not the correlative thinner, eastern/cratonic facies (East Tintic section). Due to the map scale, some formations are combined, similar to the map units in Millard County (see Hintze and Davis, 2003). This Cambrian nomenclature was also applicable in the southern Lakeside Mountains (see revisions to Young, 1953, 1955; Doelling, 1964).

Ꞓum **Upper and Middle Cambrian strata, undivided** (lowermost Ordovician, Upper to Middle Cambrian) – Combined unit at Stansbury Island. Subdivision of Cambrian formations at Stansbury Island could not be readily accomplished due to access and time restrictions, and structural complications. Locally the Cambrian section there is dolomitized, which apparently led to some prior confusion about nomenclature.

Ꞓnp **Notch Peak Formation** (lowermost Ordovician? to Upper Cambrian) – Dark-gray dolomite locally with very light gray intervals, bands and mottling; common chert nodules and stringers, *Girvanella* (microbial oncolites), pisolites, and calcite rods; medium to very thick bedded forming ledges and cliffs; contains rare trilobite fossils (Arnold, 1956); previously mapped as the Ajax Dolomite/Limestone (Rigby, 1958), part of the Lynch Dolomite (Young, 1953), and part of the Nounan–St. Charles Formations (Doelling, 1964); complete thickness is 750 to 900 feet (230–275 m) in northern Stansbury Mountains (Rigby, 1958; this study), and 1375 feet (420 m) at southern Lakeside Mountains, and incomplete in southernmost Stansbury Island.

Ꞓo **Orr Formation** (Upper Cambrian) – Upper part is light- to moderate-gray silty dolomitic limestone with rust-colored silty laminae and local rip-up clasts (possibly the Sneakover and Johns Wash Limestone Members), and intervening olive-green to pale-red shale (Corset Spring Shale Member) that includes trilobite *Housia varro* (Rigby, 1958); in southern Lakeside Mountains, upper part includes gray silty dolomite, dolomite, limestone, moderate-brown sandstone, and light-brown weathering dolomite; lower part is light- and dark-gray dolomite (Big Horse Member) with calcite rods and blebs, pisolites, oolites, and *Girvanella*; bedding is typically medium to very thick bedded; formation forms ledges, slopes, cliffs; previously mapped as the Dunderberg Shale and Opex Formation in Stansbury Mountains (Rigby, 1958), part of the Lynch Dolomite (Young, 1953), and part of the Nounan–St. Charles Formations (Doelling, 1964); thickness is 450 feet (135 m) at northern Stansbury Mountains, and 935 feet (285 m) at southern Lakeside Mountains.

Ꞓlt **Lamb Dolomite and Trippe Limestone, undivided** (Upper and Middle Cambrian) – Combined unit in northern Stansbury Mountains; ***Lamb*** includes thin upper part of moderate-gray silty limestone with rust-colored silty laminae and some oolites, and thicker lower part of light- and dark-gray dolomite; bedding is thin to thick; ***Trippe***, top part includes thin silty and shaley limestone and olive-green to pale-red shale (Fish Springs Member), underlying moderate-gray limestone and lesser silty and shaley limestone; locally includes rip-up clasts/flat pebble conglomerate in limestone; fossils include inarticulate brachiopods and agnostid trilobite fragments (Rigby, 1958); bedding is thinly laminated to medium. Combined map unit forms ledges, slopes and cliffs; Lamb previously mapped as the Cole Canyon and Bluebird Dolomites, and Trippe previously mapped as the Bowman Limestone and Herkimer Limestone (Rigby, 1958); thickness is 1200 feet (365 m).

Ꞓl **Lamb Dolomite** (Upper and Middle Cambrian) – Mapped as separate formation in southern Lakeside Mountains; see description for unit Ꞓlt above; complete thickness is 1075 feet (325 m).

Ꞓtp **Trippe Limestone and Pierson Cove Formation** (Middle Cambrian) – Combined unit in southern Lakeside Mountains; ***Trippe***, upper part is olive-green shale and shaley nodular limestone (Fish Springs Member, the upper nodular limestone unit of Doelling, 1964) and lower part is moderate-dark-gray silty limestone, limestone, dolomite that forms ledges; upper shale contains brachiopods (Doelling, 1964); ***Pierson Cove***, moderate-gray limestone (locally silty) and dolomite with calcite rods and local oolites; more resistant and poorly bedded (medium to thick) forming rounded ledges and cliffs; previously mapped as the Bowman and Hartmann Limestones (Young, 1953), and Marjum Formation (Doelling, 1964); complete thickness is 975 feet (300 m) (Doelling, 1964).

Ꞓpc **Pierson Cove Formation** (Middle Cambrian) – Mapped as separate formation in northern Stansbury Mountains; upper few beds of white and mottled dolomite (light and dark gray, called tiger-striped by Rigby [1958], and zebra-banding by Cohenour [1959]) underlain by light- and dark-gray silty limestone (silty laminae are tan, pale orange, and moderate to dark gray); locally dolomitized intervals are moderate gray to mottled gray dolomite that is more resistant and with some calcite rods; bedding is thin to very thick; forms ledges, cliffs, slopes; previously mapped as part of the Dagmar Dolomite? and Teutonic Limestone (Rigby, 1958); thickness is 575 feet (175 m).

Ꞓww **Wheeler Formation, Swasey Limestone, Whirlwind Formation, undivided** (Middle Cambrian) – Combined unit in northern Stansbury Mountains; ***Wheeler***, upper part is olive-green shale and minor moderate-gray silty limestone interbeds with tan silty laminae, middle part is silty limestone, lower part is shale and some silty limestone and limey shale; bedding is thinly laminated to very thick; contains *Peronopsis* (agnostid trilobite) (Rigby, 1958); ***Swasey*** is moderate- to dark-gray limestone and silty limestone with some small oncolites; locally dolomitized; bedding is medium to thick; Rigby (1958) reported some fragments of *Elrathia* (trilobite); ***Whirlwind*** is pale-red and tan shale, and moderate-gray silty limestone; poorly exposed; fossils include *Ehmaniella* and *Ehmania* (trilobites) (Rigby, 1958); bedding is thinly laminated to medium. Combined unit forms slopes, ledges, and few cliffs; previously mapped as middle and lower part of the Teutonic Limestone and Ophir Group, Condor Formation (Rigby, 1958); thickness is 950 feet (290 m).

Ꞓwh **Wheeler Formation** (Middle Cambrian) – Mapped as separate formation in southern Lakeside Mountains; gray silty limestone interbedded with olive-green and grayish-green shale; bedding is laminated to thin forming slopes; no fossil data; complete thickness is 441 feet (135 m) (Doelling, 1964).

Ꞓsw **Swasey Limestone** (Middle Cambrian) – Mapped as separate formation in southern Lakeside Mountains; gray limestone and lesser silty limestone; bedding is thick to very thick; unit forms cliffs between less resistant formations; sparse fossils include brachiopods and trilobites; complete thickness is 606 feet (185 m) (Doelling, 1964).

Ꞓwl **Whirlwind Formation** (Middle Cambrian) – Mapped as separate formation in southern Lakeside Mountains; moderate-gray silty limestone with light-brown silty laminae interbedded with gray and green shale; bedding is laminated to medium; forms slopes with few ledges; fossils include trilobite debris; incomplete thickness is about 300 feet (90 m) (Doelling, 1964).

Ꞓdh **Dome Limestone, Chisholm Formation, Howell Limestone, undivided** (Middle Cambrian) – ***Dome*** is moderate- to dark-gray silty limestone with tan and red silty laminae; bedding is thin to medium; in the southern Lakeside Mountains, it is orange-brown-weathering, medium-gray dolomite that is coarsely crystalline; ***Chisholm*** is olive-green shale (weathers brown), and lesser moderate-gray silty limestone and limestone with tan and orange silty laminae; bedding is thinly laminated to medium; contains uncommon *Glossopleura* (trilobite) (Rigby, 1958); ***Howell*** is moderate-gray silty limestone with orange silty laminae; bedding is thin to medium. Unit forms ledges and slopes; previously mapped as part of the Ophir Group-Dome, Burnt Canyon, Burrows equivalents, and Millard Limestone (Rigby, 1958), and as the Hartmann Limestone and Ophir Shale (Young, 1953); complete thickness is 750 feet (230 m) at northern Stansbury Mountains, and an incomplete section in the southern Lakeside Mountains is 695 feet (210 m).

Ꞓp **Pioche Formation** (Middle and Lower Cambrian) – Dark-greenish-gray and dark-reddish-gray (typically weathering to reddish brown or brown gray) quartzite, greywacke sandstone, phyllitic shale, calcareous sandstone, and sandy and silty limestone; bedding is thin to medium; unit forms slopes and some ledges; previously mapped as the lower Ophir Group including the Busby Quartzite and Pioche Shale (Rigby, 1958), and as part of the Tintic Quartzite (Young, 1953); complete thickness is 310 to 450 feet (95–135 m) at northern Stansbury Mountains (Rigby, 1958; this study), and about 500 feet (150 m) at Stansbury Island, north of Corral Canyon (Chapusa, 1969); about 545 feet (165 m) thick in the southern Lakeside Mountains.

€pm **Prospect Mountain Quartzite** (Lower Cambrian and Neoproterozoic?) – Light-brown, grayish-olive, and white quartzite with scattered iron specks that is medium to coarse grained with cross-beds; bedding is medium to very thick; thin, uncommon conglomerate lenses occur with pebbles less than 1 inch (3 cm) diameter of quartzite and chert; thin green shale beds occur near the top; forms ledges, slopes and cliffs; detrital zircon data have not constrained the age for the formation (Yonkee and others, 2014); previously mapped as the Tintic Quartzite by Young (1953), Rigby (1958), Palmer (1970), Doelling (1964); top of unit is conformable and base is not exposed; incomplete thickness is about 1150 to 2500 feet (350–760 m) at Stansbury Island (Chapusa, 1969; Palmer, 1970), and 4200 feet (1280 m) (nearly complete?) in the Stansbury Mountains (Rigby, 1958); incomplete, 665 feet (200 m) in southern Lakeside Mountains.

Northern Stansbury Island was previously mapped as the Big Cottonwood series and Formation (Chapusa, 1969; Palmer, 1970). We map this section of rock as the Mutual Formation, Inkom Formation, and Caddy Canyon Quartzite, which are faulted against Cambrian rocks.

Zm **Mutual Formation** (Neoproterozoic) – Light-brown to light-gray quartzite and quartzite conglomerate that weathers to moderate brown; conglomerate with rounded quartzite and chert pebbles in lenses and beds; common cross-bedding and some liesegang banding; thin to thick bedded; forms ledges and cliffs; detrital zircon analyses have not constrained the age of the formation (Yonkee and others, 2014); top part may not be exposed; incomplete thickness is about 1200 feet (365 m) at northern Stansbury Island.

Zi **Inkom Formation** (Neoproterozoic) – Grayish-green and maroon phyllitic shale and argillite, and minor quartzite and sandstone; thinly laminated to medium bedded; typically weathers to chips, and largely covered by surficial deposits forming a poorly exposed strike valley; DZ maximum depositional age for the formation has not been constrained (Yonkee and others, 2014); complete thickness is about 200 to 300 feet (60–90 m) at northern Stansbury Island.

Zcc **Caddy Canyon Quartzite** (Neoproterozoic) – Very pale orange to white quartzite with orange and red liesegang banding; cross-bedding and local pebble conglomerate lenses; bedding is medium to very thick; forms ledges and cliffs; DZ maximum depositional age for the formation has not been constrained (Yonkee and others, 2014); only top part of formation is exposed; incomplete thickness as much as 500 feet (150 m) at northern Stansbury Island.

Zpc **Perry Canyon Formation** (Neoproterozoic) – Dark-brown and light-gray quartzite that is part of slate and quartzite member (see Balgord and others, 2013; Yonkee and others, 2014; Yonkee and others, in preparation); one small exposure in map area at the southernmost part of Carrington Island; DZ data from Carrington Island are not yet available, but DZ data from Little Mountain (NE of Fremont Island) indicate a maximum depositional age of 683 Ma (Balgord and others, 2013); exposed (incomplete) thickness in map area is less than 100 feet (30 m).

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 (see Yonkee and Lowe, 2004; Willis and others, 2010;); 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 (Willis and others, 2010), 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).

€t **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 ledgey 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 data have not constrained the maximum depositional age (Yonkee and others, 2014); incomplete thickness is at least 800 feet (245 m), and top is 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 marbleized; bedding is finely laminated to thick bedded, partly reflecting recrystallization; the dolomite forms resistant 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, 2014) and the nomenclature may not be appropriate for the eastern thrust system (cratonic) rock units; detrital zircon data were obtained from the unit on Antelope Island, but the maximum depositional age and correlation are unclear (Yonkee and others, 2014); 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 detrital zircon maximum depositional age of 700 Ma is given for the formation in the southern Wasatch Range (Yonkee and others, 2014) where it overlies the Big Cottonwood Formation (<766 Ma) (Dehler and others, 2010); unit Zmf (eastern thrust system/cratonic) is correlative to part of Perry Canyon Formation (western thrust system/passive margin) in the northern Wasatch Range (Yonkee and others, 2014); 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). 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), although debate remains whether it is older (W.A. Yonkee, Weber State University, verbal communication to D.L. Clark, October 22, 2015). Correlation with units of the Wasatch Range is presently unclear (Bryant, 1988; Yonkee and Lowe, 2004; Coogan and King, 2016). 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 [0.05–2 m] 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 to sericite (33%); grain sizes from 0.1–5 mm.

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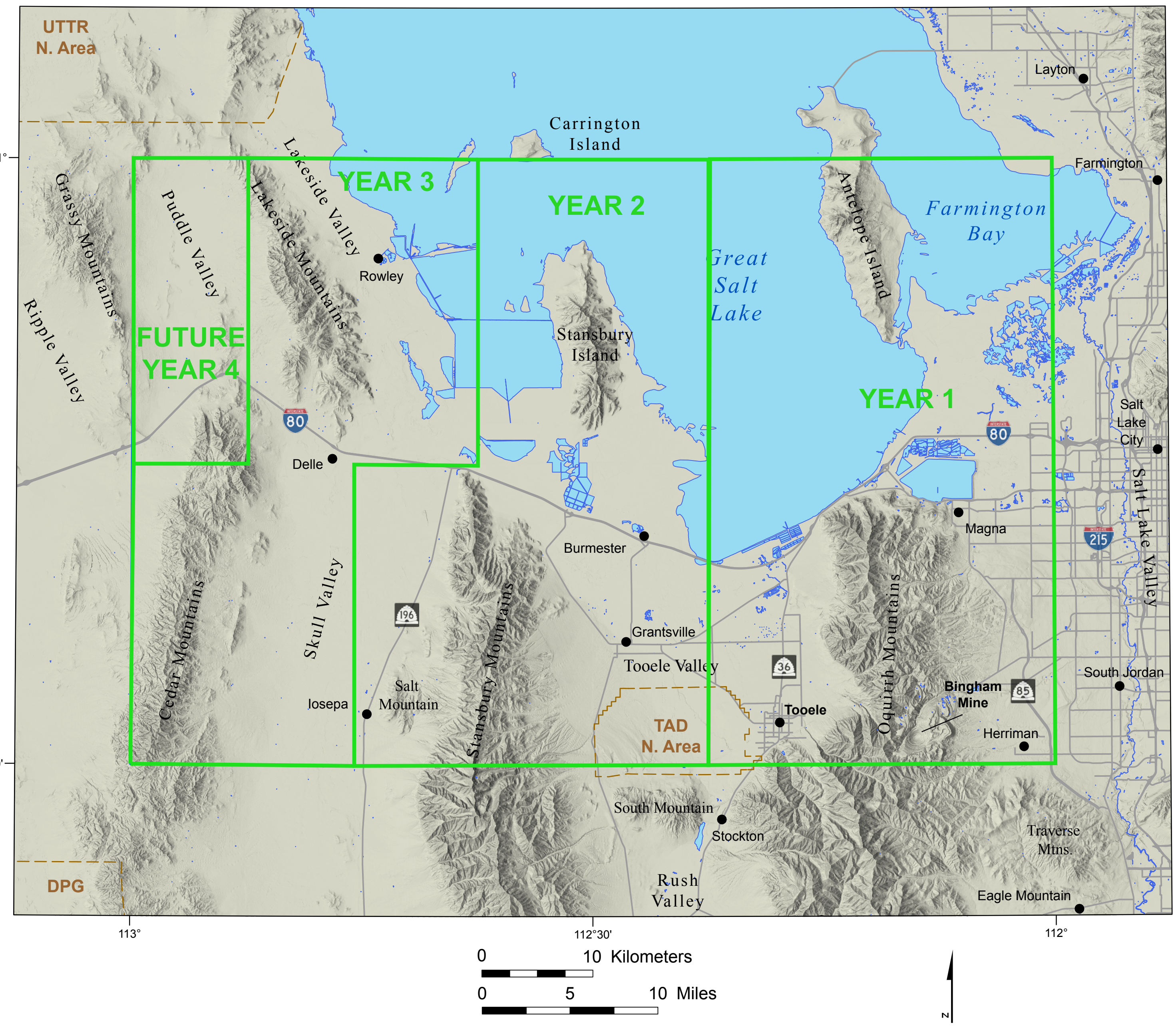


Figure 1. *Primary geographic features and progression of geologic mapping in the Tooele 30' x 60' quadrangle. TAD is Tooele Army Depot. DPG is Dugway Proving Ground (U.S. Army). UTTR is Utah Test and Training Range (U.S. Air Force). The Great Salt Lake historic average elevation of 4200 feet (1280m) is depicted on this map.*

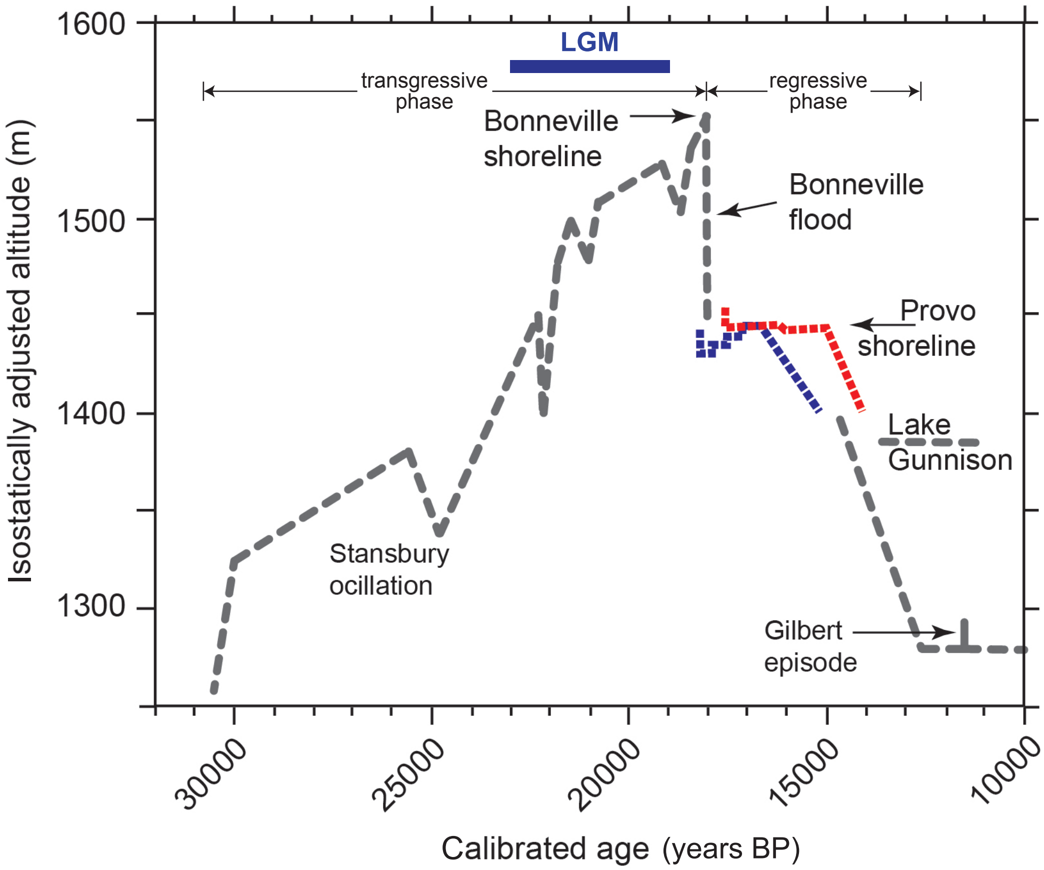


Figure 2. *Simplified Lake Bonneville hydrograph and chronology. LGM is Last Glacial Maximum. The two alternatives for the Provo-shoreline level and chronology (red and blue lines) are from Miller and others (2013). Modified from Reheis and others (2014).*

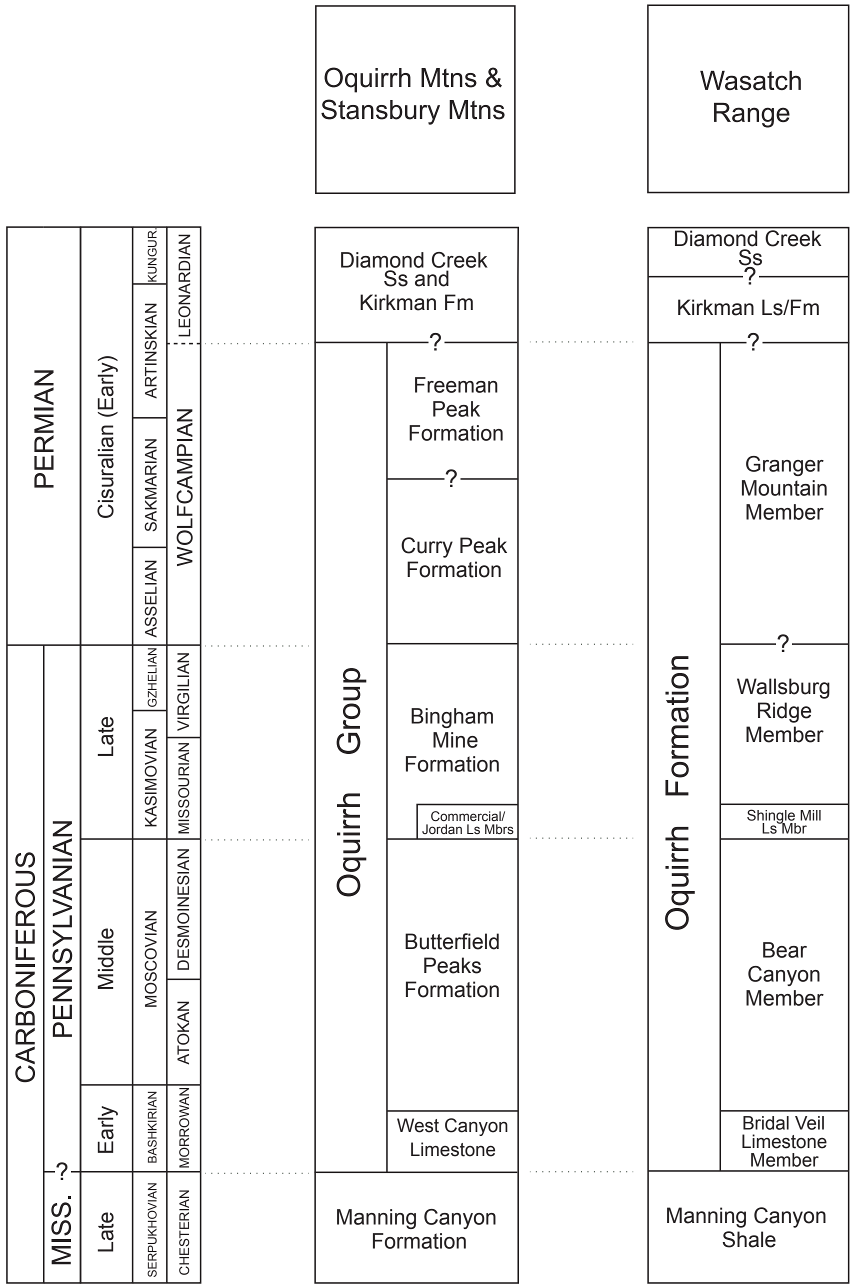
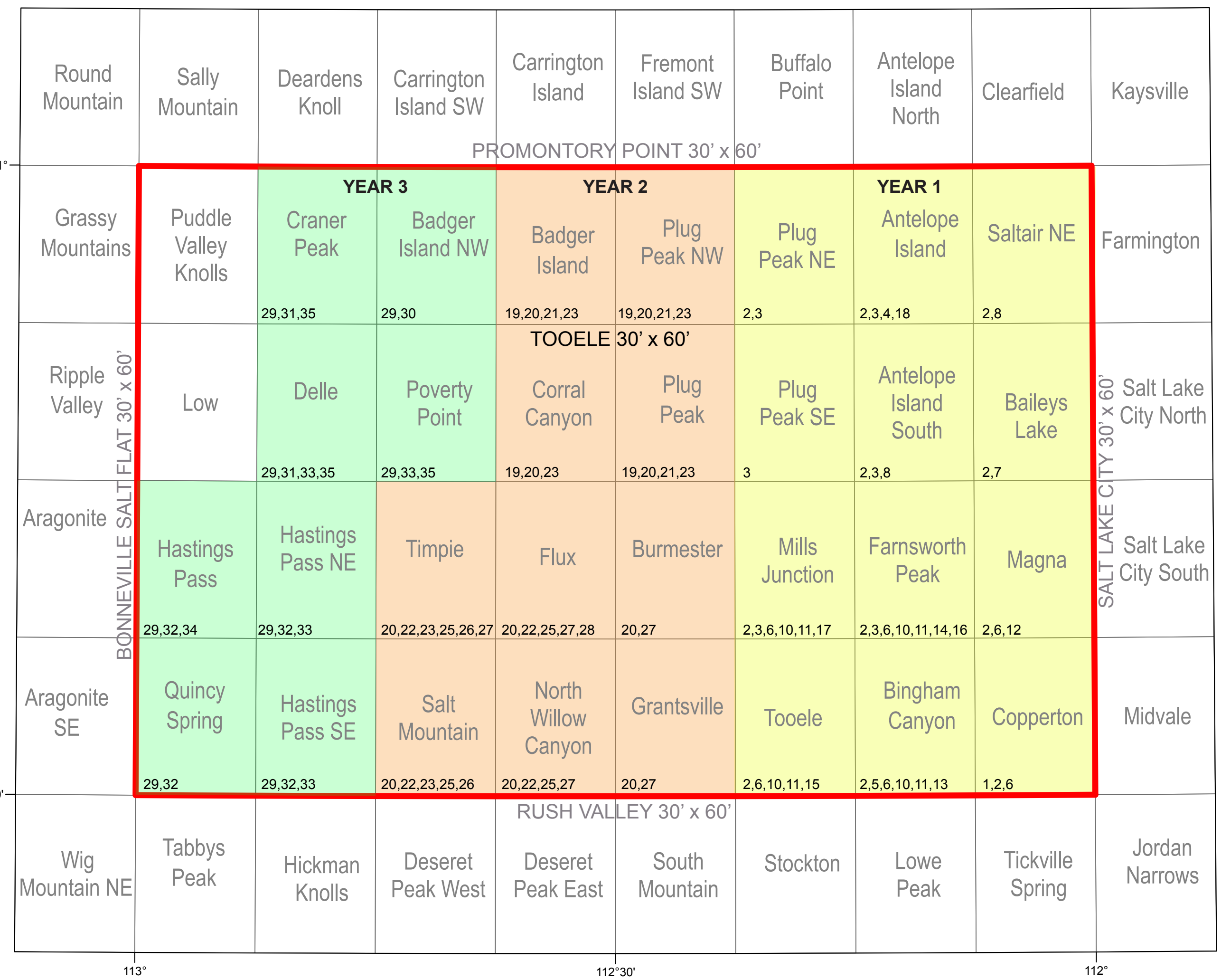


Figure 3. *Comparison of Permian-Pennsylvanian nomenclature of the Oquirrh Group/Formation and other units used in this map and adjacent areas. See Constenius and others (2011) for Wasatch Range.*



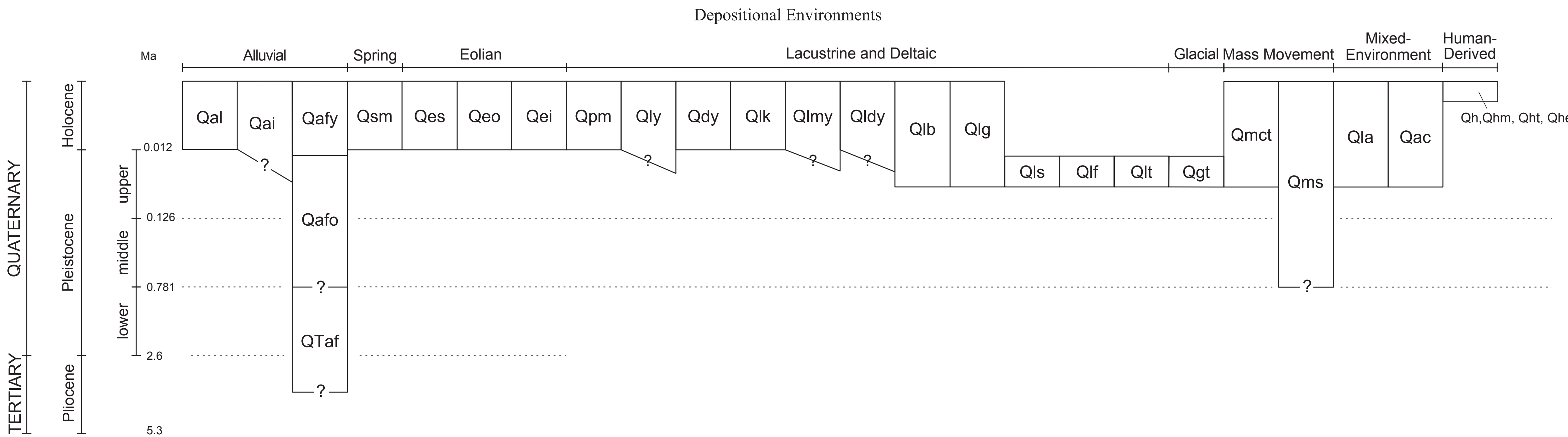
Primary Sources of Geologic Mapping

YEAR 1
1. Biek and others (2007)
2. Clark, D.L. (UGS) and Oviatt, C.G. (KSU), 2013-2014, photogeologic and limited field mapping
3. Dinter, D.A. (UU), unpublished work, data collected 1998, 2003, 2006, Great Salt Lake fault zone mapping
4. Doelling and others (1990)
6. Laes and others (1997)
7. McKean and Hylland (2013)
8. McKean (2013)
9. Schurer (1979a)
10. Solomon (1993)
11. Solomon (1996)
12. Solomon and others (2007)
13. Swensen and Kennecott staff (1991)
14. Thomas (1957)
15. Tooker (1980)
16. Tooker and Roberts (1971a)
17. Tooker and Roberts (1971b)
18. Yonkee and others (2000a)

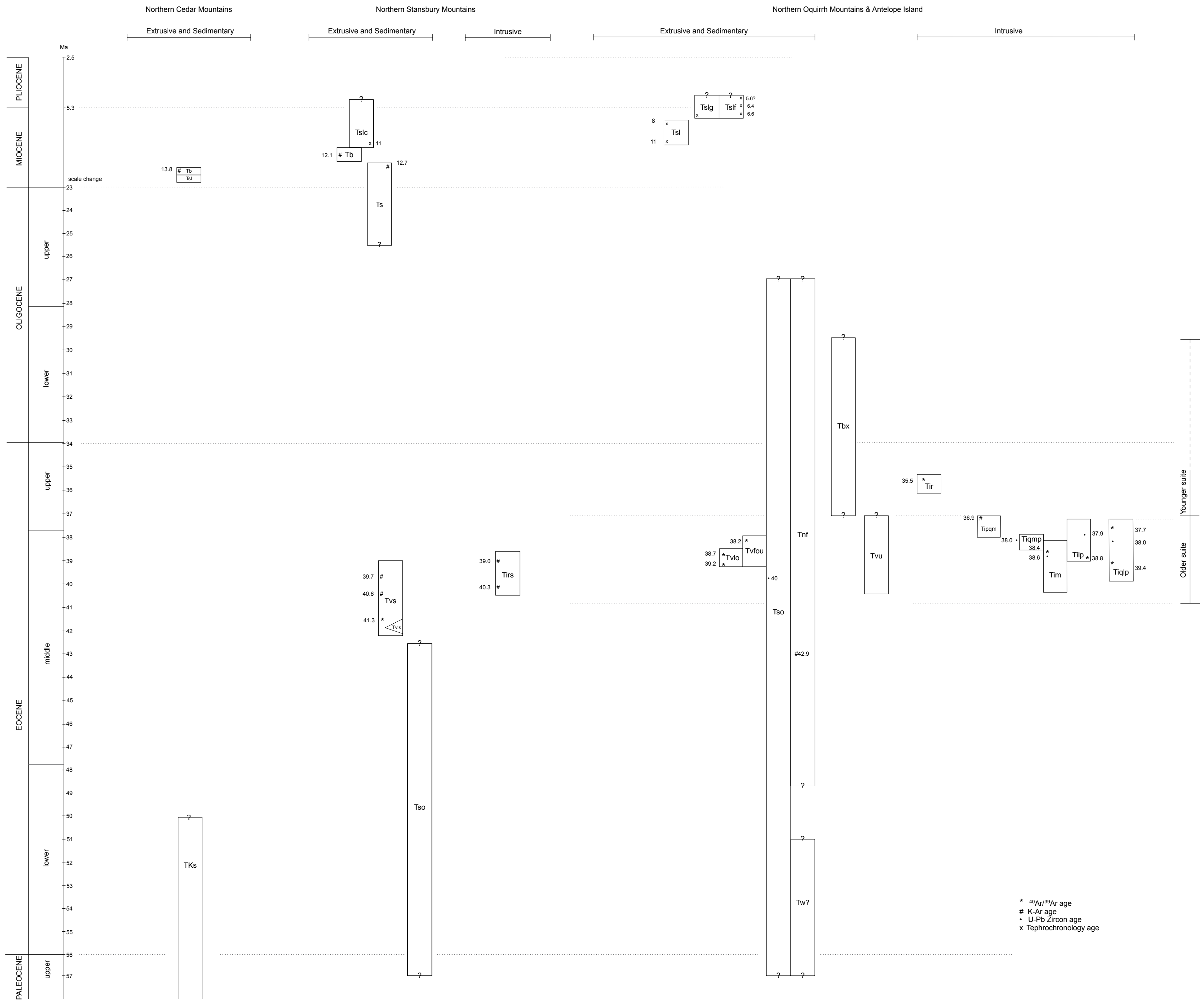
YEAR 2
19. Chapusa (1969)
20. Clark, D.L. (UGS) and Oviatt, C.G. (KSU), 2014-2015, photogeologic and limited field mapping
21. Dinter, D.A. (UU), unpublished work, data collected 1998, 2003, 2006, Great Salt Lake fault zone mapping
22. Foose (1989)
23. Helm (1994)
24. Palmer (1970)
25. Rigby (1958)
26. Sack (1993)
27. Solomon (1993)
28. Trexler (1992)

YEAR 3
29. Clark, D.L. (UGS), 2015-2016, photogeologic and limited field mapping
30. Dinter, D.A. (UU), unpublished work, data collected 1998, 2003, 2006, Great Salt Lake fault zone mapping
31. Doelling (1964)
32. Maurer (1970)
33. Sack (1993)
34. Solomon (1993)
35. Young (1953)

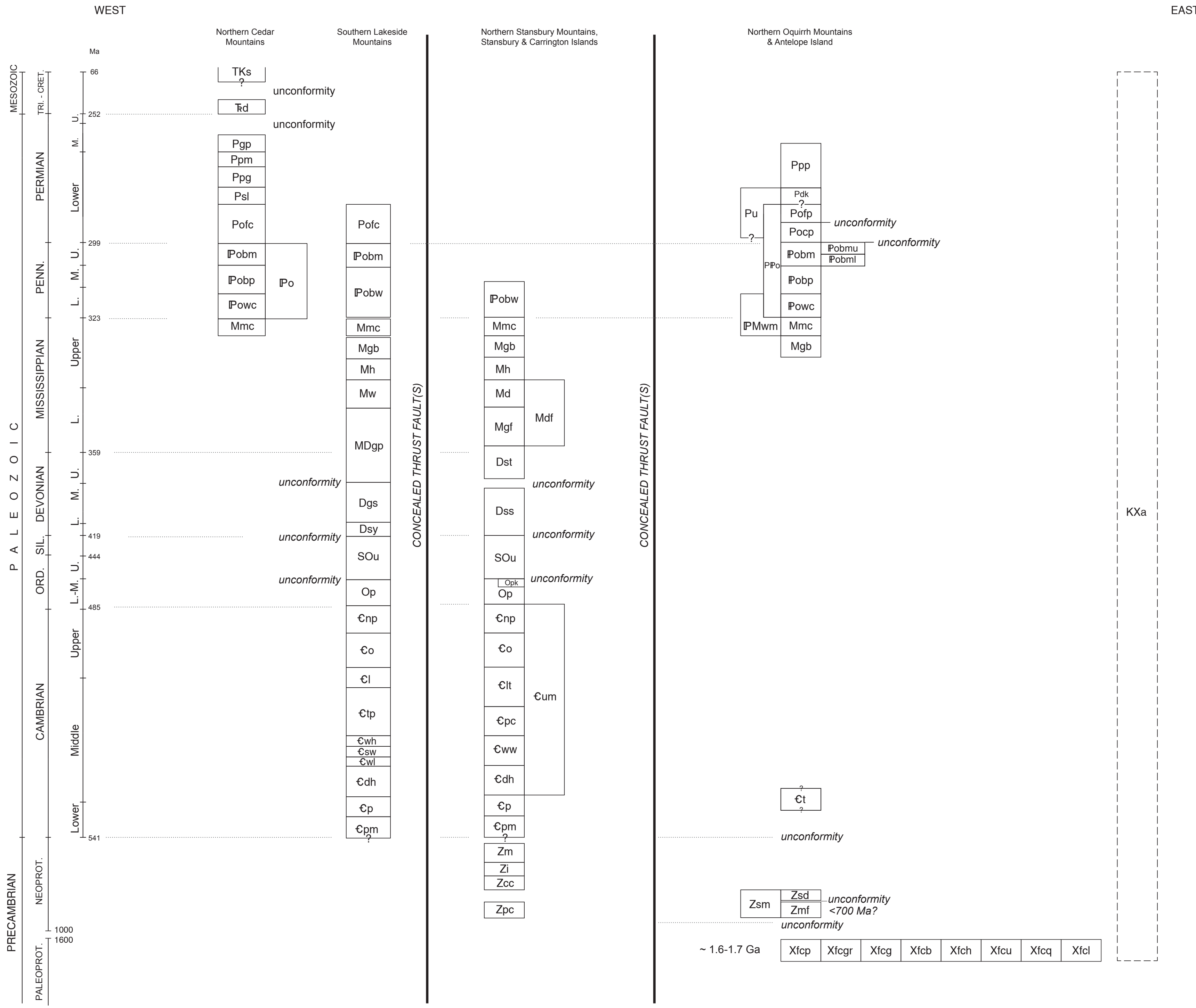
CORRELATION OF QUATERNARY-LATE TERTIARY GEOLOGIC UNITS



CORRELATION OF TERTIARY GEOLOGIC UNITS



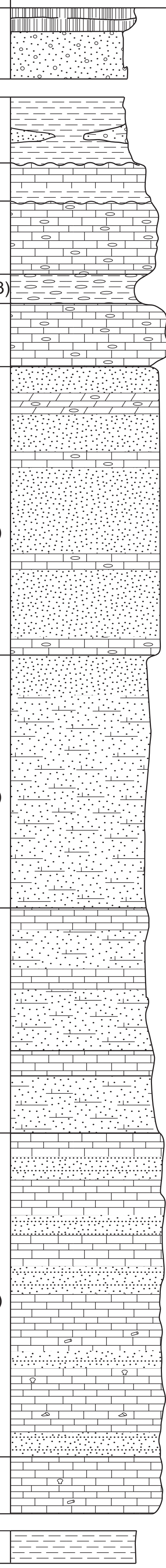
CORRELATION OF MESOZOIC, PALEOZOIC, AND PRECAMBRIAN GEOLOGIC UNITS



LITHOLOGIC COLUMN

Northern Cedar Mountains

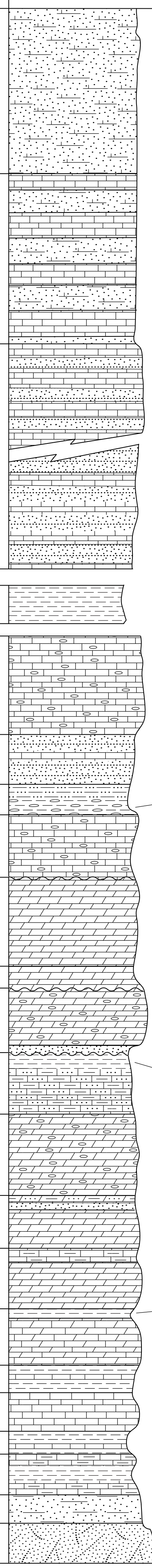
TIME-STRATIGRAPHIC UNIT		GEOLOGIC UNIT		MAP SYMBOL		THICKNESS Feet (Meters)	LITHOLOGY
TERT.	Miocene	Igneous and Sedimentary rocks		see correlation chart		300+ (90+)	
CRET.-TERT.	Upper?-lower Eocene	Tertiary-Cretaceous strata		TKs		0–1100+ (0–335+)	Unconformity
TRI.	L.	Dinwoody Fm.		TRd		<100 (30)	Unconformity
PERMIAN	Mid.	Gerster Fm. and Plympton Fm?		Pgp		511–870 (156–265)	
PERMIAN	?	Phosphoria Fm., Meade Peak Mbr.		Ppm		75–141 (23–43)	
PERMIAN	Lower	Park City Fm., Grandeur Mbr.		Ppg		419–575 (128–175)	
PERMIAN	Lower	Permian sandstone, limestone, and dolomite		Psl		3953 (1205)	*Parafusulina*
PERMIAN	Lower	Oquirrh Group	Freeman Peak and Curry Peak Formations	Pofc		3500 (1065)	*Schwagerina*; "Worm trail" markings; Unconformity?
PENNSYLVANIAN	Upper	Oquirrh Group	Bingham Mine Formation	ℙobm	ℙo	2700 (825)	*Triticites*
PENNSYLVANIAN	Middle	Oquirrh Group	Butterfield Peaks Formation	ℙobp	ℙo	4150 (1265)	Cliffy near top; *Fusulina*; *Beedeina*; Cyclic lithologic character; *Millerella*; *Chaetetes*
PENNSYLVANIAN	? Lower	Oquirrh Group	West Canyon Limestone	ℙowc	ℙo	500–800 (150–245)	
MISS.	U.	Manning Canyon Fm.		Mmc		100+ (30+)	Interval of regional decollement



LITHOLOGIC COLUMN

Southern Lakeside Mountains

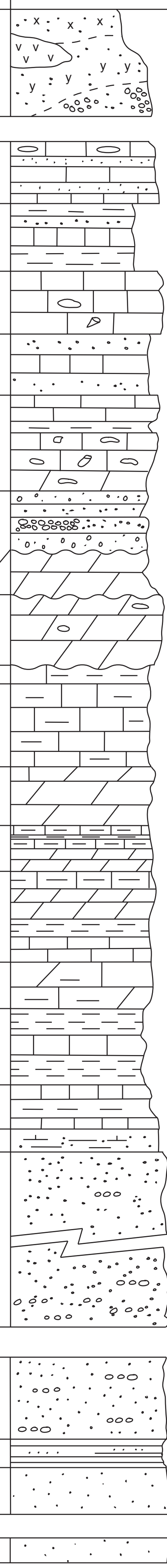
TIME-STRATI-GRAPHIC UNIT		GEOLOGIC UNIT		MAP SYMBOL	THICKNESS Feet (Meters)	LITHOLOGY
PERMIAN	LOWER	Oquirrh Group	Freeman Peak and Curry Peak Fms.	Pofc	2600? (790?)	
PENNSYLVANIAN	Upper	Oquirrh Group	Bingham Mine Formation	ℙobm	2700? (825?)	
PENNSYLVANIAN	Lower - Middle	Oquirrh Group	Butterfield Peaks Formation and West Canyon Ls.	ℙobw	4000? (1220?)	
M.	U.	Manning Canyon Formation		Mmc	500± (150±)	zone of regional decollement
MISSISSIPPIAN	Upper	Great Blue Limestone		Mgb	1537+ (469+)	
MISSISSIPPIAN	Upper	Humbug Formation		Mh	850 (260)	
MISSISSIPPIAN	?	Woodman Fm.		Mw	445(135)	Delle Phosphatic Mbr.
MISSISSIPPIAN / DEVONIAN	Lower / U.	Gardison Ls., Fitchville Fm?, Pinyon Peak Ls		MDgp	640–1000 (195–305)	unconformity
DEVONIAN	Middle	Guilmette Fm., Simonson Dolomite		Dgs	1469–1850 (448–565)	
DEVONIAN	L.	Sevy Dolomite		Dsy	220–242 (67–74)	unconformity
S. / ORDOV.	U.	Laketown Dol., Ely Springs Dol., Eureka Quartzite		SOu	1075 (328)	unconformity - Tooele Arch
ORDOV.	Lower-Middle	Pogonip Group		Op	1037–1186 (315–360)	Kanosh Shale
?	?					
CAMBRIAN	Upper	Notch Peak Formation		Ꞓnp	1375 (420)	
CAMBRIAN	Upper	Orr Formation		Ꞓo	935(285)	
CAMBRIAN	Upper / Middle	Lamb Dolomite		Ꞓl	1075 (325)	Fish Springs Mbr.
CAMBRIAN	Middle	Trippe Ls., Pierson Cove Fm.		Ꞓtp	975 (300)	
CAMBRIAN	Middle	Wheeler Fm.		Ꞓwh	441 (135)	
CAMBRIAN	Middle	Swasey Ls.		Ꞓsw	606 (185)	
CAMBRIAN	Middle	Whirlwind Fm.		Ꞓwl	300+ (90+)	
CAMBRIAN	Middle	Dome Ls., Chisholm Fm., Howell Ls.		Ꞓdh	695+ (210+)	
CAMBRIAN	Middle / L.	Pioche Fm.		Ꞓp	545 (165)	
CAMBRIAN	L.	Prospect Mountain Quartzite		Ꞓpm	665+ (200+)	



LITHOLOGIC COLUMN

Northern Stansbury Mountains,
Stansbury & Carrington Islands

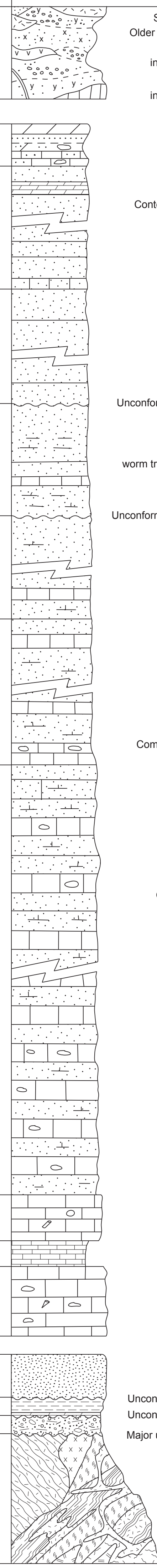
TIME-STRATIGRAPHIC UNIT		GEOLOGIC UNIT	MAP SYMBOL	THICKNESS Feet (Meters)	LITHOLOGY
TERTIARY	Miocene-Eocene	Igneous and sedimentary rocks	see correlation chart	various	
PENN.	Lower-M.	Oquirrh Group: Butterfield Peaks Formation, West Canyon Limestone	ℙobw	550+ (170+)	
MISSISSIPPIAN	Upper	Manning Canyon Formation	Mmc	1000 (305)	
MISSISSIPPIAN	Upper	Great Blue Limestone	Mgb	650–1000 (200–305)	
MISSISSIPPIAN	Upper	Humbug Formation	Mh	950–1300 (290–400)	
MISSISSIPPIAN	Lower	Deseret Limestone	Md (Mdf)	1150?(350?) (Mdf: 800–2200 (245–670))	
MISSISSIPPIAN	Lower	Gardison Limestone, Fitchville Fm.?	Mgf (Mdf)	1000–1200 (305–365)	
DEVONIAN	U.	Stansbury Formation	Dst	0–1700 (0–540)	Unconformity - Stansbury uplift
DEVONIAN	L. M	Simonson Dolomite, Sevy Dolomite	Dss	375 (115)	Unconformity
S. / ORDOVICIAN	U.	Laketown Dolomite, Ely Springs Dolomite	SOu	425–925 (130–280)	Unconformity - Tooele arch
ORDOVICIAN	Lower-Middle	Kanosh Shale	Opk	0–100 (0–30)	
ORDOVICIAN	Lower-Middle	Pogonip Group	Op	1200–1900 (365–580)	
CAMBRIAN	Upper	Notch Peak Fm. (Upper and Middle Cambrian strata)	€np (€um)	750–900 (230–275)	
CAMBRIAN	Upper	Orr Formation (Upper and Middle Cambrian strata)	€o (€um)	450 (135)	
CAMBRIAN	Upper / Middle	Lamb Dolomite, Trippe Limestone (Upper and Middle Cambrian strata)	€lt (€um)	1200 (365)	
CAMBRIAN	Middle	Pierson Cove Fm. (Upper and Middle Cambrian strata)	€pc (€um)	575 (175)	
CAMBRIAN	Middle	Wheeler Fm, Swasey Ls., Whirlwind Fm. (Upper and Middle Cambrian strata)	€ww (€um)	950 (290)	
CAMBRIAN	Middle	Dome Ls., Chisolm Fm., Howell Ls. (Upper and Middle Cambrian strata)	€dh (€um)	750 (230)	
CAMBRIAN	Middle	Pioche Formation	€p	310–500 (95–150)	
CAMBRIAN	Lower	Prospect Mountain Quartzite	€pm	4200+ (1280+)	
NEOPROTEROZOIC		Mutual Formation	Zm	1200+ (365+)	
NEOPROTEROZOIC		Inkom Formation	Zi	200–300 (60–90)	
NEOPROTEROZOIC		Caddy Canyon Quartzite	Zcc	500+ (150+)	
NEOPROTEROZOIC		Perry Canyon Formation	Zpc	100+ (30+)	



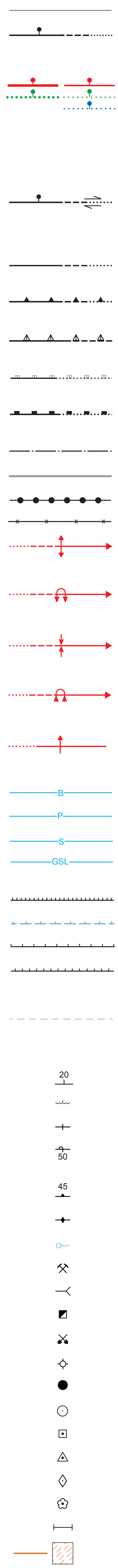
LITHOLOGIC COLUMN

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	M.	Guad.	Park City and Phosphoria Formations		Ppp		760+ (230+)	
PERMIAN	Lower	Leonardian ?–	Permian strata	Diamond Creek Sandstone and Kirkman Formation	Pu	Pdk	2000? (600?)	Contorted, folded, brecciated
PERMIAN	Lower	Wolfcampian	Permian strata	Freeman Peak Formation	Pu	Pofp	2400 (730)	Unconformity
PERMIAN	Lower	Wolfcampian	Oquirrh Group	Curry Peak Formation	PℙPo	Pocp	2450 (750)	worm trails Unconformity
PENNSYLVANIAN	Upper	Missourian - Virgilian	Oquirrh Group	Bingham Mine Formation, upper member	PℙPo	ℙobm, ℙobmu	5300 (1615); 2200 (670)	
PENNSYLVANIAN	Upper	Missourian - Virgilian	Oquirrh Group	Bingham Mine Formation, lower member	PℙPo	ℙobm, ℙobml	5300 (1615); 3100 (945)	Commercial and Jordan Limestones
PENNSYLVANIAN	Middle	Atokan - Desmoinesian	Oquirrh Group	Butterfield Peaks Formation	PℙPo	ℙobp	3606 (1099) – 9072 (2766)	Cyclic lithologic character
PENNSYLVANIAN	Lower	Morrowan	Oquirrh Group	West Canyon Limestone	ℙMwm	ℙowc	1050 (320)	
MISSISSIPPIAN	Upper	Mera.?-Chest.	Manning Canyon Formation		ℙMwm	Mmc	477 (145)	
MISSISSIPPIAN	Upper	Mera.?-Chest.	Great Blue Limestone		Mgb		1400+ (430+)	
CAMBRIAN	L. – M.		Tintic Quartzite		Ꞓt		800+ (245+)	Unconformity
Neoprot.			Slate and Dolomite		Zsm	Zsd	70–280 (20–85)	Unconformity
Neoprot.			Mineral Fork Fm.		Zsm	Zmf	0–200 (0–60)	Major unconformity
Paleoproterozoic			Farmington Canyon Complex		Xfc_		----	Altered and deformed in Cretaceous (KXa) ~1.6–1.7 Ga



GEOLOGIC SYMBOLS



Contact

High-angle normal fault – Dashed where approximately located, dotted where concealed; bar and ball on downthrown side

Normal fault, geophysical – Located from shallow seismic reflection data for Great Salt Lake fault zone; heavier line for main faults and lighter line for subsidiary faults; dotted where concealed; bar and ball on downthrown side; colors indicate relative age of sediments affected by faulting: red for lake bottom displacement, green for Holocene, blue for pre-Holocene

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 aerial photo interpretation

Extent of mine dumps

Quartz vein

Igneous dike or sill

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

Nivation hollow headwall

Landslide scarp – Hachures on down-dropped side

Pit/Open pit mine extent – SE Antelope Island gravel pit, Bingham Canyon, Barneys Canyon, Melco mines

Ditches and disturbed areas in lake bed below Great Salt Lake shoreline (4200 ft)

Sedimentary bedding attitude –

- Inclined
- Inclined approximate
- Vertical
- Overturned

Volcanic and metamorphic foliation attitude –

- Inclined
- Vertical

Spring

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