UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources

INTERIM GEOLOGIC MAP OF THE BONNEVILLE SALT FLATS AND EAST PART OF THE WENDOVER 30' X 60' QUADRANGLES, TOOELE COUNTY, UTAH—YEAR 3

2020

by

Donald L. Clark[1], Charles G. Oviatt[2], Christian L. Hardwick[1], and David Page[3]

[1] Utah Geological Survey, Salt Lake City, Utah
[2] Emeritus, Department of Geology, Kansas State University, Manhattan, Kansas
[3] Desert Research Institute, Reno, Nevada

SCALE 1:62,500

1 0.5 0 1 2 3 4 5 MILES

1 0.5 0 1 2 3 4 5 6 7 8 KILOMETERS

CONTOUR INTERVAL 5 AND 20 METERS

UTAH

MAP LOCATION

TRUE NORTH
MAGNETIC NORTH

APPROXIMATE MEAN DECLINATION, 2020

Disclaimer

This open-file release makes information available to the public during the review and production period necessary for a formal UGS publication. The map may be incomplete, and inconsistencies, errors, and omissions have not been resolved. The map may not conform to UGS policy and editorial standards and it may be premature for an individual or group to take actions based on its contents. Although this product represents the work of professional scientists, the Utah Department of Natural Resources, Utah Geological Survey, makes no warranty, expressed or implied, regarding its suitability for a particular use. The Utah Department of Natural Resources, Utah Geological Survey, shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product. Geology intended for use at 1:62,500 scale.

This geologic map was funded by the Utah Geological Survey and the U.S. Geological Survey, National Cooperative Geologic Mapping Program through USGS STATEMAP award numbers G17AC00266 (2017–18), G18AC00202 (2018–2019), and G19AC00228 (2019–20). The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government. This map and explanatory information are submitted for publication with the understanding that the U.S. Government is authorized to reproduce and distribute reprints for governmental use.

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.

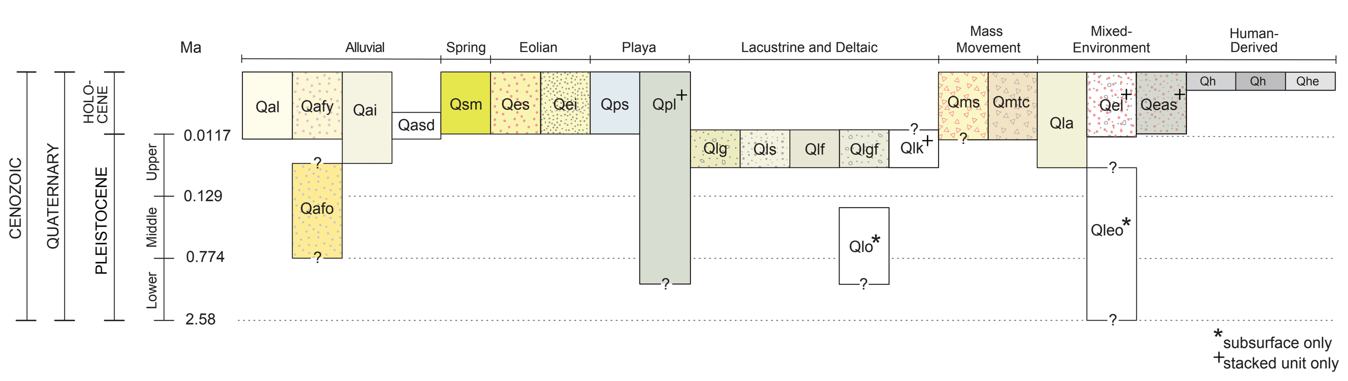
Base from USGS Bonneville Salt Flats 30' x 60' Quadrangle (1972)
and Wendover 30' x 60' Quadrangle (1985)
Shaded relief derived from USGS 10-meter NED
Projection: UTM Zone 12
Datum: NAD 1983
Spheroid: Clarke 1866

Mapping by authors: 2017-2020
Project Manager: Jon K. King
Program Manager: Grant C. Willis
GIS and Cartography: Basia Matyjasik and Donald L. Clark

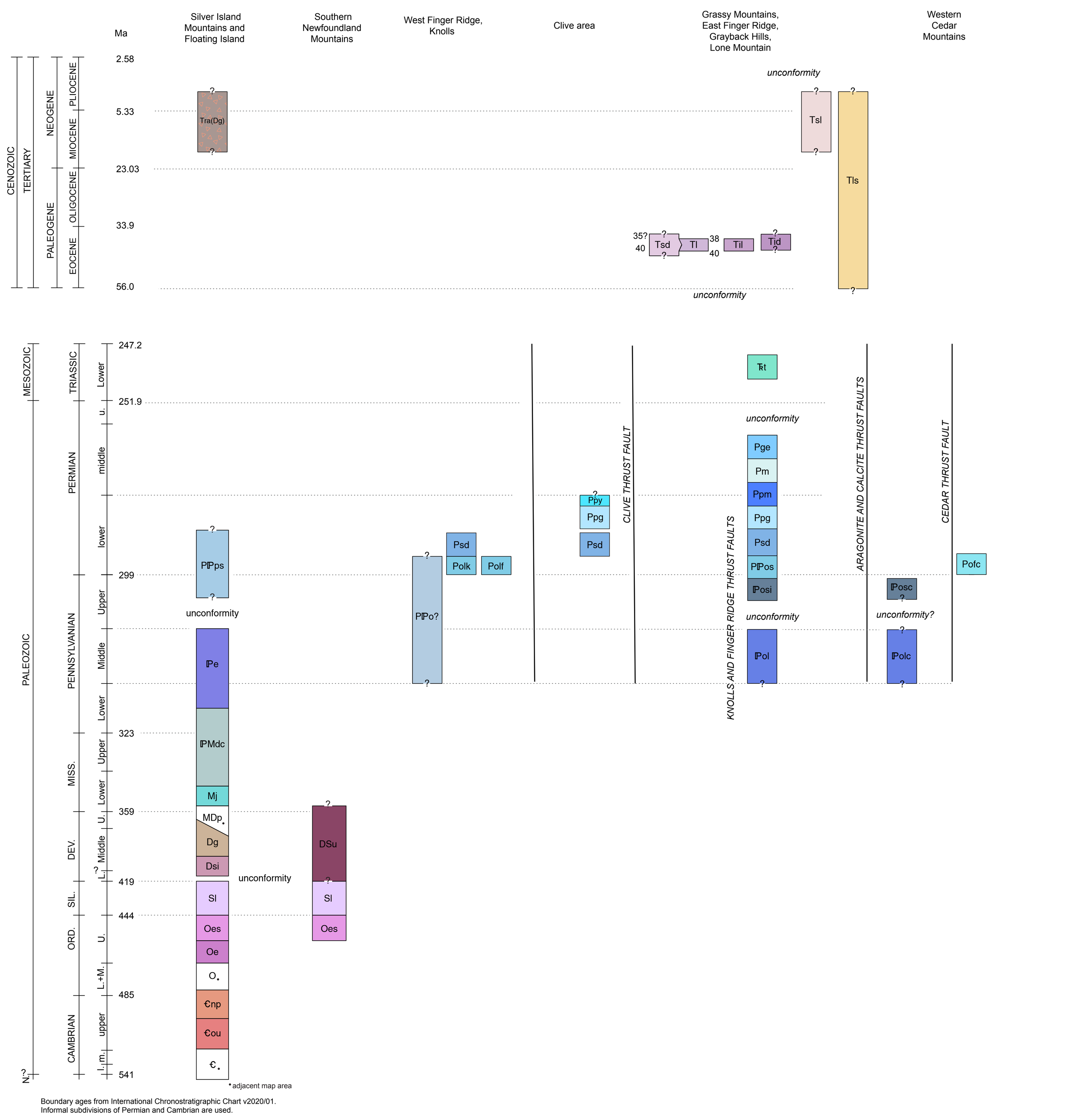
Utah Geological Survey
1594 W. North Temple, Suite 3110
Salt Lake City, UT 84116
(801) 537-3300
geology.utah.gov
https://doi.org/10.34191/OFR-731

CORRELATION OF QUATERNARY GEOLOGIC UNITS

Depositional Environments



CORRELATION OF TERTIARY, MESOZOIC, AND PALEOZOIC GEOLOGIC UNITS



GEOLOGIC SYMBOLS

- Contact
- Contact, approximately located, between upper and lower units of Guilmette Formation
- Channel of Old River Bed delta (map unit Qasd)
- Steeply-dipping normal fault – Dashed where approximately located, dotted where concealed; bar and ball on downthrown side
- Normal fault, geophysical, gravity – Located from gravity data, concealed and very approximately located; bar and ball on downthrown side
- Low-angle normal fault – Dashed where approximatley located, dotted where concealed; boxes on downthrown side
- Fault with unknown geometry and offset – Dashed where approximately located, dotted where concealed; queried where existence and location inferred
- Thrust fault – Dashed where approximately located, dotted where concealed; dotted and queried where existence and location inferred; teeth on hanging wall; bar and ball where later normal movement
- Lineament – From aerial photo interpretation
- Lineament, geophysical – Located from gravity data, concealed and very approximately located
- Igneous dike (unit Tid)
- 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, dotted and queried where existence and location is inferred
- Axial trace of syncline – Dashed where approximately located, dotted where concealed, dotted and queried where existence and location is inferred
- Axial trace of overturned syncline − Dotted where concealed
- Minor folds − anticline, overturned syncline
- Lake Bonneville shorelines (Currey, 1982; Chen and Maloof, 2017; this study) –
  - B — Bonneville shoreline 5213–5328 feet (1589–1624 m)
  - P — Provo shoreline 4856–4925 feet (1480–1501 m)
  - S — Stansbury shoreline ~4446–4500 feet (~1355–1372 m), dashed where approximately located
  - Approximate area with no Lake Bonneville deposits in subsurface (see Oviatt and others, 2020)
- Earthen dike for evaporation ponds
- Sedimentary bedding attitude –
  - 20 — Inclined
  - Inclined, photo interpreted
  - Vertical
  - 50 — Overturned
- Mine or quarry
- Sand and gravel pit
- BC1 — Sediment core and label (see table 1)
- C5-5 — Sediment pit/trench and label (see table 1)
- Lozenge section — Sediment natural exposure and label (see table 1) – adjacent map area
- DH1 — Hydrocarbon exploration well and label – Dry hole (see table 3)
- 2,C — Geochemical and geochronology samples, and label (see tables 4, 5)
- BW2 — Geochemical sample and label (see table 4)
- BW14 — Fossil sample and label (see table 6)
- Qei/Qlf — Stacked unit – Indicates thin cover of first unit overlying second unit

See booklet for geologic unit descriptions, acknowledgments, references, figures, and tables.

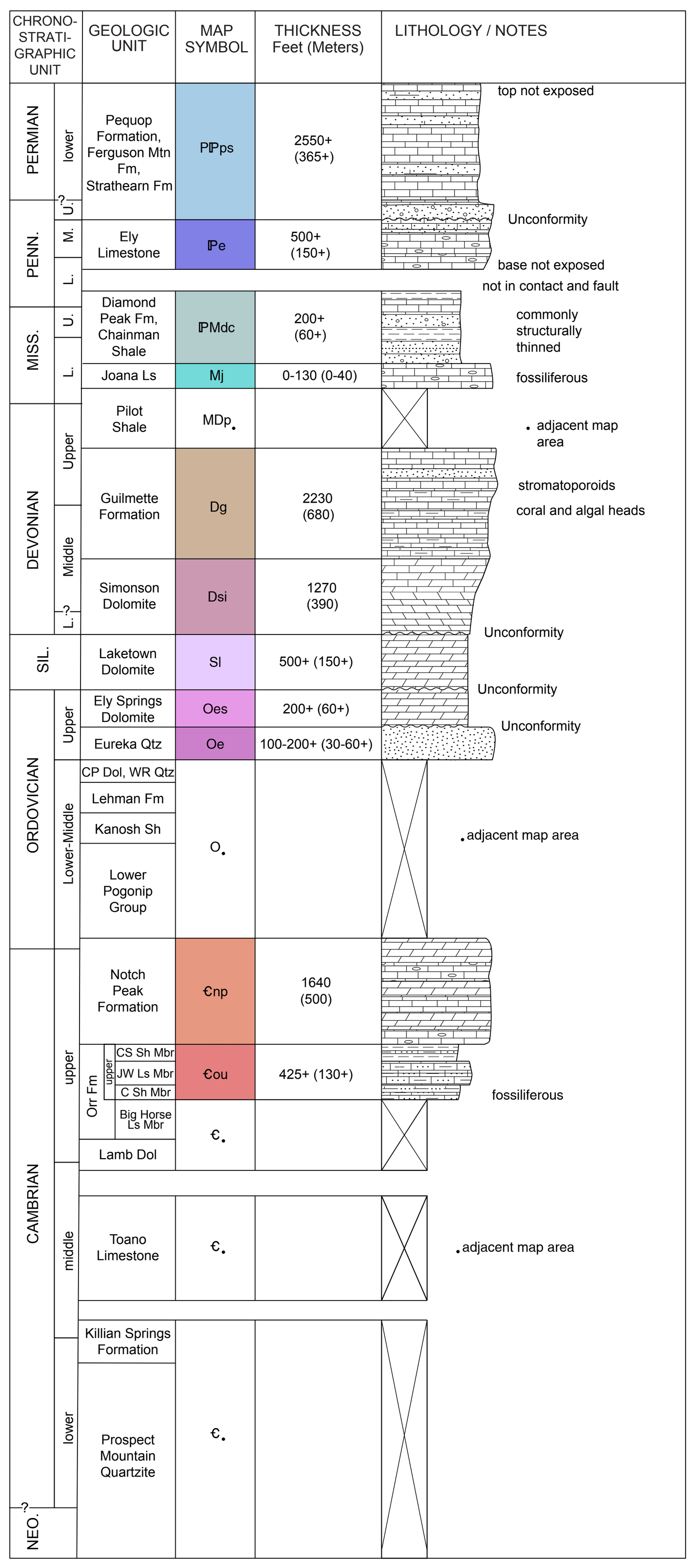
GEOLOGIC UNITS

- Qal—Stream alluvium
- Qafy—Younger fan alluvium
- Qafo—Older fan alluvium
- Qai—Alluvial silt
- Qasd—Alluvial sand of Old River Bed delta
- Qsm—Spring and marsh deposits
- Qes—Eolian sand
- Qei—Eolian silt
- Qps—Playa salt
- Qlg—Lacustrine gravel
- Qls—Lacustrine sand
- Qlf—Lacustrine fine-grained deposits
- Qlgf—Lacustrine gravel and fine-grained deposits
- Qlo—Older lacustrine deposits [subsurface only]
- Qms—Landslide deposits
- Qmtc—Talus and colluvium
- Qla—Lacustrine and alluvial deposits, undivided
- Qleo—Older lacustrine and eolian deposits, undivided [subsurface only]
- Qh—Human disturbance
- Qhw—Waste management facilities
- Qhe—Evaporation ponds
- Qpl—Playa mud over lacustrine fine-grained over lacustrine and eolian deposits
- Qei/Qlf—Eolian silt over lacustrine fine-grained deposits
- Qei/Qlg—Eolian silt over lacustrine gravel
- Qei/Qlk—Eolian silt over lacustrine carbonate deposits
- Qei/Qla—Eolian silt over lacustrine and alluvial deposits
- Qes/Qafy—Eolian sand over younger fan alluvium
- Qes/Qlg—Eolian sand over lacustrine gravel
- Qes/Qlf—Eolian sand over lacustrine fine-grained deposits
- Qes/Qlgf—Eolian sand over lacustrine gravel and fine-grained deposits
- Qes/Qla—Eolian sand over lacustrine and alluvial deposits
- Qes/Qafo—Eolian sand over older alluvial-fan deposits
- Qes/ℙosc—Eolian sand over Oquirrh Group, sandstone and siltstone unit (Cedar thrust sheet)
- Qel/ℙol—Eolian and lacustrine deposits over Oquirrh Group, limestone unit (Aragonite thrust sheet)
- Qel/ℙosc—Eolian and lacustrine deposits over Oquirrh Group, sandstone and siltstone unit (Cedar thrust sheet)
- Qel/ℙolc—Eolian and lacustrine deposits over Oquirrh Group, limestone unit (Cedar thrust sheet)
- Qlg/Tl—Lacustrine gravel over latite lava flows
- Qeas/Qpl—Eolian and alluvial sand over playa mud over lacustrine fine grained over older lacustrine deposits
- Tsl—Salt Lake Formation
- Tra(Dg)—Rock avalanche breccia of Guilmette Formation
- Tls—Tertiary limestone
- Tl—Latite lava flows
- Til—Latitic intrusion
- Tsd—Tuffaceous sandstone and tuff
- Tid—Dacitic intrusions
- Ŧt—Thaynes Formation
- Pge—Gerster Formation
- Ppy—Plympton Formation
- Pm—Murdock Mountain Formation
- Ppm—Phosphoria Formation, Meade Peak Member
- Ppg—Park City Formation, Grandeur Member
- Psd—Permian sandstone, dolomite and limestone
- Polf—Oquirrh Group, limestone unit (Finger Ridge thrust sheet)
- Pℙo?—Oquirrh Group, undivided? (Knolls thrust sheet?)
- Polk—Oquirrh Group, limestone and sandstone unit (Knolls and South Knolls thrust sheet)
- Pℙos—Oquirrh Group, sandstone and limestone unit (Calcite and Aragonite thrust sheets)
- ℙosi—Oquirrh Group, sandstone and siltstone unit (Calcite and Aragonite thrust sheets)
- ℙol—Oquirrh Group, limestone unit (Calcite and Aragonite thrust sheets)
- ℙosc—Oquirrh Group, sandstone and siltstone unit (Cedar thrust sheet)
- ℙolc—Oquirrh Group, limestone unit (Cedar thrust sheet)
- Pofc—Oquirrh Group, Freeman Peak Formation and Curry Peak Formation, undivided (footwall of Cedar thrust sheet)
- Pℙps—Pequop Formation, Ferguson Mountain Formation and Strathearn Formation, undivided
- ℙe—Ely Limestone
- ℙMdc—Diamond Peak Formation and Chainman Shale, undivided
- Mj—Joana Limestone
- DSu—Undivided dolomite and limestone
- Dg—Guilmette Formation
- Dsi—Simonson Dolomite
- Sl—Laketown Dolomite
- Oes—Ely Springs Dolomite
- Oe—Eureka Quartzite
- Ꞓnp—Notch Peak Formation
- Ꞓou—Orr Formation, upper part

Note - Duplicated queried units not included here

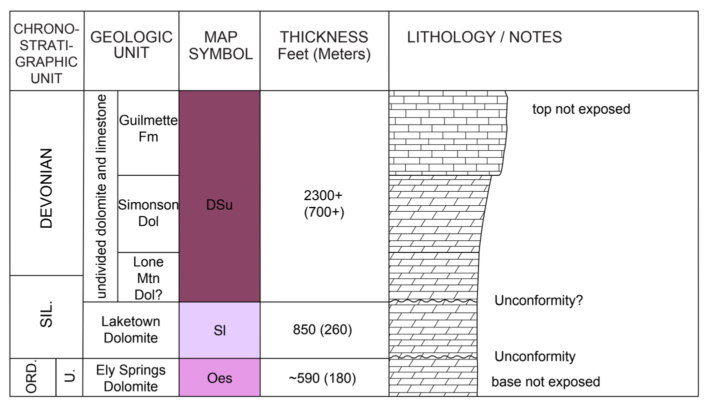
LITHOLOGIC COLUMN

Silver Island Mountains and Floating Island



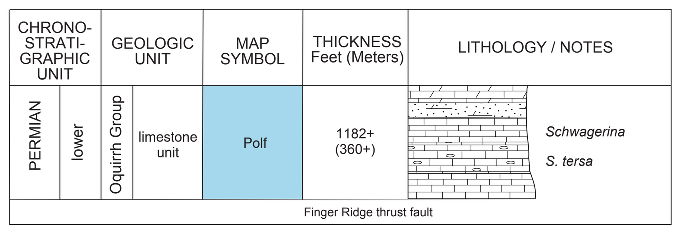
LITHOLOGIC COLUMN

Southern Newfoundland Mountains



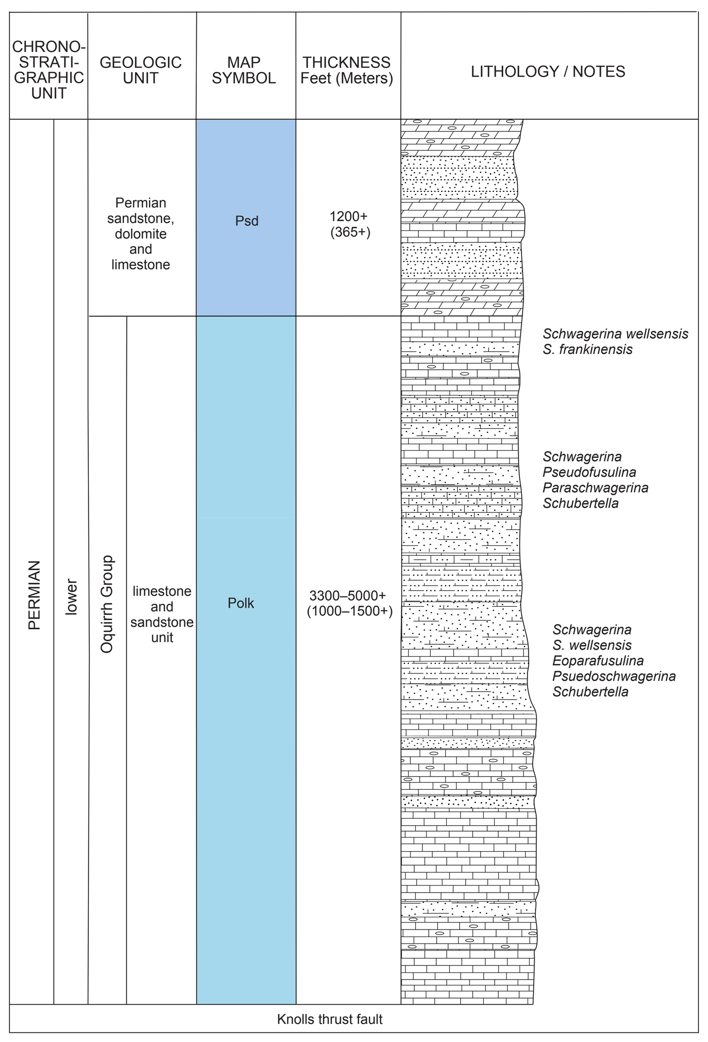
LITHOLOGIC COLUMN

Finger Ridge thrust sheet



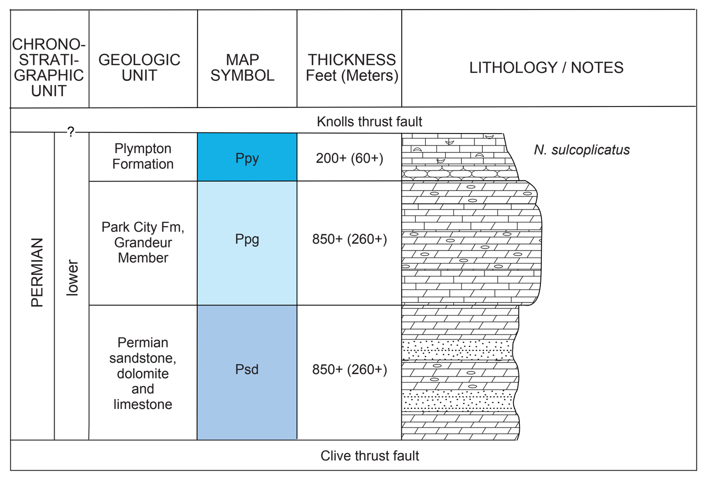
LITHOLOGIC COLUMN

Knolls and South Knolls thrust sheets



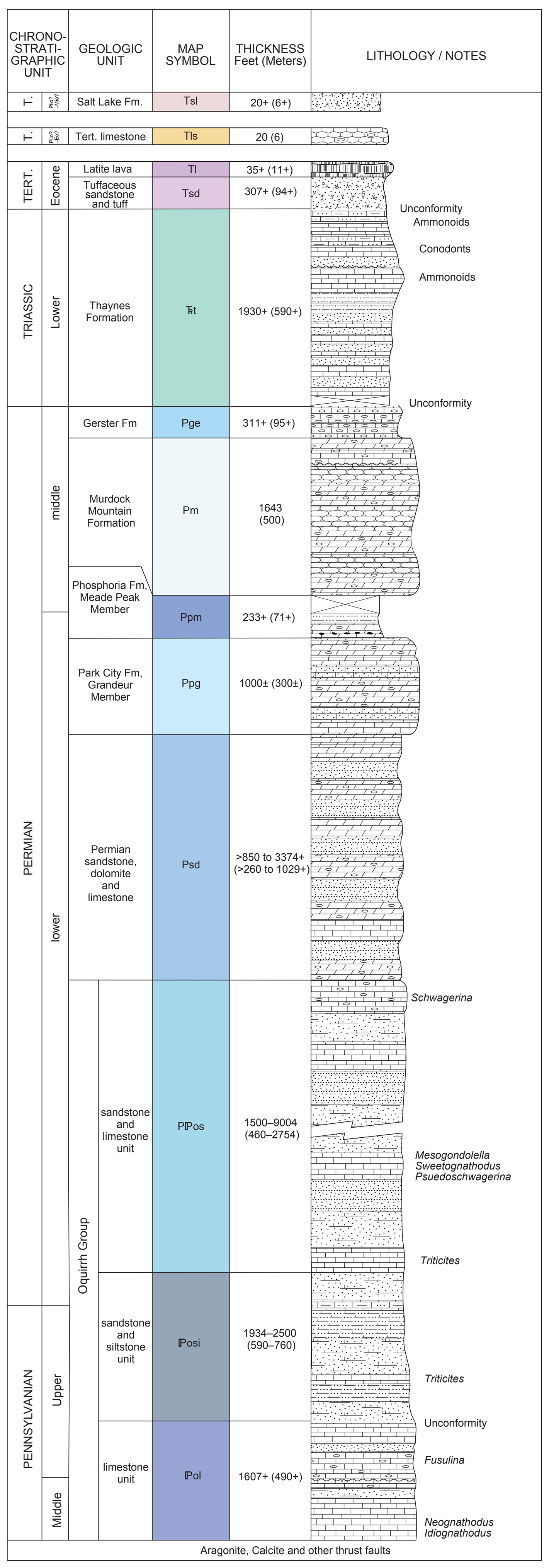
LITHOLOGIC COLUMN

Clive thrust sheet



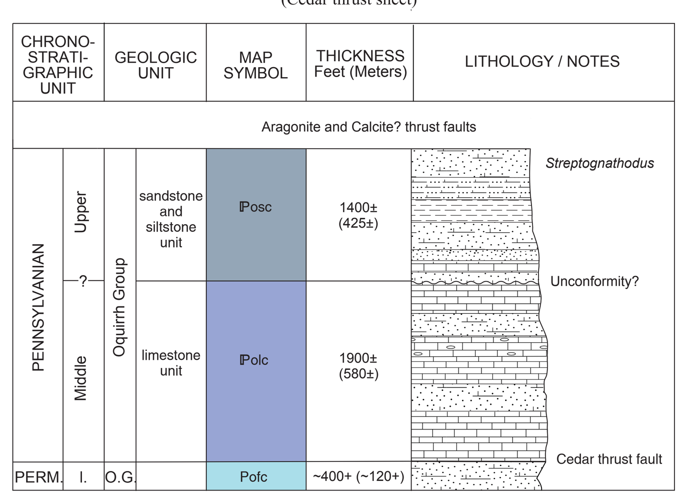
LITHOLOGIC COLUMN

Grassy Mountains, Finger Ridge, Grayback Hills, Lone Mountain
(Aragonite and Calcite thrust sheets)

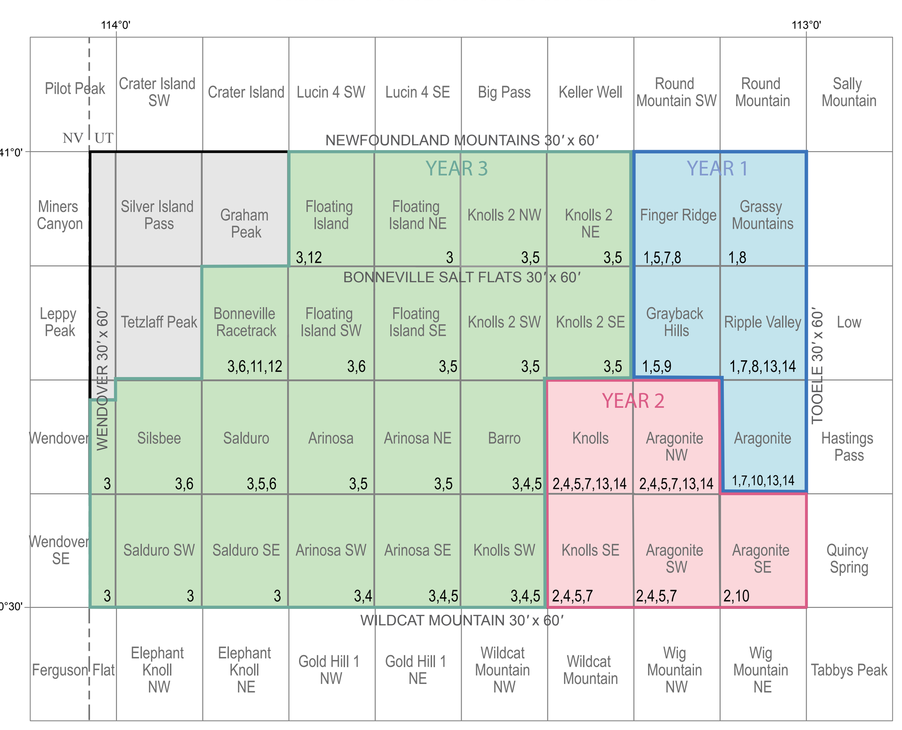


LITHOLOGIC COLUMN

Western Cedar Mountains
(Cedar thrust sheet)



PRIMARY SOURCES OF GEOLOGIC MAPPING



1. Clark [UGS] and Oviatt [KSU] (2017-18), photogeologic and limited field mapping
2. Clark [UGS] and Oviatt [KSU] (2018-19), photogeologic and limited field mapping
3. Clark [UGS] and Oviatt [KSU] (2019-20), photogeologic and limited field mapping
4. Clark [UGS] and Page [DRI] (2020), mapping of ORB delta channels

   Clark [UGS] and Hardwick [UGS] (2020), mapping of faults and lineaments from gravity data [Year 1-3 map area]
5. Boden (2016)
6. Bowen and others (2018)
7. Dames & Moore and others (1987)
8. Doelling (1964)
9. Doelling and others (1994)
10. Maurer (1970)
11. Miller and others (in progress)
12. Schaeffer (1960)
13. Solomon (1990)
14. Solomon (1993)

INTERIM GEOLOGIC MAP OF THE BONNEVILLE SALT FLATS AND EAST PART OF THE WENDOVER 30' X 60' QUADRANGLES,TOOELE COUNTY, UTAH—YEAR 3

by

Donald L. Clark [1], Charles G. Oviatt [2], Christian L. Hardwick [1], and David Page [3]

[1] *Utah Geological Survey, Salt Lake City, Utah*
[2] *Emeritus, Department of Geology, Kansas State University, Manhattan, Kansas*
[3] *Desert Research Institute, Reno, Nevada*

Suggested citation:

Clark, D.L., Oviatt, C.G., Hardwick, C.L., and Page, D., 2020, Interim geologic map of the Bonneville Salt Flats and east part of the Wendover 30' x 60' quadrangles, Tooele County, Utah—year 3: Utah Geological Survey Open-File Report 731, 30 p., 2 plates, scale 1:62.500, https://doi.org/10.34191/OFR-731.

Disclaimer

This geologic map was funded by the Utah Geological Survey and the U.S. Geological Survey, National Cooperative Geologic Mapping Program through USGS STATEMAP award numbers G17AC00266 (2017–18), G18AC00202 (2018–2019), and G19AC00228 (2019–20). The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government. This map and explanatory information are submitted for publication with the understanding that the U.S. Government is authorized to reproduce and distribute reprints for governmental use.

OPEN-FILE REPORT 731
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
2020

Blank pages are intentional for printing purposes.

INTRODUCTION

The Bonneville Salt Flats and east part of the Wendover 30' x 60' quadrangles extend along the Interstate highway 80 (I-80) corridor in northwestern Tooele County, northwest Utah (figure 1). The map area is in the eastern Basin and Range Province; on the west it includes the city of Wendover, the Leppy Hills, Silver Island Mountains, Floating Island, Pilot Valley, and a small part of the Pilot Range; on the east are the Grassy Mountains, Grassy Ridge, Finger Ridge, Grayback Hills, Thumb Ridge, other low hills, Ripple Valley, Lone Mountain (informal name after Maurer, 1970), and a small part of the western Cedar Mountains; the central part includes the Great Salt Lake Desert and southern tip of the Newfoundland Mountains (figure 1). Part of the desert includes the Bonneville Salt Flats, a salt pan known for vehicular land speed records at the Bonneville Speedway. Most of the map area is public land (Federal and State administered) and restricted-access military land (U.S. Air Force ranges, also known as UTTR—Utah Test and Training Ranges). Smaller areas of private land are used for waste management and potash extraction.

This geologic map is part of an ongoing effort by the Utah Geological Survey (UGS) to map the geology of the state of Utah at an intermediate scale (see Willis, 2017). This map displays three years of work on a multi-year project to map the geology of the Bonneville Salt Flats 30' x 60' quadrangle and the Utah part of the Wendover 30' x 60' quadrangle at 1:62,500 scale (plate 1, figure 1). The map explanation includes a booklet containing geologic unit descriptions, acknowledgments, references, figures and tables, and also includes plate 2 showing primary sources of geologic mapping, geologic units, unit correlations, lithologic columns, and geologic symbols.

Map data were compiled from several prior sources and new mapping has been added (see plate 2, mapping sources). Clark compiled and mapped the bedrock and surficial-deposit (Quaternary) geology with assistance from Oviatt. Hardwick compiled geophysical gravity data and assisted with interpretation (details below). Page provided some of the delta distributary channel mapping data. We extended intermediate-scale geologic mapping from adjacent areas including Dugway Proving Ground and UTTR South (Clark and others, 2016), Rush Valley 30' x 60' quadrangle (Clark and others, 2012, in preparation), Tooele 30' x 60' quadrangle (Clark and others, 2017, in press), and Newfoundland Mountains 30' x 60' quadrangle and adjacent Wells strip in Utah (Miller and others, in press). This map updates prior, less detailed (1:250,000 scale) geologic maps by Stokes (1963) and Moore and Sorensen (1979). Additional revisions to this map could occur in subsequent years of the project. Future work will involve collaboration with U.S. Geological Survey (USGS) geoscientists who mapped the geology of the Silver Island Mountains and adjacent areas in the northwestern part of the map area.

Hardwick compiled gravity data for this map area from the Pan-American Center for Earth and Environmental Studies (PACES) (2012) and from the UGS (collected 2011–2014 with a Scintrex CG-5 autograv gravimeter and high-precision GPS survey units [vertical resolution 0.1 m or better]) (UGS, unpublished data). The computed final data values are Complete Bouguer Gravity Anomaly (CBGA) calculated using a reduction density of 2.76 g/cm^3 (average crustal density). Principal gravity values from PACES data were checked against UGS GPS survey data and Shuttle Radar Topography Mission (SRTM) elevations (vertical resolution 3.53 m, horizontal grid size 90 m) for errors. Suspect PACES data were either adjusted for gravity anomaly corrections (Free Air, Bouguer Slab, Zone Terrain) or removed before recomputing CBGA in order to mesh the legacy PACES data with the modern UGS data. The final data were gridded in ArcGIS Pro for both small-cell and large-cell formats using Inverse Distance Weighting (power of 2). CBGA contours of 1 milliGal (mGal) were generated in ARCGIS Pro and "bullseye" contours were removed for closed areas of contours under 4 kilometers (2.5 miles) in circumference and with less than three data points (suspect data excluded). A substantial area of the Utah Test and Training Range (UTTR) South is lacking gravity coverage due to access restrictions while some areas with less dense data exist on the UTTR North. The composite CBGA raster and contour data were used for viewing and interpreting the gravity field data. Clark and Hardwick placed faults at "half max" locations between high and low contours and extended them into areas of less dense data. An east-west-trending gravity lineament was also mapped in the gravity data characterized by a series of saddles and lows. The gravity anomaly data appear to generally fit well with observations of the surface geology and topography, and respective density values. We also consulted reports by Smith and others (2011, 2012). On the UTTR, however, subsurface geologic control is generally poor over much of the map area. Three faults were extended south from the Newfoundland Mountains 30' x 60' quadrangle in an area of sparse gravity data.

Part of a proprietary 2D seismic line for hydrocarbon exploration (E-SOH-NUL81-1D) was present in the map area. The line runs from near the central Bonneville Salt Flats to the northern Stansbury Mountains in an east-southeast direction. R.W. Keach II (UGS) contacted Seismic Exchange Inc. in Denver, Colorado, to view a small portion of the line, which was determined to be of poor quality.

DESCRIPTION OF GEOLOGIC UNITS

QUATERNARY SURFICIAL DEPOSITS

See tables 1 and 2 and Oviatt and others (2020) for sediment and tephrochronology data on surficial deposits in the map area.

Alluvial Deposits

Qal **Stream alluvium** (Holocene) – Primarily clay, silt, and sand with some gravel lenses deposited by streams in channels, but in mountain valleys (Silver Island, Grassy and western Cedar Mountains) deposits are coarser grained and associated with more colluvium; 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).

Qafy **Younger fan alluvium, post-Lake Bonneville** (Holocene to uppermost Pleistocene) – Poorly sorted gravel, sand, silt, and clay; deposited by streams, debris flows, and debris floods on alluvial fans and in mountain valleys; includes alluvium and colluvium in mountain valleys; locally grades into unit Qal and also unit Qai in lacustrine lagoons; may include small areas of lacustrine fine-grained deposits below the Bonneville shoreline; includes active and inactive fans younger than Lake Bonneville, but may include older alluvial deposits above the Bonneville shoreline; locally includes eolian silt and sand cover commonly less than 6 feet (2 m) thick; 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, up to 50 feet (15 m) or more.

Qafo **Older fan alluvium, pre-Lake Bonneville** (upper to middle? Pleistocene) – Small area near Silver Island Canyon on northwest map border of poorly sorted gravel, sand, silt, and clay; similar to unit Qafy, but locally consolidated with carbonate and forms higher-level incised deposits located above the high-stand of Lake Bonneville and locally etched by the lake; Qafo fans are incised by younger alluvial deposits; also mapped as stacked unit Qes/Qafo; thickness as much as 100 feet (30 m).

Qai **Alluvial silt** (Holocene to upper Pleistocene?) – Silt, clay, some sand, and minor gravel deposited by streams and sheet wash in former lagoons related to Lake Bonneville shorelines; locally, bottom of lagoonal basins may include exposed or unexposed, thin, fine-grained lacustrine deposits; thickness less than about 20 feet (6 m).

Qasd **Alluvial sand of Old River Bed delta** (lower Holocene to uppermost Pleistocene) – Sand and silt, locally with gravel and mud, present in numerous, commonly interweaving, distributary channels that extend northward on mudflats between the Old River Bed and the southern Great Salt Lake Desert (see Madsen and others, 2015; Clark and others, 2016); channels are locally exposed due to deflation of mudflat surfaces; selected channels were mapped to show their geographic distribution, and are depicted solely as green lines on plate 1; unit Qasd is probably related to continued Sevier-basin overflow and to groundwater discharge following the decline of Lake Bonneville; ages of 8800 to 11,400 ^{14}C yr B.P. (about 10,000 to 13,000 cal yr B.P.) (Oviatt and others, 2003; Madsen and others, 2015); thickness to about 3 feet (1 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 Blue Lake; thickness 0 to about 10 feet (0–3 m).

Eolian Deposits

Qes, Qes?

Eolian sand (Holocene) – Windblown sand, silt and mud pellets in dunes and sheets; bedding is variable from laminated to thin, with abundant cross-bedding; includes well-sorted, fine to very fine grained quartz sand, and also coarse to very fine grained sand of variable composition including gypsum, ooids, carbonate lumps, and shell fragments (gastropods and ostracodes); some gypsum compositions are reported to be as much as 60 percent (Jones, 1953; Boden, 2016); we noted the dune sand composition in several locations was variable and did not map gypsum or quartz dunes separately for this project; Miller and others (in press) mapped sand dunes and sheets composed of mud pellets along the margin of the southern Newfoundland Mountains; a local source of sand for Qes accumulations is the Old River Bed delta channel system (see unit Qasd); several prior reports noted eolian sand dunes of the Great Salt Lake Desert area (Nolan, 1927; Jones, 1953; Eardley, 1962; Doelling, 1964; Stifel, 1964; Dean, 1976, 1978; Doelling and others, 1994; Boden, 2016); grades into unit Qei; Qes locally forms thin cover on map units (see stacked units), only thicker deposits mapped as unit Qes; as much as 90 feet (25 m) thick.

Qei, Qei?

Eolian silt (Holocene) – A few areas of windblown silt with minor clay and fine sand that is locally oolitic; Qei occurs extensively as sheets that typically cover lacustrine and alluvial deposits and some bedrock in stacked units and locally as low dunes; additionally forms thin, unmapped cover on several map units; thickness as much as 10 feet (3 m).

Playa Deposits

Qps **Playa salt** (Holocene) – The salt crust at Bonneville Salt Flats composed of interbedded halite (36%) and gypsum sand (64%); salt crust is white to light gray brown and is hard to brittle to plastic depending on water content; lateral extent and thickness of salt crust is continually changing due to flooding, evaporation and dessication (FED) cycles (Bowen and others, 2017); mapped extent of salt crust is from September 7, 2016 data (figure 4, Bowen and others, 2018), note the boundary of crystalline salt historically extended onto and adjacent to the potash production facility area south of Salduro (Gwynn, 1996); salt crust is underlain by pre-Lake Bonneville carbonate mud (Bowen and others, 2018; Oviatt and others, 2020; Bernau and Bowen, in prep.); unit Qps thickness from 0 to 5 feet (0–1.5 m) based on five salt crust thickness studies since 1960 (see recent studies by White and Terrazas, 2006 and Bowen and others, 2018).

Qp **Playa mud** (Holocene) – Mapped solely as stacked unit Qpl (see description below).

Lacustrine and Deltaic Deposits (Lake Bonneville)

See figure 2 for a simplified hydrograph and chronology of Lake Bonneville. Currey (1982) and Chen and Maloof (2017) provided shoreline elevation data, and Oviatt estimated Stansbury shoreline elevations using Google Earth® (see plate 2). Lake Bonneville was succeeded by a lake during the Gilbert episode (figure 2), but these deposits are localized, generally thin, and difficult to recognize. Other post-Bonneville lakes that were high enough to flood into the Great Salt Lake Desert basin from Great Salt Lake (threshold elevation ~4217 feet [1286 m]) are not dated, did not last long, and did not leave an obvious sedimentary record.

Qlg, Qlg?

Lacustrine gravel (lowermost Holocene to upper Pleistocene) – Sandy gravel to boulders composed of rock fragments deposited in shore zones of Lake Bonneville; clasts are typically well rounded and sorted; locally calcareous tufa-cemented and draped on bedrock (especially at the Provo shoreline, figure 2); includes both transgressive and regressive lake phase gravels; may include small areas of lacustrine sand and fines, eolian and pre-Lake Bonneville deposits; thinner deposits on bedrock are not mapped; thickness variable, up to 100 feet (30 m) or more.

Qls **Lacustrine sand** (lowermost Holocene to upper Pleistocene) – Lacustrine sand in two areas; one area of carbonate-coated sand, carbonate lumps and few pebbles in barrier below the Stansbury shoreline zone on south Grassy Mountains piedmont; a second area in a cove below the Provo shoreline at the eastern Grassy Mountains; may include small areas of lacustrine gravel and finer-grained material, and eolian sand and silt; thickness to 80 feet (25 m) or more.

Qlf **Lacustrine fine-grained deposits** (lowermost Holocene to upper Pleistocene) – Sand, silt, marl, and calcareous clay; thin to very thick bedded; may include ostracode- and gastropod-rich layers; locally includes small areas of sand or sand and gravel; Doelling (1964) reported diatomaceous marl in Ripple Valley and Puddle Valley and referred to an area as "Diatom Gulch" (sections 17–20, T. 3 N., R. 10 W.); a great variety of diatoms were identified by A.P. Setty from section 29, T. 1 N., R. 10 W., and Doelling (1964) also did microscopic examinations of samples from seven locations; unit Qlf locally includes the white marl of Gilbert (1890); locally can include thin eolian silt and sand deposits at surface; thickness as much as 60 feet (20 m) or more.

Qlgf **Lacustrine gravel and fine-grained deposits** (lowermost Holocene to upper Pleistocene) – Lake Bonneville deposits with mixed grain sizes; see Qlg, Qls, Qlf unit descriptions above; may include small areas of eolian and pre-Lake Bonneville deposits, as well as bedrock; thickness up to 100 feet (30 m) or more.

Qlk **Lacustrine carbonate deposits** (lowermost Holocene? to upper Pleistocene?) – Mapped solely as stacked unit Qei/Qlk.

Lacustrine Deposits (Pre-Lake Bonneville)

Qlo **Older lacustrine deposits** (middle and lower Pleistocene) – Subsurface only and lower part of stacked unit Qpl, also see unit Qleo; white to pale yellowish gray to gray carbonate mud; oolitic sand and mud; uncommon thin layers of gypsiferous sand; Qlo contains lacustrine ostracodes solely of *Limnocythere staplini*, which are not typical of the ostracode faunal succession reported in Lake Bonneville deposits (see Oviatt, 2017); unit Qlo was observed in the Knolls and Wendover cores, and in cores from the Bonneville Salt Flats area and in other shallow cores and pits examined for this project (table 1; Oviatt and others, 2020; Bernau and Bowen, 2018a, 2018b, in prep.); the entire Wendover core consists of Qlo; most of the Knolls core consists of Qlo, except for the Bonneville marl in the uppermost meter or two (the basal contact of Bonneville marl in the remnants of the Knolls core is not well defined) (Shuey, 1971; Oviatt and Thompson, July 25, 1995, unpublished evaluation of Knolls and Wendover cores; Oviatt, 2017; Oviatt, and others, 2020); Williams (1994) reported three ash beds from the Knolls core ranging in estimated age from about 0.2 Ma (undated ash, but possible age of about 0.2 Ma) to approximately 0.9 Ma, and five ash beds in the Wendover core that range in estimated age from about 0.17 Ma to about 1.15 Ma (table 2); pollen analyses for samples from the Knolls and Wendover cores were published in Martin and Mehringer (1965) and Davis (2002); Shuey (1971) conducted paleomagnetic studies of both the Wendover and Knolls cores; unit Qlo may overlie Pliocene? deposits, Pliocene-Miocene Salt Lake Formation, and other Tertiary rock units (noted in two drill holes near Salduro rail siding; table 3); incomplete thickness is greater than 560 feet (170 m) in the Wendover core, and greater than 495 feet (151 m) in the Knolls core (Oviatt and Thompson, July 25, 1995, unpublished evaluation of Wendover and Knolls cores).

Mass-Movement Deposits

Qms **Landslide deposits** (Holocene to uppermost Pleistocene?) – Two relatively small deposits in northern Silver Island Mountains and western Grassy Mountains; deposits on steeper slopes with poorly sorted, clay- to boulder-size debris, and displaced bedrock blocks; generally characterized by hummocky topography, main and internal scarps, and chaotic bedding in displaced bedrock; age and stability determinations require detailed geotechnical investigations; thickness highly variable.

Qmtc **Talus and colluvium** (Holocene to uppermost Pleistocene?) – One area of mixed talus and colluvium on the steep north side of Guilmette exposure near the Bonneville shoreline, Silver Island Mountains; thickness probably less than 15 feet (5 m).

Mixed-Environment Deposits

Qla, Qla?

Lacustrine and alluvial deposits, undivided (Holocene to upper Pleistocene) – Sand, gravel, silt, and clay; consists of alluvial deposits reworked by Lake Bonneville, lacustrine deposits reworked by streams and covered by slopewash and alluvial fans, as well as alluvial and lacustrine deposits that cannot be readily differentiated at map scale; grades into other lacustrine and alluvial deposits; near Lone Mountain unit Qla is sandier than typical gravelly piedmont deposits, probably due to source material; thickness locally exceeds 30 feet (10 m).

Qel **Eolian and lacustrine deposits, undivided** (Holocene to upper Pleistocene) – Mapped solely as stacked units Qel/ⱣPol, Qel/ⱣPosc and Qel/ⱣPolc.

Qleo **Older lacustrine and eolian deposits, undivided** (pre-Lake Bonneville) (Pleistocene) – Subsurface only, also see unit Qlo; lacustrine deposits include white to gray carbonate mud (locally laminated), oolitic sand, sandy mud, and pebbly sand; eolian deposits include fine sand, sandy mud, and paleosols, characterized in part by pale reddish to pale yellowish colors; unit Qleo was observed in the Clive area, and may be present in much of the low-lying areas east of the mudflats, east and west of the Grayback Hills and west of the Grassy Mountains, between Knolls and the Cedar

Mountains, and north of the Grayback Hills and west of the Grassy Mountains; Qleo was encountered in the Clive landfill pit walls (C5-5, C29-5) and sediment core BC1 (table 1; Oviatt and others, 2020); Qleo has not been dated except in a relative sense—the unit is older than overlying Lake Bonneville deposits; incomplete thickness is greater than 22 feet (6.7 m) in C29-5 and probably greater than 14 feet (4 m) in BC1 (Oviatt and others, 2020).

Qeas **Eolian and alluvial sand** (Holocene) – Mapped solely as stacked unit Qeas/Qpl.

Human-Derived Deposits

Qh **Human disturbance** (historical) – Deposits and disturbed areas from human development; includes sand and gravel and borrow pits, quarries, and developed areas on the former and current U.S. Air Force range (UTTR); more extensive waste management areas and evaporation ponds are mapped separately; thickness generally less than about 20 feet (6 m).

Qhw **Waste management facilities** (historical) – Deposits, disturbed areas, and borrow areas of waste management facilities within the West Desert Hazardous Industry Area (see Black and others, 1999); includes (1) Grassy Mountain landfill, located north of Knolls (hazardous waste, operated by Clean Harbors Environmental), and (2) Clive landfill (low-level radioactive and mixed hazardous and radioactive waste, operated by Energy Solutions) and adjacent U.S. Department of Energy Vitro Tailings disposal site; waste management area thicknesses are variable, but locally to as much as 65 feet (20 m) above ground at the Grassy Mountain facility, and 46 to 85 feet (14–26 m) (both below and above ground) at the Clive facility (Ed Costomiris and Charles Bishop, Utah Department of Environmental Quality, communications to Clark, 2018).

Qhe **Evaporation ponds** (historical) – Includes three evaporation system areas. First is an inactive pond system formerly operated by Amax (predecessor to Magcorp and US Magnesium) located north of Knolls; in the 1980s excess Great Salt Lake water was pumped via the West Desert pumping station (west of Lakeside) to the Newfoundland evaporation basin and subsequently transferred to the evaporation ponds—a series of diked areas used to concentrate magnesium minerals (salts) through solar evaporation (Jones and others, 2009; Tripp, 2009); second is a former potash production facility (Chloride Products Inc., 1921–1925) located south of the Arinosa rail siding (Gwynn, 1996); third is the active Intrepid Potash facility and historical operations of the Salduro salt marsh located southeast of Wendover; the Intrepid facility (2004 to present) extracts brine from wells and trenches, transports the brine to their solar evaporation pond system, and processes potassium chloride salts largely for agricultural fertilizer (Eric Rogers, Intrepid Potash Wendover, verbal communication, October 11, 2019); prior potash production near Intrepid and farther east near Salduro was by several entities with attempts from about 1907 to the 1930s, but with consistent commercial production from 1939 to 2004 (Gwynn, 1996; Kipnis and Bowen, 2018); thickness is typically less than 6 feet (<2 m).

Stacked-Unit Deposits

Consists of thin surficial deposits covering underlying surficial deposit and bedrock geologic units. See each unit for descriptions. Thin unmapped cover materials may also be present on other geologic units throughout the map area.

Qpl **Playa mud (post-Lake Bonneville) over lacustrine fine-grained deposits (Lake Bonneville) over older lacustrine (pre-Bonneville) deposits** (Holocene over upper Pleistocene over unknown Pleistocene) – Unit consists of three stacked subunits that generally comprise the extensive mudflats of the Great Salt Lake Desert in the map area, defined through subsurface investigations; for simplicity unit symbol Qpl replaces typical stacked labels; upper playa deposits of silt, mud and calcareous mud (commonly mixed eolian, alluvial, and mudflat environments) covering lacustrine marl and fine-grained deposits of Lake Bonneville (unit Qlf), which collectively overlie pre-Bonneville deposits of lacustrine mud and sand (unit Qlo); playa deposits are locally saline or gypsiferous, grade laterally into thin alluvial mud, silt and sand along playa margins, and locally cover post-Lake Bonneville alluvial channels (unit Qasd); the Lake Bonneville fines (Qlf) subunit was differentiated by lithologies and ostracode fauna (Oviatt and Thompson, July 25, 1995, unpublished evaluation of Knolls and Wendover cores; Oviatt and others, 2020); the pre-Bonneville subunit (Qlo) was differentiated by lithologies, ostracode fauna, and volcanic ashes (Williams, 1994; Oviatt and Thompson, July 25, 1995, unpublished evaluation of Knolls and Wendover cores; Oviatt and others, 2020); subsurface investigations indicate that Lake Bonneville deposits are absent from an area near the Bonneville Salt Flats (approximate area shown as orange dashed line on plate 1; Oviatt and others, 2020; Bernau and Bowen, 2018a, 2018b; in prep.); unit Qpl was mapped in adjacent areas as eolian and alluvial deposits over lacustrine fines (Clark and others, 2016) and playa mud with fringing alluvial mud (Miller and others, in press); subunit thicknesses include playa mud from 0 to 2 feet (0-0.6m), Lake Bonneville marl and fines from 0 to 8 feet (0-2.4 m), and incomplete pre-Bonneville deposits exceed 560 feet (170 m) (Oviatt and Thompson, 1995, unpublished data on the Knolls and Wendover cores; Oviatt and others, 2020); unit Qpl thickness locally exceeds 560 feet (170 m).

Qei/Qlf

Eolian silt over lacustrine fine-grained deposits (Holocene over upper Pleistocene) – Eolian silt forming a mantle on fine-grained lacustrine deposits of Lake Bonneville and the Gilbert-episode lake; surface commonly contains distinctive vegetation stripes of uncertain origin (see Oviatt and others, 2003; West and Johnson, 2005); these distinctive stripes were called desert ripples by Ives (1946), and Doelling (1964) apparently named Ripple Valley for these features; may include some areas of eolian sand as thin sheets and low dunes; cover unit thickness is 1 to 4 feet (0.4–1.1 m) at the Clive landfill and near Knolls, and underlying unit Qlf is 7 to 10 feet (2.2–3.1 m) at the Clive landfill (Oviatt, 2017; Oviatt and others, 2020).

Qei/Qlg

Eolian silt over lacustrine gravel (Holocene over upper Pleistocene) – Eolian silt forming a mantle on lacustrine gravel in German Valley (Grassy Mountains), near Clive, and near Thumb Ridge; cover unit thickness is highly variable, but possibly as much as 6 feet (2 m).

Qei/Qlk

Eolian silt over lacustrine carbonate deposits (Holocene over lowermost Holocene? to uppermost Pleistocene?) – Eolian silt on lacustrine deposits of carbonate chips in a matrix of silt and sand; poorly exposed, forms low mounds in a band on unit Qei/Qlf west of the Grayback Hills and Clive; unit is possibly related to the highstand of the Gilbert-episode lake, considering an elevation near 4250 to 4260 feet (1296–1299 m) (see Oviatt, 2014; see figure 2); Solomon (1993) and Doelling and others (1994) previously mapped as lacustrine sand; cover unit thickness is less than 3 feet (1 m), and Qlk thickness unknown, but up to 3 feet (1 m) exposed.

Qei/Qla

Eolian silt over lacustrine and alluvial deposits (Holocene over Holocene to upper Pleistocene) – Eolian silt forming a mantle on mixed alluvial and lacustrine deposits along lower margins of piedmont around Ripple Valley; cover unit thickness is highly variable, but possibly as much as 6 feet (2 m).

Qes/Qafy

Eolian sand over younger fan alluvium (Holocene over Holocene to uppermost Pleistocene) – Eolian sand and silt overlying younger fan deposits; mapped in a few areas where the eolian deposits generally obscure the surface texture of fans; cover unit thickness variably, but possibly as much as 6 feet (2 m).

Qes/Qlg

Eolian sand over lacustrine gravel (Holocene over upper Pleistocene) – Eolian sand and silt forming a mantle on lacustrine gravel of Lake Bonneville; cover unit thickness unknown, but possibly as much as 6 feet (2 m).

Qes/Qlf

Eolian sand over lacustrine fine-grained deposits (Holocene over upper Pleistocene) – Eolian sand and silt forming a mantle on lacustrine fines; also present in patchy sheets and dunes on unit Qlf, typically around perimeter of large Qes areas and leeward sides of valleys; cover unit thickness from 0 to as much as 6 feet (2 m).

Qes/Qlgf

Eolian sand over lacustrine gravel to fine-grained deposits (Holocene over upper Pleistocene) – Eolian sand and silt forming a mantle on Lake Bonneville lacustrine gravel to fines; cover unit thickness unknown, but possibly as much as 6 feet (2 m).

Qes/Qla, Qes/Qla?

Eolian sand over lacustrine and alluvial deposits (Holocene over upper Pleistocene) – Eolian sand forming a mantle on mixed lacustrine and alluvial deposits locally along the piedmont west of the Cedar Mountains, at the Knolls, and southern Newfoundland Mountains; cover unit thickness is highly variable, but possibly as much as 6 feet (2 m).

Qes/Qafo

Eolian sand over older alluvial-fan deposits (Holocene over upper to middle? Pleistocene) – Eolian sand forming a mantle on older alluvial-fan deposits along the piedmont west of the Cedar Mountains; cover unit thickness is highly variable, but possibly as much as 6 feet (2 m).

Qes/IPosc

Eolian sand over Oquirrh Group, sandstone and siltstone unit (Cedar thrust sheet) (Holocene over Upper to Middle? Pennsylvanian) – One area of eolian sand and silt overlying bedrock unit on southeast margin of map area; cover unit thickness is variable, but possibly as much as 10 feet (3 m).

Qel/IPol

Eolian and lacustrine deposits over Oquirrh Group, limestone unit (Aragonite thrust sheet) (Holocene to upper Pleistocene over Upper Pennsylvanian) – One area of eolian sand and silt and Lake Bonneville lacustrine gravel and sand overlying bedrock unit near southeast corner of map area; cover unit thickness is variable, but possibly as much as 10 feet (3 m).

Qel/IPosc

Eolian and lacustrine deposits over Oquirrh Group, sandstone and siltstone unit (Cedar thrust sheet) (Holocene to upper Pleistocene over Upper Pennsylvanian) – Eolian sand and silt and Lake Bonneville lacustrine gravel and sand overlying bedrock unit on southeast margin of map area; cover unit thickness is variable, but possibly as much as 10 feet (3 m).

Qel/IPolc

Eolian and lacustrine deposits over Oquirrh Group, limestone unit (Cedar thrust sheet) (Holocene to upper Pleistocene over Middle Pennsylvanian?) – Eolian sand and silt and Lake Bonneville lacustrine gravel and sand overlying bedrock unit at southeast margin of map area; cover unit thickness is variable, but possibly as much as 10 feet (3 m).

Qlg/Tl **Lacustrine gravel over latite lava flows** (lowermost Holocene to upper Pleistocene over Eocene) – Mapped in one area south of Clive exit on I-80; Lake Bonneville lacustrine gravel forming a mantle on bedrock; typically includes an eolian silt veneer; cover unit thickness is variable, but possibly as much as 3 to 6 feet (1–2 m).

Qeas/Qpl

Eolian and alluvial sand over playa mud over lacustrine fine-grained over older lacustrine deposits (Holocene over lowermost Holocene to upper Pleistocene over Pleistocene) – Thin sheets of sand and silt deposited by wind, streams and sheet floods along the playa margin; includes areas of coppice dunes; locally present along the margins of the Silver Island Mountains and Floating Island; cover unit thickness uncertain, probably less than 3 feet (1 m).

TERTIARY (NEOGENE-PALEOGENE) ROCK UNITS

See table 3 for data on subsurface rock units from hydrocarbon exploration wells.

Tsl, Tsl?

Salt Lake Formation (Pliocene to upper Miocene) – Two very small exposures of light-brownish-gray, tuffaceous sandstone (glassy) that is locally pebbly and conglomeratic; thin bedded; forms slopes in eastern and central Grassy Mountains; queried in small outcrop in higher Grassy Mountains; unit Tsl probably underlies pre-Lake Bonneville deposits (units Qlo and Qleo), and possibly younger Pliocene deposits, as a thick section in the subsurface of valleys as suggested by two exploration wells near Salduro siding (table 3); unit Tsl is locally exposed in the Silver Island Mountains (Miller and others, in progress); no direct age data in map area, regionally age of Salt Lake Formation is Pliocene to upper Miocene (Oaks and others, 1999; Miller and others, 2020); incomplete thickness as much as 20 feet (6 m).

Tra(Dg)

Rock avalanche breccia of Guilmette Formation (Pliocene to upper Miocene) – Two areas of brecciated bedrock in the northern Silver Island Mountains interpreted as rock avalanche breccia from extensional tectonics; dark gray and brown breccia with locally distinguishable strata of Devonian Guilmette Formation; forms massive breccia sheets (locally pulverized rock) interlayered with nearly intact rock slabs exhibiting jigsaw fractures; Miller and others (in progress) noted rock avalanche breccia exposures in the Silver Island Mountains interbedded with Salt Lake Formation conglomerate and tuff; thickness is variable, likely less than 200 feet (60 m).

Tls **Tertiary limestone** (Pliocene? to Eocene?) – Three small exposures of light grayish-brown lacustrine limestone; locally cherty or silicified; poorly bedded; present in Grassy Ridge overlying unit Psd near the Provo shoreline; Clark (this study) reevaluated exposures just south of the map area and found another exposure of unit Tls previously mapped as lacustrine tufa (see Clark and others, 2016); no direct age data, could be part of Salt Lake Formation, older Tertiary rocks, or Sevier "collapse" basin rocks (see Constenius, 1996; Hintze and Davis, 2003); thickness as much as 20 feet (6 m).

Volcanic Rocks of the Grayback Hills and Grassy Mountains

Rock names are based on the geochemical classification of Le Bas and others (1986). See table 4 for geochemical data and table 5 for radiometric age data.

Tl **Latite lava flows** (Eocene) – Black, gray, grayish-brown, and grayish-red latite and latite porphyry lava flows; locally vesicular and flow banded; phenocrysts (10–15%) include (decreasing) calcic plagioclase, pyroxene, olivine, iddingsite, and iron oxides; form extensive exposures in the Grayback Hills that have been modified by Lake Bonneville; geochemical data from Hogg (1972), Doelling and others (1994), and this study (table 4); Doelling and others (1994) called flows/unit trachyandesite; yielded K-Ar ages of 38.5 ± 0.6 Ma, whole rock (M. Best, Brigham Young University, in Davies [1980]) and 39.1 ± 1.0 Ma on groundmass (Doelling and others, 1994; UGS and Krueger Enterprises, 2018) (table 5); thickness as much as 35 feet (11 m) (Doelling and others, 1994).

Til **Latitic intrusion** (Eocene) – A single neck or plug in the northwest Grayback Hills of latite that is medium to dark gray, weathering to reddish brown; flow banded; forms resistant exposure near outcrops of units Tsd and Tl; geochemical data from Doelling and others (1994) and this study (table 4); no direct age data, but likely of similar age to unit Tl; probable source vent of unit Tl; Doelling and others (1994) called unit trachyandesite and included it with the lava flows; width is about 250 feet (75 m).

Tsd **Tuffaceous sandstone and tuff** (Eocene) – Tuffaceous conglomeratic sandstone (80%) and interbedded dacitic airfall tuff (20%) in the northern Grayback Hills; light-gray tuffaceous sandstone is conglomeratic with clasts up to cobble size of limestone, siltstone, sandstone and chert; locally cross-bedded and contains channel bed forms; bedding is thin to medium; grayish-pink and yellowish-gray dacitic tuff is poorly bedded and interlayered with thin bands of reworked tuff; tuff is composed of clayey, mostly devitrified glass shards, quartz, mica, and subordinate feldspar and mafic minerals; few exposures near northern end of volcanic outcrops; geochemical data on dacite tuff from Doelling and others (1994) in table 4; K-Ar age of 38.6 ± 1.0 Ma on sanidine (Doelling and others, 1994; UGS and Krueger Enterprises, 2018), and $^{40}Ar/^{39}Ar$ total fusion on several plagioclase grains gave a much younger weighted mean age of about 35.5 Ma (M. Pringle, USGS, in Doelling and others, 1994) (table 5); unit Tsd appears to be interlayered with and underlies unit Tl, but unit Tl lacks the sanidine phenocrysts of unit Tsd; incomplete measured thickness is 307 feet (94 m) (Doelling and others, 1994).

Tid **Dacitic intrusions** (Eocene?) – Several dark-gray to black (weathers to reddish brown) porphyritic dacite to andesite dikes and pods in the western Grassy Mountains; phenocrysts (10–20%) include (decreasing abundance) plagioclase, pyroxene and iron oxides; form discontinuous outcrops trending north to northwest; new geochemical data in table 4; no direct age data, but possibly of similar age to unit Til; Doelling (1964) called these basalt porphyry dikes; width is 15 to 50 feet (5–15 m) (Doelling, 1964).

TRIASSIC TO PERMIAN ROCK UNITS

Triassic and Permian (Post-Oquirrh Group) Strata of the Calcite, Aragonite, Clive, Knolls and South Knolls Thrust Sheets

See table 6 for selected fossil age data.

Ꞓt **Thaynes Formation** (Lower Triassic, Spathian-Smithian) – Upper part (southwest Grayback Hills) is yellowish-brown silty limestone and limestone (measured sections 1, 2, 3, 3A, 3B of Davies [1980]); middle part (northern Grayback Hills) is gray, finely crystalline limestone and some brown sandstone (measured section 4 of Davies [1980]); lower part (Thumb Ridge) is pale red, brown and gray, interbedded sandstone, limestone, shale, and siltstone (Thaynes unit and units 7 through 4 of Dinwoody Formation measured section of Doelling and others, 1994); thinly laminated to medium bedded; forms ledges, slopes, and cliffs; numerous fossils include ammonoids, conodonts, crinoids, echinoids, microgastropods, pelecypods, brachiopods, scaphopods?, and fragments of fish and sharks (Davies, 1980; Doelling and others, 1994); ammonoids and conodonts reported in table 6 indicate the upper part is upper Spathian substage, the middle part is lower Spathian, and the lower part is Smithian; lower contact was adjusted based on ammonoids, but no bed with *Meekoceras* was found to define the base (K. Bylund, independent researcher, email to Clark, Feb. 16, 2018; table 6); unconformably overlies the Gerster Formation at Thumb Ridge, but a tiny unmapped patch of intervening red beds (unit 2, Dinwoody measured section in Doelling and others, 1994) could possibly be tongue of Woodside Formation; incomplete thickness is about 1930 feet (590 m) (Davies, 1980; Doelling and others, 1994; this study), upper and lower contacts are not exposed.

Pge **Gerster Formation** (middle Permian) – Medium- to light-gray cherty limestone and chert; tan, light-gray, and light-blue-gray chert occurs as beds, nodules, blebs and stringers, some with brown weathering rinds; medium to very thick bedded; forms ledges on Thumb Ridge and east side of Finger Ridge; fossils include productid and spiriferid brachiopods, crinoid columnals, and shell fragments (Doelling, 1964; Doelling and others, 1994) that are not age diagnostic; regional age is Guadalupian (Wordian, global chronostratigraphy) (see Hintze and Kowallis, 2009; Wardlaw, 2015) [note for Permian units the chronostratigraphic scale has changed over time]; previously mapped as Gerster Limestone and part of Park City Group, undifferentiated by Doelling (1964); unit is also known as the Gerster Limestone (U.S. Geological Survey, 2019); incomplete measured thickness is 263 to 311 feet (80–95 m) (Doelling, 1964; Doelling and others, 1994), upper contact is not exposed; complete thickness is 1600 feet (485 m) in Terrace Mountain (McCarthy and Miller, 2002), 50 miles (80 km) to the northwest.

Pm, Pm?

Murdock Mountain Formation (middle Permian) – Light-gray cherty dolomite and limestone, and light-gray, blue-gray, gray-tan, and brown weathering bedded and nodular chert; bedding is typically medium; forms rubbly ledges that have commonly been modified by Lake Bonneville; locally contains poorly preserved brachiopods (Doelling, 1964; Doelling and others, 1994); regional age is Guadalupian (Wordian and Roadian, global chronostratigraphy) (see Hintze and Kowallis, 2009; Wardlaw, 2015); the Murdock Mountain Formation is a lateral correlative of the Plympton Formation and most of the Rex Chert (Wardlaw, 2015); previously mapped as Rex Chert and part of Park City Group, undifferentiated by Doelling (1964); complete thickness is 1643 feet (500 m) at Finger Ridge (Doelling, 1964); incomplete thickness is about 500 feet (150 m) at Thumb Ridge and northern Grayback Hills (Doelling and others, 1994).

Ppy, Ppy?

Plympton Formation (middle to lower Permian) – Light-olive-gray to yellowish-gray fossiliferous limestone and limestone that is locally cherty with medium to dark-gray and brown chert nodules; locally some minor bedded chert; fossil brachiopods typically abundant; lower part of formation (20 to 30 feet, 6–10 m) is dark grayish brown bedded and nodular chert with lesser medium dark brown dolomitic limestone; bedding is thin to thick, forming ledges and some cliffs; present in Clive thrust sheet where it overlies the Grandeur Formation with no intervening Meade Peak Member strata; the Plympton is Guadalupian (Wordian and Roadian, global chronostratigraphy) (see Hintze and Kowallis, 2009; Wardlaw, 2015), but here extends into the lower Permian based on sample BW30 (table 6) from lower part of limestone which yielded conodont fossil *Neostreptognathodus sulcoplicatus* indicating a late to middle Leonardian (Kungurian to Late Artinskian, global chronostratigraphy) age (S.M. Ritter, Brigham Young Univ., email to Clark, Dec. 7, 2018); top of unit Ppy is eroded; incomplete thickness is about 200 feet (60 m).

Ppm, Ppm?

Phosphoria Formation, Meade Peak Member (middle and lower Permian) – Light-brown, pale-red, black and gray cherty dolomite, cherty siltstone, phosphatic dolomitic limestone, and chert; bedding is laminated to medium; forms rough ledges and slopes at Finger Ridge and Grassy Ridge, and not exposed in Grayback Hills-Thumb Ridge area but assumed present in subsurface (Doelling and others, 1994); regional age is Guadalupian and Leonardian (Roadian and Kungurian, global chronostratigraphy) (see Hintze and Kowallis, 2009; Wardlaw, 2015); Doelling (1964) called unit Meade Peak(?) Limestone of Park City Group, and part of Park City Group, undifferentiated; unit is also known as the Meade Peak Phosphatic Shale Member and Tongue (U.S. Geological Survey geologic lexicon, 2019); incomplete measured thickness is 233 feet (71 m) at Finger Ridge (Doelling, 1964), where upper part is not exposed.

Ppg, Ppg?

Park City Formation, Grandeur Member (lower Permian) – Light-gray-weathering dolomite, dolomitic limestone, and sandy limestone; light-gray to white chert is common as nodules, blebs, and sporadic thin beds; forms cliffy outcrops at Finger Ridge, Grassy Ridge, Lone Mountain, and queried in isolated knolls west of Thumb Ridge and in Ripple Valley; regional age is Leonardian (Kungurian, global chronostratigraphy) (see Hintze and Kowallis, 2009; Wardlaw, 2015); Doelling (1964) included as Grandeur Limestone in Park City Group, undifferentiated at Grassy Ridge; Clark uses terminology of Park City Formation rather than Group of some prior studies; UGS does not use Kaibab Limestone nomenclature in northwest Utah; incomplete thicknesses are estimated at 500 to over 1000 feet (150–300+ m) at the Grassy Mountains-Thumb Ridge area (Doelling, 1964; Doelling and others, 1994), 700 feet (215 m) at Lone Mountain (this study), and as much as 850 feet (260 m) in Clive thrust sheet (this study); elsewhere, complete thicknesses are 419 feet (128 m) in Cedar Mountains (Maurer, 1970) and 1838 feet (560 m) in Hogup Mountains (Stifel, 1964; Miller and others, in press).

Psd, Psd?

Permian sandstone, dolomite, and limestone (lower Permian, Leonardian) – Interbedded sandstone, dolomite, dolomitic limestone, and limestone; sandstone is orange-tan and light tan, fine grained, and locally cross-bedded; carbonate rocks are medium to dark gray and commonly cherty; medium to very thick bedded; forms ledges, cliffs and slopes in the Grassy Mountains, Lone Mountain, and hills southwest and south of Clive; fossils include *Plagioglypta canna* (mollusk, renamed *Dentalium*) and an unidentified pelecypod (Doelling, 1964); the Leonardian age is from bracketing strata and fusulinids (*Parafusulina* sp.) in the Cedar Mountains (sample D-77, Clark and others, 2016; Utah Geological Survey and Wells, 2017); Doelling (1964) reported the upper contact is gradational and difficult to separate from the Grandeur; previously mapped as “Unnamed” formation by Doelling (1964) and Maurer (1970); unit may correlate with the Pequop Formation and Loray? Formation and/or Arcturus Formation to the west and Diamond Creek Sandstone and Kirkman Formation to the east (Hintze and Kowallis, 2009; Clark and others, in press; Miller and others, in press; figure 3); incomplete measured thicknesses are 1463 and 3374 feet (446 and 1029 m) in Grassy Mountains (Doelling, 1964), and the unit is incomplete at Lone Mountain and as much as 900 feet (275 m) thick, up to 850 feet (260 m) in Clive thrust sheet, and about 1200 feet (365 m) thick at Knolls (this study); complete thickness is 3953 feet (1205 m) in the Cedar Mountains (Maurer, 1970); also likely present in the Hogup Mountains where thickness is uncertain (Stifel, 1964; Miller and others, in press).

PERMIAN TO PENNSYLVANIAN ROCK UNITS

See figure 3 for a correlation diagram of Oquirrh Group/Formation and adjacent rock units.

Oquirrh Group Strata of the Finger Ridge Thrust Sheet

Polf **Oquirrh Group, limestone unit** (lower Permian, upper Wolfcampian) – Dark-gray limestone and dolomitic limestone and minor light-brown sandstone; limestone is locally cherty and fossiliferous; thick to very thick bedded; present in the hanging wall of the thrust fault at western Finger Ridge; Doelling (1964) reported these rocks contain fusulinid *Schwagerina* sp. that Bruce Lambson (Shell Oil paleontologist) stated is late early Wolfcampian in age (table 6); our sample BW21 yielded *Schwagerina* of late Wolfcampian (Lenoxian) age (table 6); incomplete measured thickness is 1182 feet (360 m) at western Finger Ridge (Doelling, 1964) with neither top nor bottom exposed.

Oquirrh Group Strata of the Knolls and South Knolls Thrust Sheets

PIPo? **Oquirrh Group, undivided?** (lower Permian? to Middle Pennsylvanian?) – Possible Oquirrh Group rocks of Kittycat Mountain and adjacent area (see Stokes, 1963; Moore and Sorenson, 1979; Clark and others, 2016). Connection to Knolls and South Knolls thrust sheets uncertain. No access to this part of UTTR South for the current mapping project.

Polk **Oquirrh Group, limestone and sandstone unit** (lower Permian, Wolfcampian) – Consists of four parts; *upper part* is dark-gray coarse-grained limestone that is locally cherty, sandy and fossiliferous, and typically thick to very thick bedded; local interbeds of calcareous sandstone and thinner-bedded limestone; *underlying part* is medium to dark-gray sandy limestone with brown case hardening patches and interbeds of calcareous sandstone; black chert present in lenses; typically thin bedded; thin-bedded part not present in South Knolls thrust sheet; *underlying part* is dark-gray weathering to light and dark-brown calcareous sandstone and siltstone, lesser interbeds of medium-gray limestone and cherty limestone; laminated to medium bedded; *lowermost part* is medium to dark-gray limestone and sandy limestone with lesser interbeds of dark-gray weathering to light-brown calcareous sandstone; limestone is locally bioclastic; medium to very thick bedded; unit forms cliffs, ledges and slopes; three new fusulinid fossil samples (BW23, BW24, BW27) yielded a Wolfcampian age (table 6), but no biostratigraphic control from the lower part of the unit; base and locally top of unit Polk not exposed, incomplete thickness from 3300 to 5000 feet (1000–1500 m).

Oquirrh Group Strata of Grassy Mountains and Lone Mountain (Calcite and Aragonite Thrust Sheets)

Modified from Doelling (1964) and Jordan (1979b) (see figure 3).

PIPos, PIPos?

Oquirrh Group, sandstone and limestone unit (lower Permian, Leonardian?-Wolfcampian to Upper Pennsylvanian, uppermost Virgilian) – Light- to dark-brown sandstone, gray calcareous sandstone that weathers to light and dark brown, and light- to dark-gray limestone and fossiliferous limestone that is locally siliceous; local intraformational conglomerate beds; medium to thick bedded, forms slopes and ledges; fossil fusulinids and conodonts (table 6) were reported to indicate an early Leonardian through early Wolfcampian age (Doelling, 1964; Jordan, 1979a, 1979b; this study); G.P. Wahlman (independent biostratigrapher, written communication to Clark, May 13, 2019) reevaluated the fusulinid data in Doelling (1964) and reported some issues including *Triticites* ranging too high in the section suggesting probable juvenaria of Wolfcampian *Pseudoschwagerina*, and the fusulinids listed as indicating lower Leonardian strata are questionable; Wahlman also reported that the former early Wolfcampian interval (lower part of Doelling's unit 3 and upper part of unit 2) is now transferred to the latest Virgilian "Bursumian/Newwellian" (see, for example, Wahlman, 2013; table 6); Clark (this study) reevaluated exposures just south of the map area on the Aragonite thrust sheet and found that fossil sample D-74 with *Parafusulina* (Leonardian) (Clark and others, 2016; Utah Geological Survey and Wells, 2017) appears to be from upper Oquirrh Group beds rather than from the overlying map unit; Doelling (1964) reported other fossils include crinoids, brachiopods, pelecypods, sponges, trilobites, and bryozoans; unit is queried in area northwest of Calcite thrust fault and probable backthrust where brecciated; unit PIPos corresponds to Oquirrh Formation units 6, 5, 4, 3 and upper part of unit 2 of Doelling (1964); complete thickness is 7620 to 9004 feet (2323–2745 m) in Grassy Mountains (Doelling, 1964), but only 1500 feet (460 m) in Lone Mountain (this study) on a different thrust sheet.

IPosi, IPosi?

Oquirrh Group, sandstone and siltstone unit (Upper Pennsylvanian, Virgilian) – Light-brown, light-gray, and pale-red sandstone, calcareous sandstone and siltstone, and minor silty and sandy limestone; local intraformational conglomerate beds; south of Lone Mountain locally appears to contain a limestone interval 100 to 200 feet (30–60 m) thick; thin to medium bedded; forms slopes and few ledges; fossil fusulinids from lower part were reported to be of Virgilian age (Doelling, 1964; Jordan, 1979a, 1979b) (table 6); corresponds to Doelling's (1964) Oquirrh Formation unit 2, excluding the upper part (272 feet, 83 m) of limestone that is here placed in unit PIPos; unconformably overlies unit IPol (fossils indicate Missourian missing); queried near Puddle Valley where separation from unit PIPos is difficult (see Doelling, 1964); complete thickness is 1934 feet (590 m) in Grassy Mountains (Doelling, 1964), and 2500 feet (760 m) in Lone Mountain (this study).

IPol, IPol?

Oquirrh Group, limestone unit (Middle and Lower? Pennsylvanian, Desmoinesian-Atokan?-Morrowan?) – Medium-gray limestone and cherty limestone with minor interbedded light-brown sandstone and calcareous sandstone; typically thick bedded, forming cliffs and ledges; fossil fusulinids and conodonts from the unit indicate a Desmoinesian to late Atokan? age (table 6), and Doelling (1964) noted that it is uncertain if the lower part of the unit might contain Atokan- or Morrowan-age strata; other fossils include brachiopods, corals, trilobites, and bryozoans (Doelling, 1964); corresponds to Oquirrh Formation, unit 1 of Doelling (1964); incomplete thickness is 1607 feet (490 m) in Grassy Mountains (Doelling, 1964), base is faulted; unknown thickness in Lone Mountain due to folding.

Oquirrh Group Strata of Western Cedar Mountains (Cedar Thrust Sheet)

IPosc, IPosc?

Oquirrh Group, sandstone and siltstone unit (Upper Pennsylvanian) – Medium- to dark-gray, weathering to yellowish-gray, calcareous sandstone, light-brown to pale-red to dark-gray, calcareous siltstone, minor medium- to dark-gray limestone, and light-brown to light-gray resistant quartzite at base; calcareous sandstone and siltstone contain worm trails; laminated to medium bedded; forms slopes and a few ledges; upper unit of Cedar thrust sheet overlies unit IPolc, and unit IPosc is overlain on the west by the Aragonite thrust sheet; fossil conodonts from upper part of unit indicate a Virgilian age (table 6); Maurer (1970) mapped as Oquirrh Formation unit 4 based on lithologies; probably unconformable with unit IPolc below; incomplete thickness is roughly 1400 feet (425 m).

IPolc **Oquirrh Group, limestone unit** (Middle Pennsylvanian?) – Medium- to dark-gray limestone and cherty limestone and lesser medium to dark-gray, weathering to yellowish-gray, calcareous sandstone and siltstone; medium to thick bedded; forms cliffs and ledges; lower unit of the Cedar thrust sheet; no useful fossil data yet for biostratigraphic control; Maurer (1970) mapped as Oquirrh Formation unit 3 based on lithologies; incomplete thickness is roughly 1900 feet (580 m).

Oquirrh Group Strata of Western Cedar Mountains (Footwall of Cedar Thrust Sheet)

Pofc **Oquirrh Group, Freeman Peak Formation and Curry Peak Formation, undivided** (lower Permian, Wolfcampian) – Combined unit in the northern Cedar 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 that is locally fossiliferous; laminated to thick-bedded unit typically breaks into chips and plates forming rounded hills and slopes with local ledges; worm trail markings common on bedding planes in lower part of unit; Wolfcampian fusulinids reported by Maurer (1970) and Clark and others (2016); appears to be conformable with underlying Bingham Mine Formation; incomplete thickness is estimated at 300 to 400 feet (90–120 m), Clark and others (2016) reported unit is 3500 feet (1065 m) at the Cedar Mountains.

PERMIAN TO CAMBRIAN ROCKS OF THE SILVER ISLAND MOUNTAINS, FLOATING ISLAND, AND SOUTHERN NEWFOUNDLAND MOUNTAINS

PIPps **Pequop Formation, Ferguson Mountain Formation, and Strathearn Formation, undivided** (lower Permian to Upper Pennsylvanian?) – Combined unit consisting of a thick, monotonous interval of interbedded limestone and calcareous siltstone and sandstone overlying relatively thin basal limestone and pebble-conglomerate at Floating Island (current map area) and the adjacent Silver Island Mountains and Leppy Hills. ***Pequop Formation*** is medium- to dark-gray, silty bioclastic limestone, lesser yellow and gray siltstone and sandstone, light-gray dolomite, and limestone with chert pebbles; bedding is thin to thick, typically forming slopes with some ledges and cliffs; fusulinid and crinoid columnal fossils and white calcite blebs are diagnostic; incomplete thickness about 2330 feet (710 m) (see Steele, 1959, 1960; Schaeffer and Anderson, 1960; Bissell, 1964; Schneyer, 1990); underlying ***Ferguson Mountain Formation*** (after Hodgkinson, 1961; Bissell, 1962; Schneyer, 1990) consists of gray bioclastic and argillaceous limestone and dolomite with chert nodules near base and top; bedding is thin to thick forming slopes and ledges; less than 100 to 180 feet (<30–55 m) thick in the Leppy Hills and Silver Island Mountains (also see Schaeffer and Anderson, 1960; Steele, 1960); however, Schaeffer and Anderson (1960) and Miller and others (in progress) indicate this interval changes dramatically from north to south and is difficult to separate from the Pequop Formation; different nomenclature was previously used for the Ferguson Mountain (Schaeffer and Anderson, 1960; Steele, 1960); basal ***Strathearn Formation*** locally includes an upper part of gray limestone and dolomitic limestone, red and yellowish-brown sandstone and siltstone, and lower part of distinctive brownish-gray pebble conglomerate with chert and limestone clasts in a pink silty limestone matrix; in several areas of the Silver Island Mountains formation is a single bed of conglomerate; bedding is thin to medium forming ledges and slopes; Strathearn thickness is variable from 0.3 to 150 feet (0.1–45 m) (Schaeffer and Anderson, 1960; Miller and others, in progress; this study); fusulinid fossils from the Pequop and Ferguson Mountain Formations at the Leppy Hills and Silver Island Mountains were originally reported to range from early Guadalupian to Leonardian to Wolfcampian in age (Steele, 1959, 1960; Steele and others in Schaeffer and Anderson, 1960), but the two formations are considered Leonardian, Wolfcampian and Upper Virgilian at Ferguson Mountain, Nevada (Berge, 1960; Slade, 1961; Bissell, 1962, 1964), and conodont fossils from the nearby Pequop Mountains are Leonardian to late Wolfcampian age (Behnken, 1975); the Ferguson Mountain Formation is considered Wolfcampian from fusulinids at the Leppy Hills (Hodgkinson, 1961; Bissell, 1962); the Strathearn is not well dated with fusulinid fossils in the Silver Island Mountains and Leppy Hills, but is considered lower Wolfcampian to Upper Pennsylvanian (Steele, 1959; Schaeffer and Anderson, 1960; Hodgkinson, 1961; Bissell, 1964; Schneyer, 1990); Schaeffer and Anderson (1960) also reported brachiopod, gastropod and bryozoan fossils from the combined unit; Bissell (1964) used Arcturas Group nomenclature for the Loray, Pequop and Ferguson Mountain Formations; the Strathearn unconformably overlies the Ely Limestone with a local angular unconformity (Schaeffer and Anderson, 1960; Schneyer, 1990; Miller and others, in progress); north of map area in the Newfoundland Mountains the Pequop and Strathearn unconformably overlie the Pilot Shale (Allmendinger and Jordan, 1984; Miller and others, in press); unit Pℙps thickness is as much as 2550 feet (>780 m) but incomplete in the Silver Island Mountains and Leppy Hills (Schaeffer and Anderson, 1960; Schneyer, 1990), a similar incomplete thickness exists at Floating Island (this study).

ℙe, ℙe?

Ely Limestone (Middle and Lower Pennsylvanian) – Upper part is generally brown and gray-colored sandy limestone with lesser interbeds of brown sandstone and siltstone whereas the lower part is limestone that is generally medium to dark gray, some chert as nodules and beds, and thicker bedded; bedding is typically medium to very thick, forming cliffs and ledges; queried at southeastern Floating Island where contact with overlying unit Pℙps is uncertain as the Strathearn may be absent or cover obscures structural complications; fusulinid fossils from the Leppy Hills and Ferguson Mountain, Nevada indicate age range from Desmoinesian to Morrowan (Steele, 1959, 1960; Steele and others in Schaeffer and Anderson, 1960; Slade, 1961; Bissell, 1964); sample BW34 from the upper Ely at Floating Island yielded *Idiognathodus* and *Neognathodus* conodont fossils of middle to early Desmoinesian (Moscovian) age (S.M. Ritter, BYU, email to Clark, June 16, 2020); upper part includes Hogan Formation of Hodgkinson (1961) and Bissell (1964), and Bissell (1964) used Ely Group nomenclature; incomplete thickness at Floating Island is about 500 feet (150 m) (this study), and thickness is 1640 feet (500 m) at the Leppy Hills (Schneyer, 1990) and about 1740 feet (530 m) at Rishel Peak of Silver Island Mountains (Schaeffer and Anderson, 1960), but the formation thins northward (Schaeffer and Anderson, 1960; Miller and others, in progress).

ℙMdc

Diamond Peak Formation and Chainman Shale, undivided (Lower Pennsylvanian to Upper and Lower Mississippian) – Brown sandstone, tan calcareous sandstone, dark-brown heterolithic conglomerate, black shale, and black coarse-grained limestone; typically laminated to medium bedded forming slopes and ledges; fossils include a diverse gastropod and brachiopod fauna (Yochelson and Dutro in Schaeffer and Anderson, 1960), and Poole and Sandberg (1991) report Chesterian conodont fossils; age is Late Mississippian probably ranging into the Early Pennsylvanian (Schaeffer and Anderson, 1960); thickness varies considerably along strike, apparently as a result of structural thinning (attenuation) in many locations; thickness is incomplete in the current map area at about 200 feet (60 m), but in the Silver Island Mountains is as much as 1150 feet (350 m) at Donner Canyon and other exposures are faulted (Schaeffer and Anderson, 1960; Miller and others, in progress; this study).

Mj **Joanna Limestone** (Lower Mississippian) – Black, cherty limestone with abundant fossil brachiopods and corals (Schaeffer and Anderson, 1960); bedding is thin to very thick forming cliffs; Poole and Sandberg (1991) called the unit Joana equivalent strata with Osagean and Kinderhookian conodont fossils in the Silver Island Mountains; C.A. Sandberg (verbal communication to Clark, June 21, 2018) called the unit Lodgepole Limestone in the northern Silver Island Mountains; Joanna is locally in contact with the Guilmette Formation where the Pilot Shale is absent likely due to low-angle faulting and attenuation; thickness is from 0 to 130 feet (0–40 m) (thin to absent south of Graham Peak where grouped with unit ℙMdc, and maximum thickness in the north) (Miller and others, in progress).

DSu **Undivided dolomite and limestone** (Devonian and Silurian) – Undivided rocks in the southern Newfoundland Mountains on the UTTR-North area (not field checked), shown on adjacent maps as corresponding to the Pilot Shale, Guilmette Formation, Simonson Dolomite, and Lone Mountain Dolomite? (Allmendinger and Jordan, 1989; Miller and others, in press); in the map area, top part is not exposed with about 2300 feet (700 m) present (this study), and to the north total unit thickness of about 3600 feet (1100 m).

MDp *Pilot Shale* (Lower Mississippian to Upper and Middle? Devonian) – Formation is not exposed in the current map area, but is locally present in the adjacent Graham Peak 7.5' quadrangle and southward in the Silver Island Mountains; southern Newfoundland Mountains area was not accessed; thickness is 0 to about 200 feet (60 m) in the Silver Island Mountains and 425 feet (130 m) in the nearby Leppy Hills (Schaeffer and Anderson, 1960; Miller and others, in progress).

Dg, Dg?

Guilmette Formation (Upper and Middle Devonian) – Light- to dark-gray and black limestone that is cliff-forming and prominent in the Silver Island Mountains. Mapped as undivided formation in this map but subdivided into three informal units by Miller and others (in progress) in the Graham Peak area. Upper unit, about 885 feet (270 m) thick, is cliffy, fossiliferous, medium-gray to black limestone, with lenses of sand and "rip-up" beds in upper 300 feet (100 m) in some places, and some minor intervals of platey brown sandstone and siltstone; middle unit is a slope-cliff-slope interval about 367 feet (112 m) thick consisting of argillaceous limestone for slopes and a cliff of fossiliferous dark-gray limestone in the center of the interval that is about 165 feet (50 m) high; cliffy unit locally has quartz sand and "rip-up" clasts, as well as turbidite beds; lower unit is alternating shaly and non-shaly, dark-gray limestone that forms cliffs in its upper part, fossiliferous with abundant brachiopods, and about 985 feet (300 m) thick; bedding is typically medium to very thick; on this map upper unit is locally separated from middle and lower units (see dashed line on plate 1); base of formation placed at change from cliffy finely crystalline black limestone sequence (Guilmette) to top of interbedded dolomite and limestone interval (Simonson) (Schaeffer and Anderson, 1960; Miller and others, in progress); fossil stromatoporoids are present, as well as coral and algal heads; age is considered Late and Middle Devonian (Schaeffer and Anderson, 1960; Sandberg and Poole, 1977); Guilmette thickness is about 2230 feet (680 m) in the Silver Island Mountains (Schaeffer and Anderson, 1960; Miller and others, in progress).

Dsi **Simonson Dolomite** (Middle and Lower? Devonian) – Gray interbedded limestone and dolomite in upper part (650 feet [200 m]), with limestone similar to the overlying Guillmette; lower part of dark- and light-colored, ledge-forming, laminated dolomite; base placed at bottom of lowest dark-gray to black dolomite bed with prominent laminations; bedding is thin to very thick forming ledges, cliffs and slopes; fossils include brachiopods, corals and stromatoporoids and formation is considered Middle Devonian (Schaeffer and Anderson, 1960); Simonson may be unconformable on the Laketown as the Sevy Dolomite is not present (see Hintze and Kowallis, 2009); thickness is about 1270 feet (390 m) (Schaeffer and Anderson, 1960; Miller and others, in progress).

Sl **Laketown Dolomite** (Silurian) – Thick section of dolomite forming prominent light- and dark-colored cliffs in Graham Peak area of Silver Island Mountains, Miller and others (in progress) identified three units. Upper unit is light-gray dolomite, locally poorly bedded; middle unit is black, dark-gray, and medium-gray dolomite, much of it cherty and mottled, sandy dolomite and rare quartz sandstone beds with base marked by 15 to 30 feet (5–10 m) of bedded chert; lower unit is white to pale-buff, laminated dolomite underlain by dark-gray and black, mottled and laminated, dolomite; fossils include corals, stromatoporoids and brachiopods (Schaeffer and Anderson, 1960); age from Schaeffer and Anderson (1960) and Hintze and Davis (2003); Sheehan (1979) assigned the upper 850 feet (260 m) of Schaeffer's Laketown to the Roberts Mountain Formation; Laketown is unconformable on the Ely Springs (Hintze and Kowallis, 2009); incomplete thickness in the Floating Island quadrangle is about 500 feet (150 m); thickness is 1070 feet (325 m) in Silver Island Mountains (Miller and others, in progress) and about 850 feet (260 m) at the southern Newfoundland Mountains (Miller and others, in press).

Oes **Ely Springs Dolomite** (Upper Ordovician) – Gray dolomite in tripartite section that generally forms steep cliffs; upper part is a cliff of light-gray dolomite, correlated with the Floride Member of Budge and Sheehan (1980), locally contains a central dark-gray dolomite interval, upper part is 65 feet (20 m) thick; middle part is silty, platy dolomite and sandstone that forms benches, about 130 feet (39 m) thick; lower part (most of unit) composed of mottled, cherty, black dolomite that is cliffy and about 380 feet (115 m) thick; Waite in Schaeffer and Anderson (1960) reported fossil corals and brachiopods of Late Ordovician age; Ely Springs is unconformable on the Eureka (Hintze and Kowallis, 2009); previously called Fish Haven Dolomite (Schaeffer and Anderson, 1960; Allmendinger and Jordan, 1989); only incomplete exposures in current map area about 200 feet (60 m) thick, but formation is about 575 feet (175 m) at the Silver Island Mountains (Miller and others, in progress), and about 590 feet (180 m) at the Newfoundland Mountains (Allmendinger and Jordan, 1989; Miller and others, in press).

Oe **Eureka Quartzite** (Upper Ordovician) – White to blue-gray orthoquartzite, weathers to orange and reddish brown colors; commonly fractured and poorly bedded, forming steep rubble-covered slopes and cliffs; incomplete thickness about 100 to 200 feet (30–60 m) in current map area, complete thickness is 370 feet (115 m) at the Silver Island Mountains (Schaeffer and Anderson, 1960), and north of map area is about 500 feet (150 m) in the Newfoundland Mountains (Allmendinger and Jordan, 1989).

O *Ordovician units* (Middle and Lower Ordovician) – Several Ordovician rock units of the Silver Island Mountains are not exposed in the current map area; these units include (descending) the Crystal Peak Dolomite, Watson Ranch Quartzite, Lehman Formation, Kanosh Shale, and lower Pognip Group (Juab Limestone, Wah Wah Limestone, Fillmore Formation) (Miller and others, in progress).

Ꞓnp **Notch Peak Formation** (lowermost Ordovician to upper Cambrian) – Medium- to dark-gray and black, cherty limestone and light-gray to light-brown and black dolomite; upper one-third of formation is mostly dolomite; thick bedded, forming cliffs; algal buildups, “rip-up” clasts, and ooid beds common; age is based on fossil trilobite fauna (Robison in Schaeffer and Anderson, 1960; Robison and Palmer, 1968); thickness is about 1640 feet (500 m) in Silver Island Mountains (McCollum and Miller, 1991; Miller and others, in progress).

Ꞓou **Orr Formation, upper part** (upper Cambrian) – Combined unit in Silver Island Mountains that includes (descending) the Corset Spring Shale, Johns Wash Limestone, and Candland Shale Members (modified from Miller and others, in progress); follows McCollum and Miller (1991) but with their formations as members of the Orr Formation after Hintze and Palmer (1976); unit was previously mapped with different nomenclature by Schaeffer and Anderson (1960), also see Robison and Palmer (1968); unit Ꞓou is incomplete at 425 feet (130 m) thick in current map area, but complete thickness is 605 feet (185 m) (McCollum and Miller, 1991; Miller and others, in progress). ***Corset Spring Shale Member*** consists of yellowish-green shale and silty limestone forming slopes and benches; 65 feet (20 m) thick; ***Johns Wash Limestone Member*** is limestone that is generally silty; forms cliffs with prominent white streak in center part; upper and lower parts are dark gray and thin bedded, central part is marbleized and white; brown interbeds near the base consist of siltier limestone than elsewhere; 260 feet (80 m) thick; ***Candland Shale Member*** is brown, calcareous siltstone and silty limestone, highly fossiliferous with trilobites (see Robison and Palmer, 1968), and forms steep slopes; incomplete exposure in current map area about 100 feet (30 m) thick, but complete thickness is 280 feet (85 m).

Ꞓ *Cambrian units* (upper to lower Cambrian and Neoproterozoic?) – Several Cambrian rock units of the Silver Island Mountains are not exposed in the current map area; these units include (descending) the Orr Formation-Big Horse Limestone Member, Lamb Dolomite, and parts of the underlying Toano Limestone, Killian Springs Formation, and Prospect Mountain Quartzite (McCollum and Miller, 1991; Miller and others, in progress).

ACKNOWLEDGMENTS

We thank numerous individuals and entities for assistance in completion of this project. Clean Harbors Environmental, Energy Solutions and Neptune and Company, the Utah Department of Environmental Quality (Ed Costomiris and Charles Bishop), and Hill Air Force Base and UTTR (Russ Lawrence, Michael Byrk, Michael Shane), and Intrepid Potash (Eric Rogers and Craig Peterson) helped provide access and/or technical data. Brenda Bowen and Jeremiah Bernau (University of Utah) collaborated on subsurface studies of the Bonneville Salt Flats area. Geochemical laboratory work was by ALS Global. Scott Ritter (Brigham Young University) and Greg Wahlman (Independent) identified microfossils for biostratigraphic control. Kevin Bylund and Jim Jenks (independent researchers) shared fossil data. Hellmut Doelling (UGS, retired) provided a revised and colored version of his dissertation map and a revised digital text (Doelling, unpublished, 2003). Taylor Boden (UGS) shared his gypsum dune mapping data. Peter Nielsen and Tom Dempster (Utah Core Research Center) gave access to available cores and cuttings and assisted with fossil preparation and sediment cores. David Miller (U.S. Geological Survey, Emeritus) shared preliminary mapping data for the Silver Island Mountains. UGS staff, including Jon King, Grant Willis, Stephanie Carney, and Michael Hylland, reviewed and improved this map. Martha Jensen and Lori Steadman helped prepare the explanatory materials; Basia Matyjasik organized the GIS data and addressed cartographic issues.

REFERENCES

Allmendinger, R.W., and Jordan, T.E., 1989, Geologic map of the Newfoundland Mountains, northwestern Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-2087, 1 sheet, scale 1:31,680.

Behnken, F.H., 1975, Leonardian and Guadalupian (Permian) conodont biostratigraphy in western and southwestern United States: Journal of Paleontology, v. 49, no. 2, p. 284-315.

Bensen, LV., Sund, S.P., Smoot, J.P., Rhode, D.E., Spencer, R.J., Verosub, K.L., Louderback, L.A., Johnson, C.A., Rye, R.O., and Negrini, R.M., 2011, The rise and fall of Lake Bonneville between 45 and 10.5 ka: Quaternary International, v. 235, p. 57–69.

Berge, J.S., 1960, Stratigraphy of the Ferguson Mountain area, Elko County, Nevada: Brigham Young University Geology Studies, v. 7, no. 5, 63 p., geologic map (plate 4).

Bernau, J.A. and Bowen, B.B., 2018a, Deposition and diagenesis of the Bonneville Salt Flats [abs.]: American Association of Petroleum Geologists ACE 2018 Conference, Salt Lake City, Utah, p. 1234, online, http://www.searchanddiscovery.com/abstracts/html/2018/ace2018/abstracts/2837065.html, accessed January 28, 2020.

Bernau, J. and Bowen, B., 2018b, The transition of Lake Bonneville to the Bonneville Salt Flats, *in* Lund, W.R., McKean, A.P., and Bowman, S.D., editors, Proceedings Volume—2018 Lake Bonneville Geologic Conference and Short Course, October 3–6, 2018: Utah Geological Survey Miscellaneous Publication 170, online, https://ugspub.nr.utah.gov/publications/misc_pubs/mp-170/mp-170-1.pdf.

Bernau, J.A., and Bowen, B.B., in preparation, Tectonic and climatic controls on desert sedimentation and saline pan stability—insights from the Great Salt Lake Desert and Bonneville Salt Flats: Journal unknown.

Bissell, H.J., 1962, Permian rocks of parts of Nevada, Utah, and Idaho: Geological Society of America Bulletin, v. 73, p. 1083–1110.

Bissell, H.J., 1964, Ely, Arcturus, and Park City Groups (Pennsylvanian-Permian) in eastern Nevada and western Utah: American Association of Petroleum Geologists Bulletin, v. 48, p. 565–636.

Black, B.D., Solomon, B.J., and Harty, K.M., 1999, Geology and geologic hazards of Tooele Valley and the West Desert Hazardous Industry Area, Tooele County, Utah: Utah Geological Survey Special Study 96, 65 p., 6 plates, scale 1:100,000, https://doi.org/10.34191/SS-96.

Boden, H.T., 2016, Gypsiferous sand dune deposits on SITLA lands in the Great Salt Lake Desert project area, Tooele County, Utah, *in* Comer, J.B., Inkenbrandt, P.C., Krahulec, K.A., and Pinnell, M.L., editors, Resources and geology of Utah's West Desert: Utah Geological Association Publication 45, p. 105–130, 1 plate [omitted in publication, in UGS files], scale 1:100,000.

Bowen, B.B., Kipnis, E.L., and Raming, L.W., 2017, Temporal dynamics of flooding, evaporation, and dessication cycles and observations of salt crust area change at the Bonneville Salt Flats, Utah: Geomorphology, v. 299, p. 1–11.

Bowen, B.B., Kipnis, E.L., and Pechmann, J.M., 2018, Observations of salt crust thickness change at the Bonneville Salt Flats from 2003-2016, *in* Emerman, S.H., Bowen, B., Schamel, S., and Simmons, S., editors, Geofluids of Utah: Utah Geological Association Publication 47, p. 247–285.

Budge, D.R., and Sheehan, P.M., 1980, The Upper Ordovician through Middle Silurian of the eastern Great Basin—Part 1, Introduction—historical perspective and stratigraphic synthesis: Milwaukee Public Museum Contributions in Biology and Geology, no. 28, 26 p.; see also "Part 2, Lithologic descriptions," Milwaukee Public Museum Contributions in Biology and Geology, no. 29, 80 p., 1980.

Chen, C.Y., and Maloof, A.C., 2017, Revisiting the deformed high shoreline of Lake Bonneville: Quaternary Science Reviews, v. 159, p. 169–189.

Clark, D.L., Kirby, S.M., and Oviatt, C.G., 2012, Interim geologic map of Rush Valley 30' x 60' quadrangle, Tooele, Utah, Salt Lake, and Juab Counties, Utah: Utah Geological Survey Open-File Report 593, 65 p., 2 plates, scale 1:62,500, https://doi.org/10.34191/OFR-593.

Clark, D.L., Kirby, S.M., and Oviatt, C.G., in preparation, Geologic map of Rush Valley 30' x 60' quadrangle, Tooele, Utah, Salt Lake, and Juab Counties, Utah: Utah Geological Survey Map, scale 1:62,500.

Clark, D.L., Oviatt, C.G., and Page, D., 2016, Geologic map of Dugway Proving Ground and adjacent areas, Tooele County, Utah: Utah Geological Survey Map 274DM, 31 p., 2 plates, GIS data, scale 1:75,000 https://doi.org/10.34191/M-274dm.

Clark, D.L., Oviatt, C.G., and Dinter, D.A., 2017, Interim geologic map of the Tooele 30' x 60' quadrangle, Tooele, Salt Lake, and Davis Counties, Utah: Utah Geological Survey Open-File Report 669DM, 43 p., 3 plates, GIS data, scale 1:62,500 https://doi.org/10.34191/OFR-669dm.

Clark, D.L., Oviatt, C.G., and Dinter, D.A., in press, Geologic map of the Tooele 30' x 60' quadrangle, Tooele, Salt Lake, and Davis Counties, Utah: Utah Geological Survey Map 284DM, scale 1:62,500.

Constenius, K.N., 1996, Late Paleogene extensional collapse of the Cordilleran foreland fold and thrust belt: Geological Society of America Bulletin, v. 108, p. 20–39.

Constenius, K.N., Clark, D.L., King, J.K., and Ehler, J.B., 2011, Interim geologic map of the Provo 30' x 60' quadrangle, Utah, Wasatch, and Salt Lake Counties, Utah: Utah Geological Survey Open-File Report 586DM, 42 p., 2 plates, GIS data, scale 1:62,500 https://doi.org/10.34191/OFR-586dm.

Currey, D.R., 1982, Lake Bonneville—selected features of relevance to neotectonic analysis: U.S. Geological Survey Open-File Report 82-1070, 30 p., 1 plate, scale 1:500,000.

Dames & Moore, The Ralph M. Parsons Company, and Roger Foott Associates, Inc., 1987, Site proposal for the Superconducting Super Collider, Ripple Valley site—Appendix A, Geotechnical Report, Site Geologic Map 1:50,000 scale: Utah Department of Business and Economic Development, 3 volumes, variously paginated.

Davis, O.K., 2002, Late Neogene environmental history of the northern Bonneville basin—a review of palynological studies: Smithsonian Contributions to the Earth Sciences, v. 33, p. 295–307.

Davies, S.F., 1980, Geology of the Grayback Hills, north-central Tooele County, Utah: Salt Lake City, University of Utah, M.S. thesis, 204 p., 2 geologic maps, scale 1:7,000.

Dean, L.E., 1976, Eolian sand dunes of the Great Salt Lake Desert region, Utah: Salt Lake City, University of Utah, M.A. thesis, 138 p.

Dean, L.E., 1978, Eolian dunes of the Great Salt Lake Basin: Utah Geology, v. 5, no. 2, p. 103–111.

Doelling, H.H., 1964, Geology of the northern Lakeside Mountains and the Grassy Mountains and vicinity, Tooele and Box Elder Counties, Utah: Salt Lake City, University of Utah, Ph.D. dissertation, 354 p., geologic map and cross sections (map sheets 1–5) scale 1:31,680.

Doelling, H.H., 2003, Unpublished digital update to 1964 Ph.D. dissertation: Utah Geological Survey files, text variously paginated, 6 colored maps, 10 colored cross sections.

Doelling, H.H., Solomon, B.J., and Davies, S.F., 1994, Geologic map of the Grayback Hills quadrangle, Tooele County, Utah: Utah Geological Survey Map 166, 22 p., 2 plates, scale 1:24,000, https://doi.org/10.34191/M-166.

Doelling, H.H., Solomon, B.J., and Davies, S.F., 2018, Geologic map of the Grayback Hills quadrangle, Tooele County, Utah (GIS Reproduction of UGS Map 166 [1994]): Utah Geological Survey Open-File Report 679DM, 1 plate, GIS data, scale 1:24,000 https://doi.org/10.34191/OFR-679dm.

Eardley, A.J., 1962, Gypsum dunes and evaporate history of the Great Salt Lake Desert: Utah Geological and Mineral Survey Special Studies No. 2, 27 p., https://doi.org/10.34191/SS-2.

Gilbert, G.K., 1890, Lake Bonneville: U.S. Geological Survey Monograph 1, 438 p.

Gwynn, J.W., 1996, History of potash production from the Salduro salt marsh (Bonneville Salt Flats), Tooele County: Utah Geological Survey, Survey Notes, v. 28, no. 2, p. 1–3., https://doi.org/10.34191/SNT-28-2.

Hintze, L.F., and Davis, F.D., 2003, Geology of Millard County, Utah: Utah Geological Survey Bulletin 133, 305 p., https://doi.org/10.34191/B-133.

Hintze, L.F., and Kowallis, B.J., 2009, Geologic History of Utah: Brigham Young University Geology Studies Special Publication 9, 225 p.

Hintze, L.F., and Palmer, A.R., 1976, Upper Cambrian Orr Formation, its subdivisions and correlatives in western Utah: U.S. Geological Survey Bulletin 1405-G, 25 p.

Hodgkinson, K.A., 1961, Permian stratigraphy of northeastern Nevada and northwestern Utah: Brigham Young University Geology Studies, v. 8, p. 167–196.

Hogg, N.C., 1972, Shoshonitic lavas in west-central Utah: Brigham Young University Geology Studies, v. 19, part 2, p. 133–184.

International Commission on Stratigraphy, International Chronostratigraphic Chart v 2020/01: Online, http://www.stratigraphy.org/index.php/ics-chart-timescale, accessed May 1, 2020.

Ives, R.L, 1946, Desert ripples: American Journal of Science, v. 244, p. 492–501.

Jones, D.J., 1953, Gypsum-oolite dunes, Great Salt Lake Desert, Utah: American Association of Petroleum Geologists Bulletin, v. 37, p. 2530–2538.

Jones, B.F., White, W.W. III, Conko, K.M., Webster, D.M., and Kohler, J.F., 2009, Mineralogy and fluid chemistry of surficial sediments in the Newfoundland basin, Tooele and Box Elder Counties, Utah: Utah Geological Survey Open-File Report 539, 95 p., https://doi.org/10.34191/OFR-539.

Jordan, T.E., 1979a, Evolution of the Late Pennsylvanian-Early Permian western Oquirrh basin, Utah: Palo Alto, California, Stanford University, Ph.D. thesis, 253 p.

Jordan, T.E., 1979b, Lithofacies of the Upper Pennsylvanian and Lower Permian western Oquirrh Group, northwest Utah: Utah Geology, v. 6, no. 2, p. 41–56.

Kipnis, E.L., and Bowen, B.B., 2018, Observations of salt crust change from 1960–2016 and the role of humans as geologic agents at the Bonneville Salt Flats, Utah, *in* Emerman, S.H., Bowen, B., Schamel, S., and Simmons, S., editors, Geofluids of Utah: Utah Geological Association Publication 47, p. 287–303.

Lanphere, M.A., Champion, D.E., Christiansen, R.L., Izette, G.A., and Obradovich, J.D., 2002, Revised ages for tuffs of the Yellowstone Plateau volcanic field—assignment of the Huckleberry Ridge Tuff to a new geomagnetic polarity event: Geological Society of America Bulletin, v. 114, no. 5, p. 559–568.

Le Bas, M.J., Le Maitre, R.W., Streckheisen, A., and Zenettin, B., 1986, A chemical classification of volcanic rocks based on the total alkali-silica diagram: Journal of Petrology, v. 27, p. 745–750.

Louderback, L.A., and Rhode, D.E., 2009, 15,000 Years of vegetation change in the Bonneville basin—the Blue Lake pollen record: Quaternary Science Reviews, v. 28, p. 308–326.

Madsen, D.B., Oviatt, C.G., Young, D.C., and Page, D., 2015, Chapter 3—Old River Bed delta geomorphology and chronology, *in* Madsen, D.B., Schmitt, D.N., and Page, D., editors, The Paleoarchaic occupation of the Old River Bed delta: University of Utah Press, University of Utah Anthropological Papers No. 128, p. 30–60.

Martin, P.S., and Mehringer, P.J., Jr., 1965, Pleistocene pollen analysis and biogeography of the Southwest, *in* Wright, H.E., Jr. and Frey, D.G, editors, The Quaternary of the United States: Princeton, New Jersey, Princeton University Press, p. 433–451.

Maughan, E.K., 1979, Petroleum source rock evaluation of the Permian Park City Group in the northeastern Great Basin, Utah, Nevada, and Idaho, *in* Newman, G.W., and Goode, H.C., editors, Basin and Range symposium: Rocky Mountain Association of Geologists, and Utah Geological Association, p. 523–530.

Maurer, R.E., 1970, Geology of the Cedar Mountains, Tooele County, Utah: Salt Lake City, University of Utah, Ph.D. dissertation, 184 p., 10 plates, scale 1:43,700.

McCarthy, P.T., and Miller, D.M., 2002, Geologic map of the Terrace Mountain East quadrangle, Box Elder County, Utah: Utah Geological Survey Miscellaneous Publication 02-2, 14 p., 2 plates, scale 1:24,000, https://doi.org/10.34191/MP-02-2.

McCollum, L.B., and Miller, D.M., 1991, Cambrian stratigraphy of the Wendover area, Utah and Nevada: U.S. Geological Survey Bulletin 1948, 43 p.

Miller, D.M., Clark, D.L., Wells, M.L., Oviatt, C.G., Felger, T.J., and Todd, V.R., 2020, Interim geologic map of the Grouse Creek and Utah part of the Jackpot 30' x 60' quadrangles, Box Elder County, Utah, and Cassia County, Idaho: Utah Geological Survey Open-File Report 716DM, 31 p., 1 plate, scale 1:62,500, https://doi.org/10.34191/OFR-716dm.

Miller, D.M., Felger, T.J., and Langenheim, V.E., in press, Geologic and geophysical maps of the Newfoundland Mountains and part of the adjacent Wells 30' x 60' quadrangles, Box Elder County, Utah: Utah Geological Survey Miscellaneous Publication 173DM, scale 1:62,500.

Miller, D.M., Felger, T.J., and Langenheim, V.E., in progress, Geologic and geophysical maps of the Silver Island Mountains, Tooele County, Utah: U.S. Geological Survey Map, scale 1:24,000. [Graham Peak, Silver Island Pass, Teztlaff Peak, and Bonneville Racetrack 7.5' quadrangles]

Miller D.M., and Phelps, G.A., 2016, The Pilot Valley shoreline, an early record of Lake Bonneville dynamics, *in* Oviatt, C.G., Shroder Jr., J.F., editors, Lake Bonneville—a scientific update: Developments in Earth Science Processes, v. 20, Elsevier, p. 60–74.

Moore, W.J., and Sorensen, M.L., 1979, Geologic map of the Tooele 1° x 2° quadrangle, Utah: U.S. Geological Survey Miscellaneous Investigation Series Map I-1132, scale 1:250,000.

Munroe, J.S., Laabs, B.J.C., Oviatt, C.G., Jewell, P.W., 2015, Trip 1 — New investigations of Pleistocene pluvial and glacial records from the northeastern Great Basin, *in* Rosen, M.R., compiler, Sixth International Limnogeology Congress—Field Trip Guidebook, Reno, Nevada, June 15–19, 2015: U.S. Geological Survey Open-File Report 2015-1108, p. 1–60.

Nolan, T.B., 1927, Potash brines in the Great Salt Lake Desert, Utah: U.S. Geological Survey Bulletin 795, p. 25–44.

Oaks, R.Q., Jr., Smith, K.A., Janecke, S.U., Perkins, M.E., and Nash, W.P., 1999, Stratigraphy and tectonics of Tertiary strata of southern Cache Valley, north-central Utah, *in* Spangler, L.E., and Allen, C.J., editors, Geology of northern Utah and vicinity: Utah Geological Association Publication 27, p. 71–110.

Oviatt, C.G., 2014, The Gilbert episode in the Great Salt Lake basin, Utah: Utah Geological Survey Miscellaneous Publication 14-3, 20 p., https://doi.org/10.34191/MP-14-3.

Oviatt, C.G., 2015, Chronology of Lake Bonneville, 30,000 to 10,000 yr B.P.: Quaternary Science Reviews, v. 110, p. 166–171.

Oviatt, C.G., 2017, Ostracodes in Pleistocene Lake Bonneville, eastern Great Basin, North America: Hydrobiologia, v. 786, p. 125–135.

Oviatt, C.G., Clark, D.L., Bernau, J.A., and Bowen, B.B., 2020, Data on the surficial deposits of the Great Salt Lake Desert, Bonneville Salt Flats and east part of the Wendover 30' x 60' quadrangles, Tooele County, Utah: Utah Geological Survey Open-File Report 724, 70 p., https://doi.org/10.34191/OFR-724.

Oviatt, C.G., Madsen, D.B, and Schmitt, D.N., 2003, Late Pleistocene and early Holocene rivers and wetlands in the Bonneville basin of western North America: Quaternary Research, v. 60, p. 200–210.

Oviatt, C.G., Pigati, J.S., Madsen, D.B., Rhode, D.E., and Bright, J., 2018, Juke Box trench—a valuable archive of late Pleistocene and Holocene stratigraphy in the Bonneville basin, Utah (USA): Utah Geological Survey Miscellaneous Publication 18-1, 15 p., https://doi.org/10.34191/MP-18-1.

Pan-American Center for Earth and Environmental Studies (PACES), 2012, North American Gravity and Magnetic Database, University of Texas, El Paso; Online, http://irpsrvgis08.utep.edu/viewers/Flex/GravityMagnetic/GravityMagnetic_CyberShare, accessed September 17, 2012; site is inactive.

Poole, F.G., and Sandberg, C.A., 1991, Mississippian paleogeography and conodont stratigraphy of the western United States, *in* Cooper, J.D., and Stevens, C.H., editors, Paleozoic paleogeography of the western United States II: Los Angeles, Pacific Section, Society of Economic Paleontologists and Mineralogists, v. 1, p. 107–136.

Robison, R.A., and Palmer, A.R., 1968, Revision of Cambrian stratigraphy, Silver Island Mountains, Utah: American Association of Petroleum Geologists Bulletin, v. 52, no. 1, p. 167–171.

Sandberg, C.A., and Poole, F.G., 1977, Conodont biostratigraphy and depositional complexes of Upper Devonian cratonic-platform and continental-shelf rocks in the western United States, *in* Murphy, M.A., and others, editors, Proceedings of the 1977 annual meeting of the Paleontological Society on Devonian of western North America: University of California-Riverside, Campus Museum Contributions, Paleontological Society, 1977 annual meeting, Riverside, California, November, 1977, no. 4, p. 144–182.

Sarna-Wojcicki, A.M., Reheis, M.C., Pringle, M.S., Fleck, R.J., Burbank, D., Meyer, C.E., Slate, J.L., Wan, E., Budahn, J.R., Troxel, B., and Walker, J.P., 2005, Tephra layers of Blind Spring Valley and related upper Pliocene and Pleistocene tephra layers, California, Nevada, and Utah—isotopic ages, correlation, and magnetostratigraphy: U.S. Geological Survey Professional Paper 1701, 69 p.

Schaeffer, F.E., and Anderson, W.L., 1960, Geology of Silver Island Mountains, *in* Schaeffer, F.E., editor, Guidebook to the Geology of Utah, Number 15: Utah Geological Society, 192 p., 6 plates [Plates 1A and 1B, Geologic map of the central and southern Silver Island Mountains, Box Elder and Tooele Counties, Utah, and Elko County, Nevada (Silver Island and Leppy Range), scale 1:42,240].

Schneyer, J.D., 1990, Geologic map of the Leppy Peak quadrangle and adjacent area, Elko County, Nevada, and Tooele County, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1938, 1 sheet, scale 1:24,000.

Sheehan, P.M., 1979, Silurian continental margin in northern Nevada and northwestern Utah: University of Wyoming Contributions to Geology, v. 17, no. 1, p. 25–35.

Shuey, R.T., 1971, Paleomagnetic chronology and correlation of Great Salt Lake basin sediments: Washington D.C., National Science Foundation, Final Technical Report for grant GA-16134, 15 p.

Slade, M.L., 1961, Pennsylvanian and Permian fusulinids of the Ferguson Mountain area, Elko County, Nevada: Brigham Young University Geology Studies, v. 8, p. 55–94.

Smith, R.P., Breckenridge, R.P., and Wood, T.R., 2011, Preliminary Assessment of geothermal resource potential at the UTTR: Idaho National Laboratory, prepared for the U.S. Department of Energy, Assistant Secretary for Energy Efficiency and Renewable Energy, Under DOE Idaho Operations Office, Contract DE-AC07-05ID14517, 30 p.

Smith, R.P., Breckenridge, R.P., and Wood, T.R., 2012, Assessment of geothermal resource potential at a high-priority area on the Utah Testing and Training Range–South (UTTR–S): Idaho National Laboratory, prepared for the U.S. Department of Energy, Assistant Secretary for Energy Efficiency and Renewable Energy, Under DOE Idaho Operations Office, Contract DE-AC07-05ID14517, 156 p.

Solomon, B.J., 1990, Unpublished preliminary Quaternary geologic mapping of parts of the Ripple Valley, Aragonite, Aragonite NW, Knolls, and Knolls 2 SE 7.5' quadrangles, Tooele County, Utah [not included in Solomon, 1993]: Utah Geological Survey files, scale 1:24,000.

Solomon, B.J., 1993, Quaternary geologic maps of Tooele Valley and the west desert hazardous industry area, Tooele County, Utah: Utah Geological Survey Open-File Report 296, 20 plates, 48 p., scale 1:24,000, https://doi.org/10.34191/OFR-296.

Steele, G., 1959, Stratigraphic interpretation of the Pennsylvanian-Permian Systems of the eastern Great Basin: Seattle, University of Washington, Ph.D. dissertation, 264 p.

Steele, G., 1960, Pennsylvanian-Permian stratigraphy of east-central Nevada and adjacent Utah: Intermountain Association of Petroleum Geologists Guidebook 11th Annual Field Conference, p. 91–113.

Stifel, P.B., 1964, Geology of the Terrace and Hogup Mountains, Box Elder County, Utah: Salt Lake City, University of Utah, Ph.D. dissertation, 174 p., 14 plates, geologic map (plate 1) scale 1:63,360.

Stokes, W.L., 1963, Geologic map of the northwest quarter of Utah: Utah State Land Board, 1 plate, scale 1:250,000.

Thompson, M.L., 1954, American Wolfcampian fusulinids: University of Kansas Paleontological Contributions Protozoa, Article 5, p. 1–226, 52 plates, 14 figures.

Thompson, M.L., Verville, G.J., and Bissell, H.J., 1950, Pennsylvanian fusulinids of the south-central Wasatch Mountains, Utah: Journal of Paleontology, v. 24, no. 4, p. 430–465.

Tripp, T.G., 2009, Production of magnesium from Great Salt Lake, Utah USA: Natural Resources and Environmental Issues, v. 15 Saline lakes around the world—unique systems with unique values, article 10, 8 p.

U.S. Geological Survey, 2019, U.S Geologic Names Lexicon: Online, https://ngmdb.usgs.gov/Geolex/search, accessed May 21, 2019.

Utah Division of Oil, Gas and Mining (UDOGM), 2020, Well database: Online, https://oilgas.ogm.utah.gov/oilgasweb/live-data-search/lds-well/well-main.xhtml, accessed May 21, 2020.

Utah Geological Survey and Krueger Enterprises, Inc., Geochron Laboratory Division, 2018, K-Ar geochronology results for the Grayback Hills quadrangle, Utah: Utah Geological Survey Open-File Report 685, variously paginated, https://doi.org/10.34191/OFR-685.

Utah Geological Survey and Wells, A.J., 2017, Fossil fusulinid evaluation results for the Rush Valley, Wildcat Mountain, Grouse Creek, and Tremonton 30' x 60' quadrangles, Utah: Utah Geological Survey Open File Report 664, 64 p., https://doi.org/10.34191/OFR-664.

Wahlman, G.P., 2013, Pennsylvanian to lower Permian (Desmoinesian-Wolfcampian) fusulinid biostratigraphy of Midcontinent North America: Stratigraphy, v. 10, nos. 1–2, p. 73–104.

Wardlaw, B.R., 2015, Gondolellid condonts and depositional setting of the Phosphoria Formation: Micropaleontology, v. 61, nos. 4-5, p. 335–368.

West, N.E., and Johnson, D.A., 2005, Probable origin of laterally coalesced nabkas and adjacent bare lanes at Dugway Proving Ground, Utah, USA: Arid Land Research and Management, v. 19, p. 241–255.

White, W.W. and Terrazas, M., 2006, Analysis of recent and historical salt-crust thickness measurements and assessment of their relationship to the salt laydown project, Bonneville Salt Flats, Tooele County, Utah, *in* Harty, K.H., and Tabet, D.E., editors, Geology of northwest Utah: Utah Geological Association Publication 34, p. 272-302.

Williams, S.K., 1994, Late Cenozoic tephrochronology of deep sediment cores from the Bonneville basin, northwest Utah: Geological Society of America Bulletin, v. 105, p. 1517–1530.

Willis, G.C., 2017, History and evolution of geologic mapping in Utah with emphasis on the Wasatch area, *in* Lund, W.R., Emerman, S.H., Wang, W., and Zanazzi, A., editors, Geology and Resources of the Wasatch—back to front: Utah Geological Association Publication 46, p. 375–398.

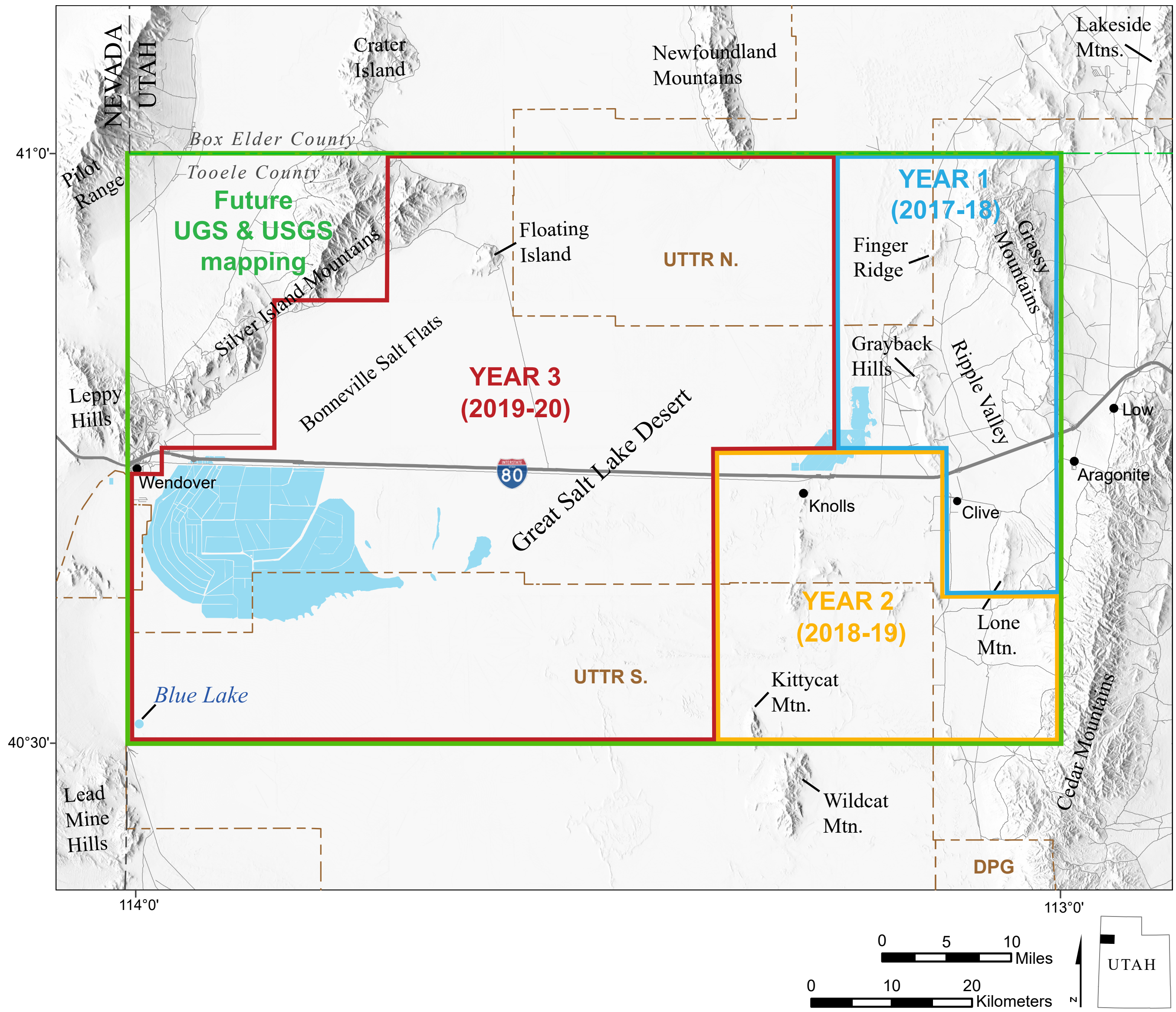


Figure 1. *Primary geographic features and progress of geologic mapping in the Bonneville Salt Flats and east part of Wendover 30' x 60' quadrangles (green rectangle). UTTR is Utah Test and Training Range (U.S. Air Force) and DPG is Dugway Proving Ground (U.S. Army).*

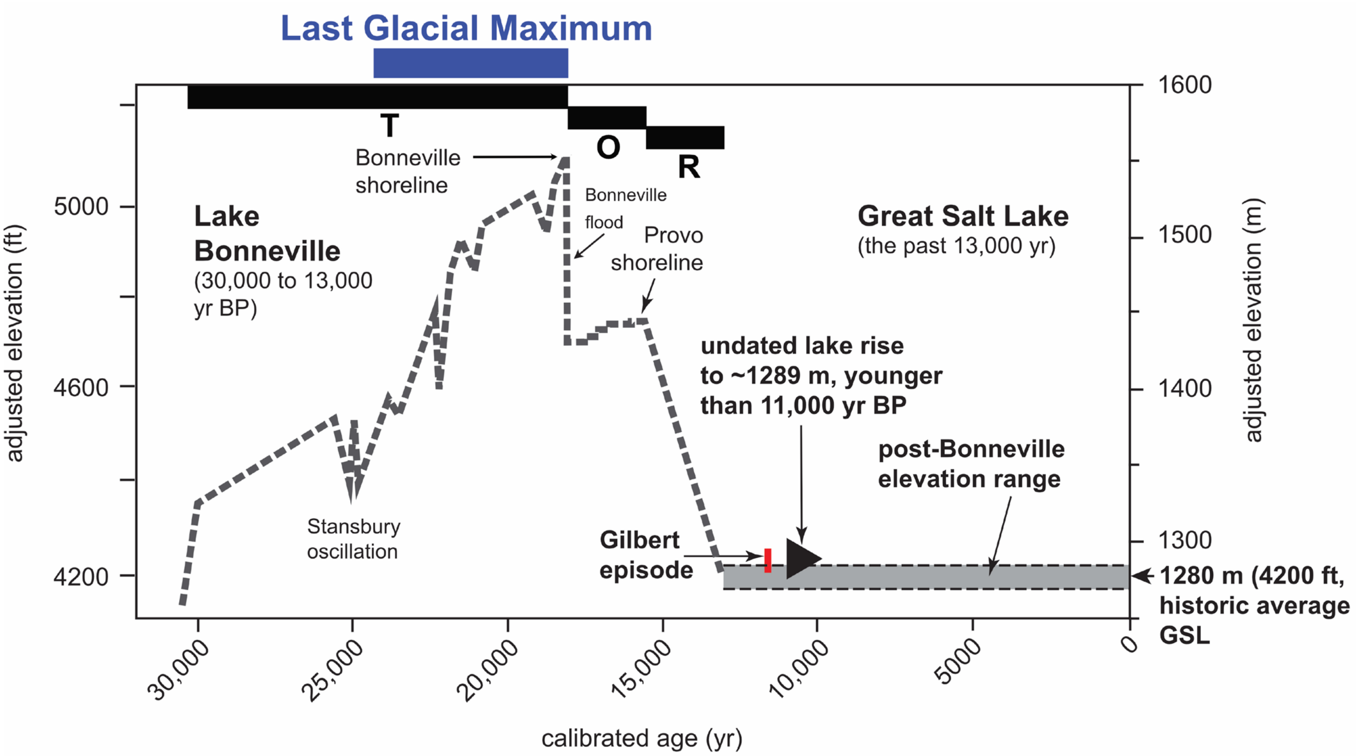


Figure 2. *Simplified Lake Bonneville hydrograph and chronology (based on Oviatt, 2015). Elevation adjusted for isostatic rebound. GSL is Great Salt Lake. Elevations are adjusted for differential isostatic rebound in the basin (Oviatt, 2015).*

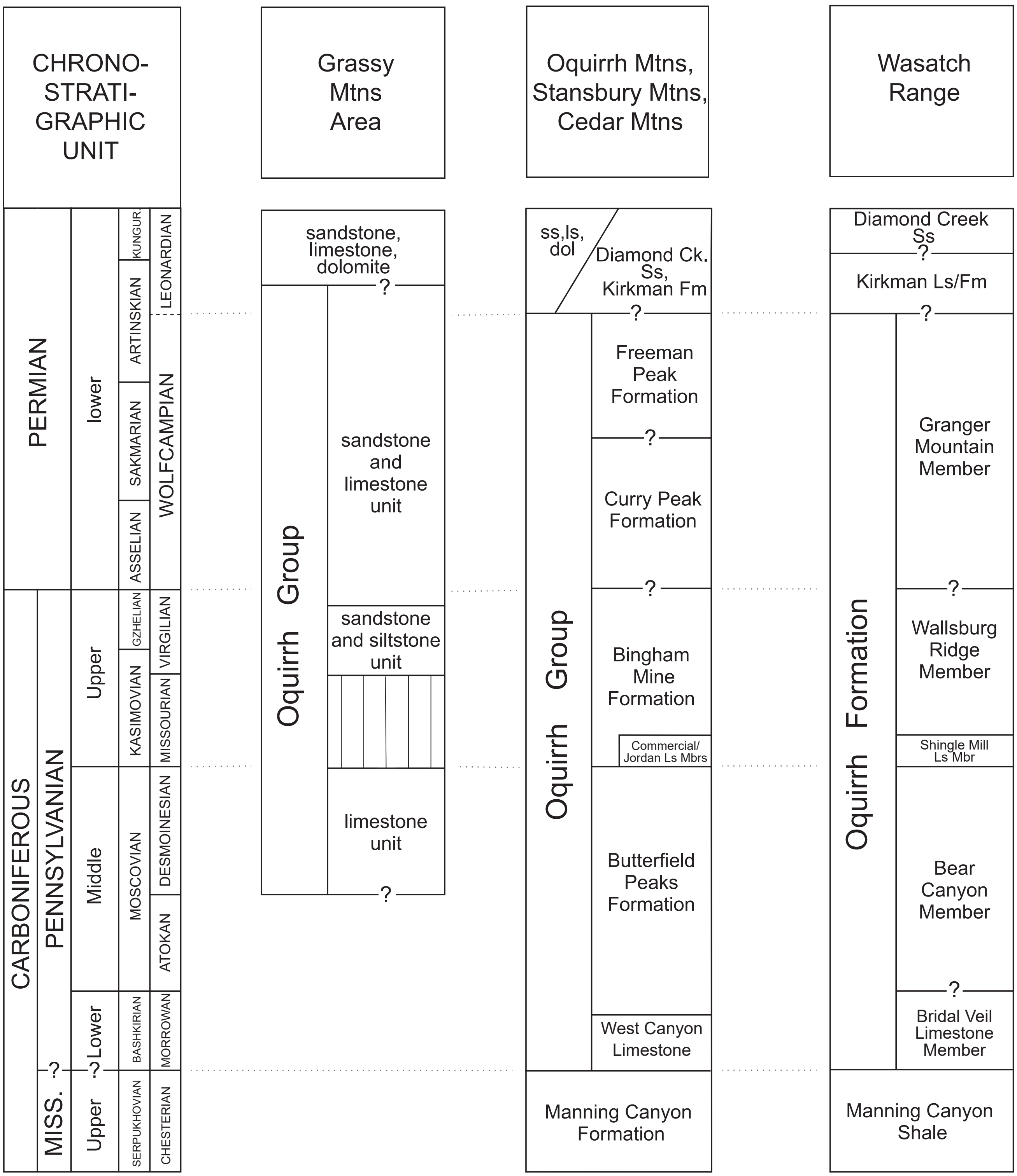


Figure 3. *Comparison of Permian-Pennsylvanian nomenclature of the Oquirrh Group/Formation and other units used in this map and adjacent areas. Grassy Mountains modified from Doelling (1964) and Jordan (1979a, 1979b). See Clark and others (2017) for Oquirrh, Stansbury, and Cedar Mountains. See Constenius and others (2011) for Wasatch Range.*

Table 1. *Summary of UGS shallow pits and cores and other selected sediment data sites from the Bonneville Salt Flats and east part of the Wendover 30' x 60' quadrangles, Utah.*

Map ID/Site ID	Type	Collection Year	7.5' Quadrangle	Latitude (°N) WGS84	Longitude (°W) WGS84	UTM easting NAD83-12	UTM northing NAD83-12	Ground Elevation (ft)	Total Depth (m)	Total Depth (ft)	Samples for Ostracode Evaluation	Summary of Deposits Encountered	Collector/Reference
C29-5	landfill pit wall N	2014	Aragonite	40.70608	113.11609	321240	4508283	4283	10	33		post-Bonneville, Lake Bonneville, pre-Bonneville	Oviatt, 2017
C5-5	landfill pit wall S	2014	Aragonite	40.67403	113.12063	320771	4504734	4272	3.5	12		post-Bonneville, Lake Bonneville, pre-Bonneville	Oviatt, 2017
CH1	pit	2017	Grayback Hills	40.76902	113.23968	310977	4515529	4226	0.55	1.8		post-Bonneville, Lake Bonneville	Oviatt and Clark; this study
CH2	wall of excavation	2017	Grayback Hills	40.82862	113.20423	314135	4522072	4240	1.5	4.9		post-Bonneville	Oviatt and Clark; this study
Kn1	pit	2017	Knolls	40.72439	113.35040	301499	4510819	4220	1.15	3.8	yes	post-Bonneville, Lake Bonneville, pre-Bonneville	Oviatt and Clark; this study
NUTTR1	pit	2018	Knolls 2 SE	40.86745	113.26466	309151	4526511	4223	0.32	1.1		post-Bonneville, Lake Bonneville	Oviatt and Clark; this study
NUTTR2	pit	2018	Knolls 2 NE	40.90242	113.28255	307745	4530432	4217	0.55	1.8		post-Bonneville	Oviatt and Clark; this study
FI1	pit	2018	Floating Island SE	40.79875	113.59486	281096	4519656	4216	1.15	3.8	yes	post-Bonneville, Lake Bonneville	Oviatt and Clark; this study
SI1	pit	2019	Floating Island	40.99435	113.72300	270944	4541701	4234	0.07	0.23	yes	Lake Bonneville	Clark; this study
BC1	core	2019	Aragonite NW	40.72753	113.23363	311371	4510910	4247	6	20	yes	post-Bonneville, pre- or post-Bonneville (?), pre-Bonneville	Oviatt and Clark; this study
BC2	core	2019	Tetzlaff Peak	40.76275	113.95078	250932	4516610	4218	6	20	yes	pre-Bonneville	Oviatt and Clark; this study
BC3	core	2019	Salduro	40.73342	113.75719	267172	4512821	4220	6	20	yes	pre-Bonneville	Oviatt and Clark; this study
BC4	core	2019	Knolls	40.72598	113.41927	295687	4511153	4220	0.55	1.8	yes	post-Bonneville?, Lake Bonneville, pre-Bonneville?	Oviatt and Clark; this study
BC5	core	2019	Arinosa NE	40.73829	113.57438	282627	4512893	4218	0.63	2.1	yes	post-Bonneville?, Lake Bonneville	Oviatt and Clark; this study
BC6	core	2019	Floating Island SE	40.86785	113.61382	279725	4527375	4216	0.61	2	yes	post-Bonneville?, Lake Bonneville, pre-Bonneville	Oviatt and Clark; this study
BC7	core	2019	Graham Peak	40.88566	113.78649	265235	4529802	4218	0.49	1.6	yes	pre-Bonneville	Oviatt and Clark; this study
BC8	core	2019	Arinosa	40.73190	113.67546	274069	4512439	4215	1.03	3.4	yes	post-Bonneville, pre-Bonneville	Oviatt and Clark; this study
BC9	core	2019	Barro	40.66622	113.40869	296399	4504494	4217	0.51	1.7	yes	post-Bonneville	Oviatt and Clark; this study
USOL (BSF Solstice core)	core	2017	Bonneville Racetrack	40.76316	113.89519	255626	4516499	~4212	3.20	10.5		post-Bonneville, pre-Bonneville	Bernau and others, unpublished
UWS2 (BSF Weather Station 2 core)	core	2019	Bonneville Racetrack	40.78451	113.82990	261214	4518689	~4212	3.48	11.4		post-Bonneville, pre-Bonneville	Bernau and others, unpublished
USC (BSF Short Course 1 core)	core	2019	Bonneville Racetrack	40.81252	113.77194	266204	4521643	~4212	3.90	12.8		post-Bonneville, pre-Bonneville	Bernau and others, unpublished
JBT (Juke Box trench, section 1)	trench	1986, 2009	Leppy Peak	40.75491	114.01021	245885	4515909	4254	3	9.8		post-Bonneville, Lake Bonneville, pre-Bonneville	Oviatt and others, 2018
LS (Lozenge section)	outcrop	NA	Graham Peak	40.89261	113.79781	264306	4530604	4245	4	13		Lake Bonneville, pre-Bonneville	Green, unpublished; Munroe and others, 2015
BLC (Blue Lake core, BL04-4)	core	2004	Ferguson Flat	40.49997	114.03614	242717	4487681	4257	8.58	28.1		post-Bonneville, Gilbert-episode, Lake Bonneville, pre-Bonneville	Benson and others, 2011
WC (Wendover core)	core	1960	Salduro	40.73712	113.87185	257501	4513544	4217	171	560			Williams, 1994
KC (Knolls core)	core	1960	Knolls	40.72685	113.30903	305000	4511000	4234	152	500			Williams, 1994

Notes:
Map ID corresponds to plate 1.
Sites in gray highlight are not in current map area.
See Oviatt and others, 2020 for details on sediment pit, core and other data.
Landfill pit walls (for sections C29-5 and C5-5) were at the Energy Solutions landfill at Clive, Utah; CH2 was a pit-wall exposure in an excavation at Clean Harbors Grassy Mountain landfill.
Shallow pits were dug using a shovel.
Cores BC1, BC2, BC3 were collected by Push Drilling, LLC.
Remaining sediment cores were collected by hand-driving a PVC pipe into the mud.
Ground elevation determined from 7.5' topographic maps.
The Wendover and Knolls cores were taken by A.J. Eardley (Univ. of Utah), core locations are approximate; detailed logs of the cores have never been published. These cores are archived at the Utah Core Research Center (Salt Lake City, Utah).
No reevaluation of the Wendover and Knolls cores was conducted for this study.
"Green, unpublished": Sue Green was a graduate student of D.R. Currey (University of Utah) in the 1980s; this "lozenge" section was part of her Master's thesis, which was not completed.
It is anticipated that the 2017-2019 cores will be archived at the Utah Core Research Center.

Table 2. *Summary of tephrochronology data from the Bonneville Salt Flats and east part of the Wendover 30' x 60' quadrangles.*

Map ID	Core Name	7.5' Quadrangle	Latitude (°N) NAD83	Longitude (°W) NAD83	Tephra Name	Depth (ft.in)	Depth (m)	Correlation Age (Ma)	Reference
KC	Knolls	Knolls	40.72685	113.30903	KNL-142.0	142.0	43.3	nd	Williams, 1994
KC	Knolls	Knolls	40.72685	113.30903	Lava Creek B	346.0, 350.6	105.5, 106.9	0.639 ± 0.002	Williams, 1994; Lanphere and others, 2002
KC	Knolls	Knolls	40.72685	113.30903	Glass Mtn D?	486.10	148.2	<0.88 ± 0.07	Williams, 1994; Sarna-Wojcicki and others, 2005
WC	Wendover	Salduro	40.73712	113.87185	Paoha Island	88.6	27.0	0.17*	Williams, 1994
WC	Wendover	Salduro	40.73712	113.87185	Lava Creek B	271.8, 272.8	82.8, 83.13	0.639 ± 0.002	Williams, 1994; Lanphere and others, 2002
WC	Wendover	Salduro	40.73712	113.87185	Bishop	323.0	98.5	0.759 ± 0.002	Williams, 1994; Sarna-Wojcicki and others, 2005
WC	Wendover	Salduro	40.73712	113.87185	Glass Mtn D?	372.7	113.6	<0.88 ± 0.07	Williams, 1994; Sarna-Wojcicki and others, 2005
WC	Wendover	Salduro	40.73712	113.87185	Bailey	497.4	151.6	1.15*	Williams, 1994

Notes:

Map ID corresponds to plate 1.

Knolls and Wendover core locations are approximate.

Correlation age is based on geochemical correlation of glass composition to the database of analyses/stratigraphic data/age dates for late Cenozoic vitric tephra layers in the Western U.S. assembled at the University of Utah, Dept. of Geology and Geophysics. Geochemical analysis was by electron microprobe and x-ray fluroescence. Refer to Williams (1994) for methods and sources of radiometric ages on various ash beds. Updated ages are used for the Lava Creek B and Glass Mtn D tephras.

* Estimated ages in Wendover core (Williams, 1994, figure 6).

nd is no data.

Table 3. *Data and formation tops for hydrocarbon exploration wells in the Bonneville Salt Flats and east part of Wendover 30' x 60' quadrangles.*

Map ID	API Number	Operator	Well Name	Year	Status	Type	7.5' Quadrangle	Latitude NAD83 (°N)	Longitude NAD83 (°W)	Cadastral Location	Ground Elevation (ft)	Unit/Formation	Top (ft)	Thickness (ft)	Elevation (ft)	Notes
DH1	4304511076	Shell	Salduro 1	1956	Plugged & abandoned	Dry hole	Silsbee	40.68416	113.89716	C, SE1/4, NW1/4, s. 4, T. 2 S., R. 18 W.	4216	alluvium	0	1375	4216	cuttings and core at UCRC
												Tertiary	1375	225	3991	
												volcanic breccia	1600	192	3799	
												volcanic tuff	1792	48	3751	
												volcanic sandstone	1840	20	3731	
												breccia	1860	780	2951	
												andesite	2640	100	2851	
												basalt	2740	210	2641	
												TD	2950		1266	
DH2	4304530001	Alpha Minerals	Alpha Govt 1	1975	Plugged & abandoned	Dry hole	Salduro	40.70155	113.76509	NE1/4, NW1/4, s. 34, T. 1 S., R. 17 W.	4225	not reported	0	500	4225	no cuttings or core
												Tertiary volcanics	500	628	3597	
												Tertiary shale	1128	1852	1745	
												Paleozoic limestone and dolomite	2980	1280	465	
												TD	4260		-35	

Notes:
Data from Utah Division of Oil, Gas and Mining online database and well files.
TD is total depth.
UCRC is Utah Core Research Center.
UCRC has samples from Phillips Petroleum Co. Grassy Mountain Sec. (October 1949) from T. 2 N., R. 11 W. probably from a surface section, rather than a drill hole. There are no known Phillips drill holes from this area.

Table 4. *Major- and trace-element whole-rock geochemical analyses from the Bonneville Salt Flats and east part of the Wendover 30' x 60' quadrangles.*

								ME-XRF06	ME-XRF06	ME-XRF06	ME-XRF06	ME-XRF06	ME-XRF06	ME-XRF06	ME-XRF06	ME-XRF06	ME-XRF06	ME-XRF06	ME-XRF06	ME-XRF06	OA-GRA06	ME-XRF06	ME-4ACD81	ME-4ACD81	ME-4ACD81	ME-4ACD81	ME-4ACD81	ME-4ACD81
								%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm
Map ID	**Sample ID**	**Map Unit**	**Rock Name**	**7.5' Quad**	**Location Data Latitude (°N) WGS84**	**Location Data Longitude (°W) WGS84**	**Source**	SiO2	Al2O3	Fe2O3	CaO	MgO	Na2O	K2O	Cr2O3	TiO2	MnO	P2O5	SrO	BaO	LOI	Total	Ag	As	Cd	Co	Cu	Li
BW1	BW1	Tl	Latite	Aragonite NW	40.74466	113.14455	This study	58.94	17.27	6.96	5.33	2.21	3.22	3.9	<0.01	0.72	0.12	0.312	0.06	0.13	1.02	100.2	<0.5	5	<0.5	18	14	20
BW2	BW2	Til	Latite	Grayback Hills	40.80745	113.16499	This study	58.38	17.05	6.57	5.02	2.52	3.13	4.03	<0.01	0.71	0.08	0.307	0.05	0.12	1.81	99.78	<0.5	<5	0.5	17	14	30
BW5	BW5	Tl	Latite	Grayback Hills	40.80001	113.16483	This study	57.25	16.96	6.93	5.83	2.58	3.11	3.61	0.01	0.71	0.11	0.313	0.06	0.13	1.76	99.36	<0.5	<5	0.8	16	17	30
BW7	BW7	Tid	Dacite	Grassy Mountains	40.90357	113.09988	This study	63.12	16.32	5.26	4.57	1.83	3.44	3.18	0.01	0.73	0.08	0.184	0.04	0.12	1.28	100.15	<0.5	<5	<0.5	11	15	10
BW8	BW8	Tid	Andesite	Grassy Mountains	40.94005	113.11605	This study	61.27	16.88	4.99	5.08	1.62	3.45	3.23	0.01	0.99	0.09	0.298	0.05	0.15	1.61	99.72	<0.5	<5	<0.5	14	36	10
					Location Data UTM83-12 E	**Location Data UTM83-12 N**																						
1	1	Til	Trachyandesite	Grayback Hills	317373	4519662	Doelling and others, 1994, 2018	58.83	16.25	6.53	5.04	2.37	3.09	3.71		0.07	0.08	0.29			2.02	98.91						
2	2	Tl	Andesite	Grayback Hills	318247	4515096	Doelling and others, 1994, 2018	60.97	16.03	5.70	4.78	1.45	3.43	3.21		0.98	0.08	0.28			2.04	98.95						
3	3	Tl	Trachyandesite	Grayback Hills	319277	4520243	Doelling and others, 1994, 2018	58.50	16.57	6.53	5.25	2.40	3.08	3.60		0.71	0.10	0.25			2.06	99.05						
4	4	Tl	Trachyandesite	Grayback Hills	318393	4517621	Doelling and others, 1994, 2018	58.30	16.62	6.97	5.60	2.52	3.26	3.69		0.75	0.11	0.36			1.98	100.16						
5	5	Tl	Trachyandesite	Grayback Hills	317820	4519418	Doelling and others, 1994, 2018	58.32	16.50	6.52	5.63	2.44	3.09	3.60		0.69	0.10	0.27			2.04	99.02						
--	6	Tl	Banakite	nd	nd	nd	Hogg, 1972, table B-4, p. 180	57.93	16.65	7.22	5.93	2.44	3.13	4.46		0.87	0.09	0.35			nd	99.07						
7	7	Tsd	Dacite	Grayback Hills	317387	4519725	Doelling and others, 1994, 2018	63.96	15.12	4.75	4.15	1.90	3.02	nd		0.60	0.06	0.20			1.95	98.80						
8	8	Tsd	Dacite	Grayback Hills	318274	4520355	Doelling and others, 1994, 2018	63.30	17.82	3.28	0.88	5.02	3.79	nd		0.36	0.04	0.16			1.75	98.78						

Table 4. *Continued.*

								ME-4ACD81	ME-4ACD81	ME-4ACD81	ME-4ACD81	ME-4ACD81	ME-4ACD81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81
								ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Map ID	**Sample ID**	**Map Unit**	**Rock Name**	**7.5' Quad**	**Location Data Latitude (°N) WGS84**	**Location Data Longitude (°W) WGS84**	**Source**	Mo	Ni	Pb	Sc	Tl	Zn	Ba	Ce	Cr	Cs	Dy	Er	Eu	Ga	Gd	Hf	Ho	La	Lu	Nb	Nd	Pr	Rb
BW1	BW1	Tl	Latite	Aragonite NW	40.74466	113.14455	This study	2	5	21	11	<10	89	1140	77.5	20	2.56	4.25	2.15	1.42	21	5.42	5.1	0.89	43.7	0.33	13.5	32.2	8.85	138
BW2	BW2	Til	Latite	Grayback Hills	40.80745	113.16499	This study	2	5	24	11	<10	92	1095	74.9	20	3.31	4.18	2.19	1.35	20.9	5.14	4.8	0.81	42.2	0.33	13.3	31.5	8.52	156.5
BW5	BW5	Tl	Latite	Grayback Hills	40.80001	113.16483	This study	2	5	20	11	<10	89	1170	77.8	20	3.12	3.95	2.14	1.39	23.9	5.22	5.1	0.86	43	0.33	13.7	32.3	8.71	138.5
BW7	BW7	Tid	Dacite	Grassy Mountains	40.90357	113.09988	This study	3	4	26	11	<10	77	1075	108	20	2.44	6.94	4.02	1.62	22.5	7.78	8.7	1.5	60.7	0.58	22.3	44.2	12.2	117
BW8	BW8	Tid	Andesite	Grassy Mountains	40.94005	113.11605	This study	3	7	28	12	<10	88	1310	135	20	3.18	7.68	4.38	1.96	23.4	8.28	10.1	1.59	75.6	0.62	23.5	54.8	15.05	104

Table 4. *Continued.*

								ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81	ME-MS81
								ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Map ID	**Sample ID**	**Map Unit**	**Rock Name**	**7.5' Quad**	**Location Data Latitude (°N) WGS84**	**Location Data Longitude (°W) WGS84**	**Source**	Sm	Sn	Sr	Ta	Tb	Th	Tm	U	V	W	Y	Yb	Zr
BW1	BW1	Tl	Latite	Aragonite NW	40.74466	113.14455	This study	6.09	2	444	0.8	0.73	14.2	0.37	3.5	123	2	21.6	1.92	196
BW2	BW2	Til	Latite	Grayback Hills	40.80745	113.16499	This study	5.97	2	422	0.7	0.66	13.8	0.32	3.62	119	1	21	2.24	190
BW5	BW5	Tl	Latite	Grayback Hills	40.80001	113.16483	This study	6.43	2	470	0.7	0.74	14.5	0.36	3.52	120	1	22.1	2.14	197
BW7	BW7	Tid	Dacite	Grassy Mountains	40.90357	113.09988	This study	8.31	3	262	1.4	1.14	21.5	0.64	5.14	102	1	38.4	3.87	332
BW8	BW8	Tid	Andesite	Grassy Mountains	40.94005	113.11605	This study	10.3	3	389	1.3	1.29	22.8	0.63	4.93	126	2	40.2	4.23	389

Notes:
Map ID and map unit correspond to plate 1.
Rock names for this study from total alkali-silica diagram of Le Bas and others (1986). Other rock names are from sources cited.
Analyses for this study performed by ALS Global. Analytical Procedures: ME-XRF06 (whole-rock package by XRF; major oxides), OA-GRA06 (LOI for ME-XRF06 by WST-SIM), ME-4ACD81 (base metals 4-acid digestion by ICP-AES, elemental), and ME-MS81 (lithium borate fusion by ICP-MS, trace elemental).
Major oxides reported in weight percent (%); < indicates value below detection limit.
LOI is loss on ignition.
Minor and trace elements reported in parts per million (ppm); < indicates value below detection limit.
nd is no data.
Analytical lab for samples from Doelling and others (1994) not given.
Hogg (1972) sample collected from southern Grayback Hills.
Analytical lab for Hogg (1972) sample not given, probably Brigham Young University.
Total Fe reported as FeO (Hogg, 1972).

Table 5. *Summary of radiometric age analyses of Tertiary rocks from the Bonneville Salt Flats and east part of the Wendover 30' x 60' quadrangles and adjacent areas.*

Map ID	Sample ID	Map Unit	Rock Name	7.5' Quadrangle	Location	Location Data UTM83-12 E	Location Data UTM83-12 N	Age (Ma)	Material Dated	Laboratory	Analysis Type (Year)	Comments	References
A	A	Tsd	dacite tuff	Grayback Hills	Grayback Hills	317387	4519725	35.52 ± 0.38	plagioclase	USGS	$^{40}Ar/^{39}Ar$ (1992?)	total fusion ages, weighted age	Doelling and others, 1994, 2018
B	B	Tsd	dacite tuff	Grayback Hills	Grayback Hills	317387	4519725	38.6 ± 1.0	sanidine	KE	K-Ar (1992)		Doelling and others, 1994, 2018; UGS and Krueger Enterprises, 2018
C	C	Tl	latite lava flow	Grayback Hills	Grayback Hills	318247	4515096	39.1 ± 1.0	groundmass	KE	K-Ar (1992)		Doelling and others, 1994, 2018; UGS and Krueger Enterprises, 2018
--	nd	Tl	latite lava flow	nd	Grayback Hills	nd	nd	38.5 ± 0.6	whole rock	BYU	K-Ar (1977)		Davies, 1980; Doelling and others, 1994

Notes:
Map ID and map unit correspond to plate 1.
Laboratory: USGS is U.S. Geological Survey Lab; KE is Krueger Enterprises, Cambridge, MA; BYU is Brigham Young University Lab.
nd is no data.

Table 6. *Selected fossil identifications and ages from the Bonneville Salt Flats and east part of the Wendover 30' x 60' quadrangles.*

Map ID	Sample ID	Map Unit	7.5' Quadrangle	Location Data	Location Data	Fossil Type	Fauna	Age	Paleontologist
Data from map area (this study)				**Latitude (°N) WGS84**	**Longitude (°W) WGS84**				
BW30	BW30	Ppy	Aragonite SW	40.62267	113.13719	conodont	*Neostreptognathodus sulcoplicatus*	middle to late Leonardian	S.M. Ritter
BW21	BW21	Polf	Finger Ridge	40.91021	113.16137	fusulinid	*Schwagerina* cf. *lineanoda*, *Schwagerina tersa*	late Wolfcampian (Lenoxian)	G.P.Wahlman
BW23	BW23	Polk	Knolls	40.70362	113.28771	fusulinid	Schwagerina wellsensis, Schwagerina franklinensis	late Wolfcampian (Lenoxian)	G.P.Wahlman
BW27	BW27	Polk	Knolls	40.67122	113.28897	fusulinid	*Psuedofusulina* aff. *P. loringi*, *Paraschwagerina?* sp., *Schwagerina* spp., *Schubertella* sp.	Wolfcampian, probably Early Wolfcampian (Nealian)	G.P.Wahlman
BW24	BW24	Polk	Knolls	40.67147	113.28205	fusulinid	*Eoparafusulina* cf. *E. linearis*, *Schwagerina wellsensis*, *Pseudoschwagerina* aff. *P. convexa*, *Schwagerina* cf. *S. modica*, *Schwagerina* cf. *S. eolata*, *Schubertella* spp.	Wolfcampian, most likely middle to early late Wolfcampian (early Lenoxian)	G.P.Wahlman
BW14	BW14	PIPos	Aragonite	40.67721	113.05872	conodont	*Mesogondolella bisselli*, *Sweetognathus whitei*	late Wolfcampian	S.M. Ritter
BW14	BW14	PIPos	Aragonite	40.67721	113.05872	fusulinid	*Pseudoschwagerina* sp.	late Wolfcampian	S.M. Ritter
BW12	BW12	IPosc	Aragonite	40.63655	113.02796	conodont	*Streptognathodus pawkuskaensis*, *Streptognathodus virgilicus*	early Virgilian	S.M. Ritter
BW13	BW13	IPol	Ripple Valley	40.77859	113.05003	conodont	*Neognathodus* sp.	Desmoinesian or perhaps late Atokan	S.M. Ritter
BW9	BW9	IPol	Aragonite	40.66021	113.03593	conodont	*Neognathodus* sp., *Idiognathodus* sp., *Adetognathus lautus*	Desmoinesian	S.M. Ritter
BW34	BW34	IPe	Floating Island	40.92284	113.64429	conodont	*Neognathodus*, *Idiognathodus*	early to middle Desmoniesian	S.M. Ritter
Data from Thumb Ridge (Bylund, unpublished data)				**Latitude (N) WGS84**	**Longitude (W) WGS84**				
FB1	nd	TRt	Grayback Hills	40° 50.885'	113° 11.322'	ammonoid	*Anasibirites* sp.	late Smithian	K. Bylund
FB2	nd	TRt	Grayback Hills	40° 50.827'	113° 11.266'	ammonoid	*Owenites?* sp.	middle Smithian	K. Bylund
Selected Data from Grayback Hills (Davies, 1980)				**Cadastral**	**Bed Unit in Measured Section**				
FD1	nd	TRt	Aragonite NW	W1/2 SE1/4 s. 12, T1S, R12W	unit 25	ammonoid	*Prohungarites* sp.	late Spathian	B. Kummel
FD1	nd	TRt	Aragonite NW	W1/2 SE1/4 s. 12, T1S, R12W	units 15, 11, 9, 5, 1	ammonoid	*Prohungarites* sp., *Prohungarites?* sp., *Keyserlingites bearlakensis*, *Keyserlingites bearlakensis?*	late Spathian	B. Kummel
FD1	nd	TRt	Aragonite NW	W1/2 SE1/4 s. 12, T1S, R12W	units 9, 5, 1	ammonoid	*Keyserlingites bearriverensis*?	late Spathian	B. Kummel
FD4	nd	TRt	Grayback Hills	N1/2 SW1/4 SW1/4 s. 13, T1N, R12W	unit 11	conodont	*Platyvillosus asperatus*	early Spathian	David L. Clark
FD4	nd	TRt	Grayback Hills	N1/2 SW1/4 SW1/4 s. 13, T1N, R12W	unit 11	conodont	*Neospathodus? triangularis*	early Spathian	David L. Clark
Data from Grassy Mountains (Jordan, 1979a)				**Cadastral**					
FJ10	f14051	PIPos	Grassy Mountains	NW1/4 NE1/4 s. 33, T3N, R11W		fusulinid	*Schwagerina* sp.	early Leonardian	R.C. Douglass
FJ9	f14050	PIPos	Grassy Mountains	SW1/4 NE1/4 s. 10, T2N, R11W		fusulinid	*Schwagerina* sp.	Wolfcampian	R.C. Douglass
FJ8	f14049	PIPos	Grassy Mountains	NW1/4 SW1/4 s. 11, T2N, R11W		fusulinid	*Pseudofusulina* sp., *Schwagerina* sp., *Pseudoschwagerina* sp.	Wolfcampian	R.C. Douglass
FJ7	GM15	PIPos	Grassy Mountains	NW1/4 SW1/4 s. 11, T2N, R11W		fusulinid	*Schwagerina* sp., *Pseudoschwagerina* aff. *convexa*, *Eoparafusulina* sp.	early late Wolfcampian	C.H. Stevens
FJ6	f14048	PIPos	Grassy Mountains	NE1/4 SW1/4 s. 11, T2N, R11W		fusulinid	*Triticites* sp., *Pseudofusulina* sp., *Schwagerina* sp., *Pseudoschwagerina* sp.	Wolfcampian	R.C. Douglass
FJ5	f14047	PIPos	Grassy Mountains	SE1/4 SE1/4 s. 2, T2N, R11W		fusulinid	*Schwagerina* sp.	Wolfcampian	R.C. Douglass
FJ4	f14046	PIPos	Grassy Mountains	NW1/4 NW1/4 s. 12, T2N, R11W		fusulinid	*Triticites* sp., *Pseudofusulina* sp.	Wolfcampian	R.C. Douglass
FJ3	f14045	PIPos	Grassy Mountains	near center SW1/4 s. 12, T2N, R11W		fusulinid	*Pseudofusulinella* sp., *Triticites* sp., *Pseudofusulina* sp.	Wolfcampian	R.C. Douglass
FJ2	f14044	IPosi	Grassy Mountains	SE1/4 SE1/4 s. 1, T2N, R11W		fusulinid	*Pseudofusulinella* sp., *Triticites* sp.	Virgilian	R.C. Douglass
FJ1	f14043	IPosi	Grassy Mountains	SW1/4 SE1/4 s. 12, T2N, R11W		fusulinid	*Bartramella?*, *Pseudofusulinella* sp., *Triticites* sp.	Virgilian	R.C. Douglass

Table 6. *Continued.*

Map ID	Sample ID	Map Unit	7.5' Quadrangle	Location Data	Location Data	Fossil Type	Fauna	Age	Paleontologist
Data from Grassy Mountains (Doelling, 1964)				**Cadastral**	**Bed Unit in Measured Section**				
	nd	Polf	Finger Ridge	nd (Finger Ridge)	Oquirrh Fm	fusulinid	*Schwagerina* sp.	late early Wolfcampian	B. Lambson
	nd	Pℙos	Grassy Mountains	S1/2 s. 3, T2N, R11W	Oquirrh Fm Unit 6, 21	fusulinid	*Schwagerina* cf. *communis*, *Schwagerina* cf. *japonica* subsp. *cincta*	early Leonardian	B. Lambson
	nd	Pℙos	Grassy Mountains	S1/2 s. 3, T2N, R11W	Oquirrh Fm Unit 6, 5	fusulinid	*Schwagerina* sp. (partially replaced)	early Leonardian	B. Lambson
	nd	Pℙos	Grassy Mountains	S1/2 s. 3, T2N, R11W	Oquirrh Fm Unit 6, 3	fusulinid	*Schwagerina* cf. *modica*	early Leonardian	B. Lambson
	nd	Pℙos	Grassy Mountains	nd	Oquirrh Fm Unit 5	fusulinid	*Pseudofusulinella* sp., *Triticites* sp., *?Pseudofusulina* sp., *Bradyina* sp., *Schwagerina* sp., *Pseudoschwagerina* sp.	Early Permian (perhaps early Leonardian to late Wolfcampian)	R.C. Douglass
	nd	Pℙos	Grassy Mountains	nd	Oquirrh Fm Unit 5 (upper part)	fusulinid	*Parafusulina shaksgamensis* var. *crassimarginata*	early Leonardian	B. Lambson
	nd	Pℙos	Grassy Mountains	nd	Oquirrh Fm Unit 4	fusulinid	*Bradyina* sp., *Pseudofusulinella* sp., *Triticites* sp., *Schubertella* aff. *S. kingi*, *Pseudofusulina* sp. (rare)	Early Permian	R.C Douglass
	nd	Pℙos	Grassy Mountains	s. 2, T2N, R11W	Oquirrh Fm Unit 4, 12	fusulinid	*Schwagerina* sp. (partially replaced)	middle to late Wolfcampian	B. Lambson
	nd	Pℙos	Grassy Mountains	s. 2, T2N, R11W	Oquirrh Fm Unit 4, 1	fusulinid	*Schwagerina* aff. *providens*, *Schwagerina* aff. *wellsensis*, *Triticites* sp.	middle to late Wolfcampian	B. Lambson
	nd	Pℙos	Grassy Mountains	nd	Oquirrh Fm Unit 3	fusulinid	*Pseudofusulinella?*, *Pseudofusulina*, *Triticites* sp. (advanced form), *Pseudofusulina* sp.	Early Permian?	R.C. Douglass
	nd	Pℙos	Grassy Mountains	NW1/4 s. 1, T2N, R11W	Oquirrh Fm Unit 3, 9	fusulinid	*Triticites cellamagnus*, *Schwagerina aculeata*	middle to late Wolfcampian	B. Lambson
	nd	Pℙos	Grassy Mountains	NW1/4 s. 1, T2N, R11W	Oquirrh Fm Unit 3, 8	fusulinid	*Triticites* aff. *providens*	middle to late Wolfcampian	B. Lambson
	nd	Pℙos	Grassy Mountains	NW1/4 s. 1, T2N, R11W	Oquirrh Fm Unit 3, 3	fusulinid	*Triticites* cf. *rockensis*, *Schwagerina* sp.?	early Wolfcampian*	B. Lambson
	nd	Pℙos	Grassy Mountains	NW1/4 s. 1, T2N, R11W	Oquirrh Fm Unit 3, 1	fusulinid	*Triticites* cf. *rockensis*, *Pseudofusulinella* sp.	early Wolfcampian*	B. Lambson
	nd	Pℙos	Grassy Mountains	s. 12, T2N, R11W	Oquirrh Fm Unit 2, 27	fusulinid	*Triticites creekensis*, *Pseudofusulinella* sp.	Wolfcampian*	B. Lambson
	nd	Pℙos	Grassy Mountains	s. 12, T2N, R11W	Oquirrh Fm Unit 2, 25	fusulinid	*Triticites meeki*, *Pseudofusulinella utahensis*	Wolfcampian*	B. Lambson
	nd	Pℙos	Grassy Mountains	s. 12, T2N, R11W	Oquirrh Fm Unit 2, 23	fusulinid	*Triticites rockensis*, *Triticites creekensis*, *Pseudofusulinella* sp.	Wolfcampian*	B. Lambson
	nd	Pℙos	Grassy Mountains	s. 12, T2N, R11W	Oquirrh Fm Unit 2, 22	fusulinid	*Triticites* cf. *creekensis*, *Pseudofusulinella utahensis*, *Bartramella heglarensis*	Wolfcampian*	B. Lambson
	nd	Pℙos	Grassy Mountains	s. 12, T2N, R11W	Oquirrh Fm Unit 2, 18	fusulinid	*Triticites notus*, *Psedofusulinella* cf. *utahensis*	Wolfcampian*	B. Lambson
	nd	ℙosi	Grassy Mountains	s. 12, T2N, R11W	Oquirrh Fm Unit 2, 17	fusulinid	*Triticites hobblensis*	Virgilian	B. Lambson
	nd	ℙosi	Grassy Mountains	s. 12, T2N, R11W	Oquirrh Fm Unit 2, 16	fusulinid	*Triticites* cf. *rhodesi*	Virgilian	B. Lambson
	nd	ℙosi	Grassy Mountains	s. 12, T2N, R11W	Oquirrh Fm Unit 2, 14	fusulinid	*Triticites* sp.	Virgilian	B. Lambson
	nd	ℙosi	Grassy Mountains	s. 12, T2N, R11W	Oquirrh Fm Unit 2, 3	fusulinid	*Triticites gallowayi*, *Pseudofusulinella* sp.	Virgilian	B. Lambson
	nd	ℙosi	Grassy Mountains	nd	Oquirrh Fm Unit 2 (lower part)	fusulinid	*Triticites* app. (2 species)	Virgilian	R.C. Douglass
	nd	ℙosi	Grassy Mountains	nd	Oquirrh Fm Unit 2 (lower part)	fusulinid	*Schubertella* sp. aff. *S. kingi*	Virgilian	R.C. Douglass
	nd	ℙol	Grassy Mountains	NE1/4 s. 12, T2N, R11W	Oquirrh Fm Unit 1, 29	fusulinid	*Fusulina* cf. *haworthi*	Desmoinesian	B. Lambson
	nd	ℙol	Grassy Mountains	NE1/4 s. 12, T2N, R11W	Oquirrh Fm Unit 1, 21	fusulinid	*Fusulina* sp. (partial replacement)	Desmoinesian	B. Lambson

Notes:
Map ID and map unit correspond to plate 1.
Sample locations for Doelling (1964), Davies (1980), and Jordan (1979a) are approximate.
nd is no data.
Samples from Doelling (1964) are not included on the map.
Davies (1980) small measured sections are indicated by fossil symbols.
FD2, FD3, FD3AB are other section locations of Davies (1980) that contain fossils.
Ages from paleontologists listed.
* Age reevaluated by G.P. Wahlman to be latest Virgilian "Bursumian/Newwellian."
Triticites hobblensis is lower Virgilian (Thompson and others, 1950).
Triticites rockensis may be the juvenile, since was described as starved fauna by Thompson (1954).
Paleontologist Affiliation: S.M. Ritter (Brigham Young Univ.), K. Bylund (independent researcher), B. Kummel (Harvard Univ.), David L. Clark (Univ. of Wisconsin, Madison), B. Lambson (Shell Oil Co.), R.C. Douglass (USGS), C.H. Stevens (San Jose State Univ.), G.P. Wahlman (independent).