Geologic Map of Dugway Proving Ground and Adjacent Areas, Tooele County, Utah

By

Donald L. Clark, Charles G. Oviatt, and David Fogg

2009

Utah Geological Survey, 1201 W. Center Street, Salt Lake City, Utah 84117-0900

Utah Department of Natural Resources, 1 North Broadway, Salt Lake City, Utah 84103

Utah Geological Survey

Utah Department of Natural Resources
GEOLOGIC MAP OF DUGWAY PROVING GROUND AND ADJACENT AREAS, TOOELE COUNTY, UTAH

by Donald L. Clark¹, Charles G. Oviatt², and David Page³

¹Utah Geological Survey, P.O. Box 146100, Salt Lake City, UT 84114-6100
²Emeritus, Department of Geology, Kansas State University, Manhattan, KS 66506-3201
³Desert Research Institute, 2215 Raggio Parkway, Reno, NV 89512

SCALE: 1:75,000

Cover photo: Southern margin of Cedar Mountains with view south of dune field and Camels Back Ridge in immediate background.

ISBN: 978-1-55791-912-0

MAP 274DM
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
2016
Although this product represent 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, and does not guarantee accuracy or completeness of the data. 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 1:75,000 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 06HQAG0037, 07HQAG0141, and G09AC00152. 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.
INTRODUCTION
In addition to this text booklet, the work product includes a geologic map (plate 1), explanation sheet (plate 2), photo gallery, and GIS geodatabase that includes geologic map data and PACES gravity dataset.

This geologic map encompasses the entirety of Dugway Proving Ground (DPG) and some adjacent areas on the northeast, north, and southeast (figure 1). The map covers the eastern two-thirds of the Wildcat Mountain 30' x 60' quadrangle, and smaller parts of the Rush Valley and Fish Springs 30' x 60' quadrangles, in Tooele County, northwest Utah (index map, plate 2). The map area lies in the eastern Basin and Range Province and encompasses the lower lying areas (basins) of the southern Great Salt Lake Desert, Government Creek Basin, and parts of other valleys, whereas ranges include the southern Cedar Mountains, Wildcat Mountain, Granite Peak (Mountain), northern Dugway Range, and a few other smaller mountains and ridges (figure 1; photo gallery).

In addition to the DPG area, we extended the map area to cover (1) part of the Utah Test and Training Range (aka Wendover Air Force Range) between the DPG boundary and 40° 30' N. latitude, (2) the entire southern Cedar Mountains north to 40° 30' N. latitude, including part of the Cedar Mountain Wilderness Area, and (3) the southeastern strip between DPG and 40° 00' N. latitude. This additional area outside of DPG included military, federal, state, and private lands.

DPG is a U.S. Army facility covering approximately 800,000 acres (~3200 km²) and used for military testing and training operations. Although public access to DPG is restricted, scientists on the Utah Geological Survey (UGS) mapping team were allowed access for the geological and archeological investigations, except for Simpson Buttes, and some areas west of Wildcat Mountain and Granite Peak (leased by the U.S. Air Force). This project evolved from UGS geologic mapping of the Granite Peak and Sapphire Mountain area (Clark and others, 2009), and geologic/archeologic studies by the Desert Research Institute (see Oviatt and others, 2003; Page, 2008; Madsen and others, 2015). Also, our mapping coincided with hydrogeologic and environmental studies on DPG (Fitzmayer and others, 2004; Parsons, 2004, 2007a, 2007b, 2007c). Accurate geologic mapping is needed to plan development and protect resources.

Prior geologic mapping of the area primarily includes work by Stokes (1963), Maurer (1970), Staatz (1972), Moore and Sorensen (1977, 1979), Oviatt (1991), and Sack (1993). The primary sources of mapping are indicated on plate 2. We map much of the area in greater detail and spatial accuracy, map the Quaternary surficial deposits, and include new geochronologic, paleontologic, geochemical, and tectonic data to provide an updated view of the geology. Oviatt and Clark conducted field and photogeologic mapping on aerial photographs (1:40,000 scale, NAPP, 1998, black and white) and transferred geologic data to 1:24,000-scale paper orthophotoquadrangles in 2006–08. We produced two open-file report maps (UGS OFR-501 and OFR-532) that have been superceded by this map. The eastern part of the map area was updated in 2010–11 during mapping of the Rush Valley 30' x 60' quadrangle (Clark and others, 2012, in review). Co-author Page contributed most of the Old River Bed delta channel mapping (also see Page, 2008; Madsen and others, 2015). Some digital mapping updates were done in 2012–14. The mapping was vectorized and largely compiled in CAD (VROne software) and converted to ArcGIS. Kent Brown (UGS) compiled the GIS data. We selected a 1:75,000 map scale, rather than our typical 1:62,500 intermediate scale, so that plots of the map will fit on a standard 36-inch roll of paper.

GEOLOGIC OVERVIEW
Exposed bedrock map units range from Proterozoic? to Miocene in age and are extensively blanketet by Quaternary surficial deposits. A small area of Neoproterozoic? to Paleozoic? metasedimentary rocks of unclear protoliths is at the south end of Granite Peak. Paleozoic rocks cropping out in other ranges are about 27,000 feet (8230 m) thick, and are predominantly marine sedimentary strata (Cambrian through Lower Permian) deposited initially in basins, subsequently along a subsiding passive margin (miogeocline) (Hintze and Kowalis, 2009; Yonkee and Weil, 2011), and later in the Oquirrh basin (Chamberlin and Clark, 1973; Welsh and Bissell, 1979; Jordan and Douglass, 1980). Paleozoic strata were affected by the Toolee arch (Hintze, 1959), a structural upwarp that removed some Ordovician strata, and the Stansbury uplift (Rigby, 1959) that apparently depositionally thinned Devonian strata. Mapping and paleontologic data helped to update the Permian-Pennsylvanian Oquirrh Group to reflect the stratig-
Cenozoic volcanism related to the change in subduction regime swept from north to south across the western U.S. (Christiansen and McKee, 1978; Best and Christiansen, 1991). Tertiary volcanic rocks and intrusions in the map area are Eocene and Miocene. We obtained geochemical and geochronologic data on the southern Cedar Mountains volcanic field that show it is intermediate to silicic in composition and predates Eocene (about 42 to 38 Ma) are of Eocene age based on U-Pb zircon dating to the east (UGS & AtoZ, 2013). Basin and Range extension began about 20 Ma (Miocene) and continues to the present; it is characterized by distinctive topography and bimodal volcanism (see, for example, Best and others, 1980, 1989; Zoback, 1983; Christianson and Yeats, 1992; DeCelles, 2004; Christiansen and others, 2007a). Exhumation of Granite Peak occurred from about 15 to 5 Ma based on 40Ar/39Ar data (Clark and others, 2009). Numerous normal faults in the ranges and buried along the valley margins are related to the Cenozoic extensional regime. Some faults were delineated by gravity data, but basin geometry is largely unknown. Although Quaternary normal faults and scarps exist in northwest Utah (Barnhard and Dodge, 1988; Black and others, 2003), we found none exposed in the map area. The Great Salt Lake Desert forms an unusually large gap in otherwise relatively consistent spacing between ranges of the Basin and Range Province. The basins in northwest Utah were largely filled with deposits of the Miocene Salt Lake Formation, but some such deposits are exposed in the map area and their subsurface extent is presently unclear. Rhyolite dikes in Granite Peak and the Sapphire Mountain lava flow are Miocene (~8 Ma), related to a pulse of younger volcanism.

The extensive cover of Quaternary deposits is related largely to Lake Bonneville, as well as other depositional environments including alluvial, spring, eolian, colluvial, mass movement. Pleistocene Lake Bonneville was the youngest and deepest of several large pluvial lakes that developed in northern Utah (Oviatt and others, 1992; Oviatt, 2015). Although large fluvioglacial systems filled the lake to at least 18,000 cal yr B.P. (table 1). Subsequently, during the Bonneville flood, the lake quickly fell from its greatest extent (Bonneville shoreline) to the Provo shoreline (18,000 to 15,000 cal yr B.P.), and the lake continued to regress until about 13,000 cal yr B.P., when it remained at low levels until the beginning of the Gilbert episode, about 12 ka (Oviatt and others, 1992, 2003; Godsey and others, 2011; Oviatt, 2015). The Gilbert episode peaked at about 11,600 cal yr B.P. (Oviatt, 2014), and subsequently the Great Salt Lake remained at altitudes similar to those of the modern average lake, far below DPG, with minor lake rises during wet intervals (Murchison, 1989; Oviatt, 2014). Evidence of Lake Bonneville is recorded in the lake deposits (mud, marl, sand, and gravel) and shoreline remnants including the Stansbury, Bonneville, and Provo shorelines. Although the Gilbert shoreline was mapped on DPG (on mudflats north of Granite Peak) by Currey (1982), no evidence was found of Gilbert deposits or shorelines (Oviatt and others, 2003; Madsen and others, 2015), and more work is needed at Wild Isle, just north of DPG (Oviatt, 2014). A basaltic ash from a local source (Pony Express ash) helps to constrain timing of the Lake Bonneville transgression prior to the formation of the Stansbury shoreline (Oviatt and others, 1994; Oviatt and Nash, 2014). A unique feature of the map area is the Old River Bed and associated delta complex. The Old River Bed is an abandoned river valley that extends northward onto DPG from the Old River Bed topographic threshold, at the northern edge of the Sevier Desert basin (about 30 miles [50 km] southeast of the southern boundary of DPG). The Old River Bed formed during the most recent episode of overflow from the Sevier basin (Lake Gunnison) to the Great Salt Lake Basin (Lake Bonneville) (Oviatt, 1987; Oviatt and others, 1994; Madsen and others, 2015). Where the river flowed out onto the flat basin floor, a delta formed with numerous distributary channels from about 13,000 to 10,000 cal yr B.P. (Oviatt and others, 2003). This delta complex was occupied by prehistoric humans that are the focus of the archeological studies (see, for example, Shaver, 1997; UGS, 2000; Madsen, 2001; Madsen and others, 2015). Additional distributary channels were observed on the mudflats southwest of the Old River Bed delta. The streams that formed these channels flowed northward from the Deep...
Creek/Fish Springs area west of Granite Peak (see figure 3.3 in Madsen and others, 2015). These channels have not been studied in detail, so we do not include them herein. The widespread mud flats in the southern Great Salt Lake Desert are mapped as mixed eolian and alluvial deposits over fine-grained (offshore) Lake Bonneville and Great Salt Lake deposits. Holocene deposition is dominated by eolian and alluvial processes. Large sand sheets and dune fields occur on and around the margins of the southern Great Salt Lake Desert in the map area.

**NOTES ON STRATIGRAPHY**

For Devonian and Cambrian stratigraphic nomenclature of the northern Dugway Range, Wig Mountain, and Camels Back Ridge, we prefer to use regional stratigraphic names of Hintze (1980) and Hintze and Kowallis (2009), rather than local names of Staatz and Carr (1964) and Staatz (1972) from the Dugway Range.

Lithofacies changes occur in Mississippian rocks from the southern Cedar Mountains to Wig Mountain and the northern Dugway Range; these changes occur across the Wig Mountain thrust fault. Lithostratigraphy similar to the Dugway Range occurs in the northern Deep Creek Mountains (Nolan, 1935; Staatz and Carr, 1964; Robinson, 1993). Hence we use different nomenclature for this change from northeast (Great Blue Limestone and Humbug Formation) to southwest (Ochre Mountain Limestone and underlying Woodman Formation and Joana Limestone) (Gutschick and others, 1980; Sandberg and Gutschick, 1984).

We remapped Oquirrh strata in the southern Cedar Mountains to conform to the updated stratigraphy and nomenclature of the Oquirrh Mountains/Bingham mine area. Also refer to figure 2 for a comparison of Oquirrh strata between this map and that of Maurer (1970). Considering regional relations, and following Laes and others (1997), Constenius and others (2011), and Clark and others (2012), we combine Lower Permian (Wolfcampian) and Pennsylvanian formations within the Oquirrh Group; this nomenclature differs from previous formal terminology established in the Oquirrh Mountains (Welsh and James, 1961; Tooker and Roberts, 1970), which restricts the Oquirrh Group to strata of Pennsylvanian age. We mapped the Oquirrh strata on Wildcat Mountain as Oquirrh Group, undivided as we are not sure of the relationship to the Cedar and Grassy Mountains.

**NOTES ON STRUCTURE**

Previous structural interpretations are shown on geologic cross sections by others, including those by Geomatrix Consultants, Inc. (2001) across Skull Valley and adjacent areas, and by Budding and others (1984) who include two cross sections from the Deep Creek Mountains to the Cedar Mountains and two sections from the central part of the map area to the south and southeast.

Delineating thrust belt architecture was challenging considering disruption by Cenozoic faulting and concealment by basin fill deposits. We mapped the Cedar, Wig Mountain, and Cochran Spring thrust faults. We differ from Tooker's (1983) regional thrust interpretation by mapping the Wig Mountain thrust and the Onaqui fault separately rather than as parts of the Skull Valley thrust. In addition, the northern extent of the concealed Wah Wah-Frisco thrust may also extend into the area (see Morris, 1987), but may instead lie west of the northern Dugway Range rather than to the east (J.K. King, UGS, verbal communication, 2007). No decollement is needed around Granite Peak considering its rocks are Jurassic rather than Paleoproterozoic (see Morris, 1987). We reinterpret the Buckhorn fault as a low-angle normal fault rather than the thrust fault of Staatz (1972).

The map area may also include large-scale accommodation zones, which are essentially regional rupture barriers to normal-fault systems (Faulds and Varga, 1998). A significant transverse accommodation zone in the Basin and Range Province is indicated by Stewart (1998) and Faulds and Varga (1998); this zone trends roughly east-west on the south side of the southern Cedar Mountains volcanic field and extends west-northwest into Nevada. This zone may trend south and west of Granite Peak through the Ibapah intrusion, similar to the inferred tear fault of Morris (1987), or it may be associated with reactivation of the substantial structural discordance in Paleozoic strata in the northern Deep Creek Mountains (Nolan, 1935; Malan, 1989). Another transverse zone that cuts across the map area is discussed by Rowley (1998) and has various names, but trends from the Uinta Mountains south-southwest to Gold Hill in the northern Deep Creek Mountains. This transverse zone contains many geophysical anomalies, similar fault trends, plutons, and major mining districts such as Park City, Bingham, Ophir, and Gold Hill.

Subsurface interpretations are hindered by the lack of deep exploration drill holes, limited geophysical data, and extensive cover of surficial deposits. There are no petroleum exploration wells and environmental/groundwater investigations did not determine the complete thickness of basin-fill deposits. Therefore, geophysical data were consulted to aid in structural interpretations (see, for example, Stein and others, 1989). Existing bouger gravity data (Johnson and Cook, 1957; Cook and others, 1989; PACES, 2012) are relatively sparse in the map area because of the access restrictions. We relied largely on the PACES bouger gravity data (included in the GIS database), and also basin depth data for the area from Saltus and Jachens (1995). A few concealed faults were mapped solely based on gravity gradients. Areas with gravity lows indicating grabens include Skull Valley, along Government Creek northeast of Camels Back Ridge, and north of the Dugway Range. Gravity highs are associated with range blocks/horsts in the southern Cedar Mountains, Little Granite Mountain–Little Davis Mountain area, Camels Back Ridge area, Granite Peak–Dugway Range, and northeast of Gold Hill. A broad gravity high extends northwest from Granite Peak across the Great Salt Lake Desert. A regional gravity
trend (decreasing) extends west of the gravity high through the Deep Creek Mountains and into Nevada. Aeromagnetic data are available (Stein and others, 1989), although of older vintage. No new data, however, were obtained for this project. Magnetic highs are associated with the southernmost Cedar Mountains, southwest of Wig Mountain, north and northwest of Granite Peak, in the Dugway Range, and possibly east of Wildcat Mountain. Also, a broad magnetic high extends northwest from the north end of Granite Peak. These highs are presumed to be associated with magnetic volcanic and plutonic rocks; some of these rocks are only present in the subsurface.

We include a geologic cross section that traverses Wig Mountain and the southern Cedar Mountains into Skull Valley (plate 2). We refrained from extending the section across the central and western parts of the map area due to the limited subsurface and geophysical data.

NOTES ON RESOURCES

Some of the key reports on water resources and hydrogeology in this part of the Great Basin include those by Hood and Wad dell (1968), Bolke and Sumison (1978), Gates and Druer (1981), Steiger and Freethy (2001), Fitzmayer and others (2004), Parsons (2004, 2007a, 2007b, 2007c), Rowley and others (2009), and Hurlow and others (2014). Geothermal resources are summarized by Blackett and Wakefield (2004) and further studies are ongoing by the UGS. Mineral resources and potential resources are summarized by Stein and others (1989) and Tripp and others (1989). Bullock (1976) reported on fluorspar resources in Wildcat Mountain. DPG personnel reported that the consulting firm Kleinfelder was previously contracted to evaluate gravel resources.

GEOLOGIC UNIT DESCRIPTIONS

QUATERNARY SURFICIAL DEPOSITS

Alluvial Deposits

Qal Alluvial deposits (Holocene) – Primarily clay, silt, and sand with some gravel lenses, deposited by streams in channels and filling drainages; locally includes alluvial-fan, colluvial, and eolian deposits; thickness generally less than about 20 feet (6 m).

Qafo Older alluvial-fan deposits (upper to middle Pleistocene) – Deposits of higher-level, poorly sorted gravel with sand, silt, and clay that have been incised by younger alluvial deposits; present along the margin and interior valleys of the eastern Cedar Mountains; may locally include small areas of lacustrine or eolian deposits; thickness variable, to 100 feet (30 m) or more.

Qasd Younger alluvial-fan deposits (Holocene to upper Pleistocene) – Poorly sorted gravel with sand, silt, and clay deposited by streams, debris flows, and flash floods on alluvial fans and in canyon and mountain valleys above the Bonneville shoreline; includes alluvium and colluvium in canyon and mountain valleys; may include small areas of eolian deposits and lacustrine fine-grained deposits below the Bonneville shoreline; may include small areas of older alluvial-fan deposits difficult to map at this scale; thickness variable, to 100 feet (30 m) or more.

Qafy Younger alluvial-fan deposits (Holocene to upper Pleistocene) – Poorly sorted gravel with sand, silt, and clay deposited by streams, debris flows, and flash floods on alluvial fans and in canyon and mountain valleys above the Bonneville shoreline; includes alluvium and colluvium in canyon and mountain valleys; may include small areas of eolian deposits and lacustrine fine-grained deposits below the Bonneville shoreline; may include small areas of older alluvial-fan deposits difficult to map at this scale; thickness variable, to 100 feet (30 m) or more.

Qafy Younger alluvial-fan deposits (Holocene to upper Pleistocene) – Poorly sorted gravel with sand, silt, and clay deposited by streams, debris flows, and flash floods on alluvial fans and in canyon and mountain valleys above the Bonneville shoreline; includes alluvium and colluvium in canyon and mountain valleys; may include small areas of eolian deposits and lacustrine fine-grained deposits below the Bonneville shoreline; may include small areas of older alluvial-fan deposits difficult to map at this scale; thickness variable, to 100 feet (30 m) or more.

Qafy Younger alluvial-fan deposits (Holocene to upper Pleistocene) – Poorly sorted gravel with sand, silt, and clay deposited by streams, debris flows, and flash floods on alluvial fans and in canyon and mountain valleys above the Bonneville shoreline; includes alluvium and colluvium in canyon and mountain valleys; may include small areas of eolian deposits and lacustrine fine-grained deposits below the Bonneville shoreline; may include small areas of older alluvial-fan deposits difficult to map at this scale; thickness variable, to 100 feet (30 m) or more.

Qafy Younger alluvial-fan deposits (Holocene to upper Pleistocene) – Poorly sorted gravel with sand, silt, and clay deposited by streams, debris flows, and flash floods on alluvial fans and in canyon and mountain valleys above the Bonneville shoreline; includes alluvium and colluvium in canyon and mountain valleys; may include small areas of eolian deposits and lacustrine fine-grained deposits below the Bonneville shoreline; may include small areas of older alluvial-fan deposits difficult to map at this scale; thickness variable, to 100 feet (30 m) or more.

Qafy Younger alluvial-fan deposits (Holocene to upper Pleistocene) – Poorly sorted gravel with sand, silt, and clay deposited by streams, debris flows, and flash floods on alluvial fans and in canyon and mountain valleys above the Bonneville shoreline; includes alluvium and colluvium in canyon and mountain valleys; may include small areas of eolian deposits and lacustrine fine-grained deposits below the Bonneville shoreline; may include small areas of older alluvial-fan deposits difficult to map at this scale; thickness variable, to 100 feet (30 m) or more.

Qafy Younger alluvial-fan deposits (Holocene to upper Pleistocene) – Poorly sorted gravel with sand, silt, and clay deposited by streams, debris flows, and flash floods on alluvial fans and in canyon and mountain valleys above the Bonneville shoreline; includes alluvium and colluvium in canyon and mountain valleys; may include small areas of eolian deposits and lacustrine fine-grained deposits below the Bonneville shoreline; may include small areas of older alluvial-fan deposits difficult to map at this scale; thickness variable, to 100 feet (30 m) or more.

Qafy Younger alluvial-fan deposits (Holocene to upper Pleistocene) – Poorly sorted gravel with sand, silt, and clay deposited by streams, debris flows, and flash floods on alluvial fans and in canyon and mountain valleys above the Bonneville shoreline; includes alluvium and colluvium in canyon and mountain valleys; may include small areas of eolian deposits and lacustrine fine-grained deposits below the Bonneville shoreline; may include small areas of older alluvial-fan deposits difficult to map at this scale; thickness variable, to 100 feet (30 m) or more.

Qafy Younger alluvial-fan deposits (Holocene to upper Pleistocene) – Poorly sorted gravel with sand, silt, and clay deposited by streams, debris flows, and flash floods on alluvial fans and in canyon and mountain valleys above the Bonneville shoreline; includes alluvium and colluvium in canyon and mountain valleys; may include small areas of eolian deposits and lacustrine fine-grained deposits below the Bonneville shoreline; may include small areas of older alluvial-fan deposits difficult to map at this scale; thickness variable, to 100 feet (30 m) or more.

Qafy Younger alluvial-fan deposits (Holocene to upper Pleistocene) – Poorly sorted gravel with sand, silt, and clay deposited by streams, debris flows, and flash floods on alluvial fans and in canyon and mountain valleys above the Bonneville shoreline; includes alluvium and colluvium in canyon and mountain valleys; may include small areas of eolian deposits and lacustrine fine-grained deposits below the Bonneville shoreline; may include small areas of older alluvial-fan deposits difficult to map at this scale; thickness variable, to 100 feet (30 m) or more.

Qafy Younger alluvial-fan deposits (Holocene to upper Pleistocene) – Poorly sorted gravel with sand, silt, and clay deposited by streams, debris flows, and flash floods on alluvial fans and in canyon and mountain valleys above the Bonneville shoreline; includes alluvium and colluvium in canyon and mountain valley
phases of Lake Bonneville, prior to 11,000 and after 12,500 \(^{14}\text{C}\) yr B.P. (about 13,000 to 14,600 cal yr B.P.) (Oviatt and others, 2003; Madsen and others, 2015); thickness to about 12 feet (4 m).

**Spring Deposits**

Qsm  **Spring and marsh deposits** (Holocene) – Clay, silt, and sand that is locally organic-rich, calcareous, or saline; present in saturated (marshy) areas near springs along margins of mudflats; thickness undetermined.

Qst  **Spring tufa** (Holocene) – Tufa present in mounds around hot springs northwest of Fish Springs at south border of map; area referred to as Wilson Health Springs on Fish Springs NW 7.5' quadrangle map; thickness undetermined.

**Eolian Deposits**

Qes  **Eolian sheet-sand deposits** (Holocene) – Wind-blown sand and silt deposited as sheets rather than well-developed dunes; generally thin with no distinct bedding; mostly silty, well-sorted, fine-grained quartz sand; mapped along northern Snake Valley, east of Wildcat Mountain, and in two smaller areas; also commonly mapped as stacked units; may include local areas with some dune development; generally between 3 and 10 feet (1–3 m) thick.

Qed  **Eolian dune-sand deposits** (Holocene) – Wind-blown sand and silt in well-developed dunes and dune fields; mostly fine-grained quartz sand and aggregates of clay, silt, and sand; present as parabolic, linear, dome, lunette, and shrub-coppice dunes (see Dean, 1976, 1978); larger dune fields may include a fringe of unmapped sheet sand; to 70 feet (20 m) thick.

Qei  **Eolian silt** (Holocene) – Windblown silt mapped as stacked units Qei/Qal, Qei/Qac, and Qei/Qlf; see descriptions below.

Qeg  **Eolian gypsum deposits?** (Holocene) – Dunes probably composed of windblown gypsum grains on mudflats along western border of map area, not field checked due to access restrictions; Dean (1976, 1978) reported gypsum dunes in the Great Salt Lake Desert area; as much as 10 feet (3 m) thick.

**Lacustrine Deposits (post Bonneville lake cycle)**

Qpm  **Playa mud** (Holocene to upper Pleistocene) – Laminated clay and silt, with minor sand, typically calcareous or saline; locally present east of Granite Peak and on mudflats at areas of local groundwater discharge; probably less than 20 feet (6 m) thick.

**Lacustrine and Deltaic Deposits (Bonneville lake cycle)**

Table 1 presents ages and elevations of Lake Bonneville shorelines in the map area. Shoreline elevation ranges were determined from 1:24,000-scale topographic maps. These elevations generally increase from south to north across the map area due to isostatic rebound. Crittenden (1963) and Currey (1982) provided regional data on shoreline elevations and rebound. The Pony Express ash, about 24 cal ka in age (Oviatt and Nash, 2014), was identified from two localities on Camels Back Ridge within Lake Bonneville deposits. Table 2 presents radiocarbon age data from DPG and adjacent areas.

Qdag  **Deltaic gravel** (upper Pleistocene) – Sand and gravel deposited near the mouth of the Sevier River in the Old River Bed area during the Bonneville lake cycle; well-sorted pebbly sand containing volcanic and sedimentary pebbles; cross-bedded to very thick bedded; regressive deposits were locally reworked by waves into a thin sheet with delta ridge crests; to 50 feet (15 m) thick.

Qlg  **Lacustrine gravel** (upper Pleistocene) – Sandy gravel to boulders composed of locally derived rock fragments deposited in shore zones of Lake Bonneville; locally tufa-cemented and draped on bedrock; thickness variable, to 100 feet (30 m) or more.

Qls  **Lacustrine sand** (upper Pleistocene) – Sand and silt deposited by regressive phase of Lake Bonneville; thickness to 100 feet (30 m) or more.

Qlf  **Lacustrine fine-grained deposits** (upper Pleistocene) – Sand, silt, marl, and calcareous clay of Lake Bonneville; thinly to very thick bedded; locally includes the white marl of Gilbert (1890) and sand, silt and clay deposited at the margin of Lake Bonneville by a river flowing north from the Sevier basin during the transgressive phase (the Yellow Clay of Gilbert, 1890) and the regressive phase; thickness to 100 feet (30 m) or more.

Qlt  **Lacustrine tufa** (upper Pleistocene) – Two areas of carbonate rock deposited at the shore of Lake Bonneville on bedrock outliers west of Cedar Mountains; some unmapped Qlt also present on Wildcat Mountain; thickness to 40 feet (12 m).

**Colluvial Deposits**

Qc  **Colluvial deposits** (Holocene to upper Pleistocene) – Fine-grained to coarse detritus derived from local bedrock; commonly includes talus in upper parts of deposits; may locally include lacustrine, alluvial, or eolian deposits; mapped more commonly on Granite Peak and northern Dugway Range than elsewhere; 0 to 20 feet (6 m) thick.
Mass-Movement Deposits

**Qmtc**  
Talus and colluvial deposits (Holocene to upper Pleistocene) – Mixed talus and colluvium locally present on steeper slopes of Tabbys Peak, on west side of Cedar Mountains, and on Camels Back Ridge; 0 to 15 feet (5 m) thick.

Mixed-Environment Deposits

**Qla**  
Lacustrine and alluvial deposits, undivided (Holocene to upper Pleistocene) – Mixed and reworked, gravelly lacustrine and alluvial deposits on piedmont slopes; includes pre-Bonneville alluvial fans etched by waves in Lake Bonneville, and thin alluvial-fan deposits overlying fine to coarse-grained lake sediments; grades from pebbly sand and silt to sandy pebble gravel; locally includes areas of thicker alluvial-fan deposits in western Skull Valley and west of Simpson Mountains; thickness locally exceeds 30 feet (10 m).

**Qac**  
Alluvial and colluvial deposits, undivided (Holocene to upper Pleistocene) – Primarily gravel, with sand, silt, and clay; form aprons of small alluvial-fan and colluvial surfaces that spill out onto and grade into alluvial-fan deposits; also present within upland valleys; thickness generally less than 20 feet (6 m).

**Qlc**  
Lacustrine and colluvial deposits, undivided (Holocene to upper Pleistocene) – Primarily gravel and sand, but may include lacustrine fine-grained deposits; commonly includes talus in upper parts of deposits; mantles bedrock and fills washes, locally remobilized by slope-wash and rock-fall processes; locally marked by prominent secondary shorelines; mapped on northwest side of Granite Peak; thickness typically 0 to 10 feet (3 m), but locally thicker.

**Qea**  
Eolian and alluvial deposits, undivided (Holocene) – Mixed eolian and alluvial deposits mapped as stacked units Qea/Qlf and Qed-Qea/Qlf; see descriptions below.

Human-Derived Deposits

**Qh**  
Human disturbance (Historical) – Fill and disturbance from human development on more extensive areas including wastewater treatment lagoons, sanitary landfill, and Michael Army Airfield; thickness generally less than about 10 to 20 feet (3–6 m).

Stacked-unit deposits

We map 22 stacked-unit deposits consisting of a discontinuous veneer of the first unit (surficial deposits) overlying the second unit (surficial deposits or bedrock). Several of these units are mapped across the area and primarily include eolian deposits (Qei, Qes, Qed) and lacustrine gravel of Lake Bonneville (Qlg). Although most bedrock in the map area is partly covered by colluvium or other surficial deposits, we use stacked units to indicate those areas where bedrock is mostly obscured by thin or discontinuous surficial deposits that are derived from more than just residual weathering of underlying bedrock.

**Qei/unit (Qei/Qal, Qei/Qac, Qei/Qlf)**

Eolian silt over unit (Holocene over Holocene through upper Pleistocene) – Windblown silt overlying various surficial-deposit units; Qei/Qlf surface commonly contains distinctive vegetation stripes (characteristic landforms of sheetflow plains in arid to semiarid regions) (see, for example, Klausmeier, 1999; Wakelin-King, 1999; also see Oviatt and others, 2003); thickness of upper unit less than 3 feet (1 m).

**Qes/unit (Qes/Qla, Qes/Qafy, Qes/Qlg, Qes/Qlf, Qes/Tlw?, Qes/Psl, Qes/Pofc)**

Eolian sheet sand over unit (Holocene over Holocene through Lower Permian) – Windblown sand and some silt in sheets overlying various surficial-deposit and bedrock units; thickness of upper unit probably less than 10 feet (3 m).

**Qed/unit (Qed/Qla, Qed/Qlf, Qed/Tac)**

Eolian dune sand over unit (Holocene over Holocene through Tertiary) – Windblown sand and some silt in dunes and dune fields overlying various surficial-deposit and bedrock units; thickness of upper unit probably less than 20 feet (6 m).

**Qlg/unit (Qlg/Tlw, Qlg/Psl, Qlg/Pobp, Qlg/PlPo, Qlg/rx)**

Lacustrine gravel (Lake Bonneville) over unit (upper Pleistocene over Tertiary through Cambrian?) – Sandy and pebbly gravel overlying various bedrock units; thickness of upper unit probably less than 20 feet (6 m).

**Qal/Qlf**  
Alluvial deposits over lacustrine fine-grained deposits (Holocene over upper Pleistocene) – Sand, silt, clay, and some gravel in alluvial channels and sheets overlying lacustrine silt, clay, marl, and some sand; present between Granite Peak and Old River Bed; thickness of upper unit probably less than 6 feet (2 m).
Qafy/Qlf

Younger alluvial-fan deposits over lacustrine fine-grained deposits (Holocene to upper Pleistocene over upper Pleistocene) – Gravel, sand, and fine-grained alluvial-fan deposits overlying lacustrine sand, silt, marl, and clay; present along periphery of Granite Peak and in some upland valleys of eastern Cedar Mountains; thickness of upper unit probably less than 10 feet (3 m).

Qea/Qlf

Eolian and alluvial deposits over lacustrine fine-grained deposits (Holocene over upper Pleistocene) – Windblown silt in sheet form adjacent to and locally covering alluvial sand and gravel in unmapped channels that collectively overlie lacustrine marl and fine-grained deposits; locally saline or gypsiferous; form extensive mudflats of southern Great Salt Lake Desert; may locally include small areas of thicker eolian deposits; thickness of upper unit probably less than 15 feet (5 m).

Qes-Qea/Qlf

Eolian sand with eolian and alluvial deposits over lacustrine fine-grained deposits (Holocene over upper Pleistocene) – Discontinuous exposures of windblown dune sand and some silt interspersed with windblown silt in sheet form adjacent to and locally covering alluvial sand and gravel in unmapped channels that collectively overlie lacustrine marl and fine-grained deposits; locally saline or gypsiferous; mapped in three areas on mudflats where small dunes are difficult to map individually at this scale; thickness of upper unit probably less than 20 feet (6 m).

TERTIARY ROCK UNITS

Geochemical and age data for Tertiary rocks are presented in Clark (2015), figures 3 and 4, table 3, UGS & NMGR, 2007, 2009a, 2009b, and UGS & NIGL (2012). Rock names are from the total alkali-silica classification diagram of LeBas and others (1986).

Tbx

Breccia (Tertiary?) – One northern Dugway Range exposure of heterogeneous jumbled bedrock blocks and fragments in a reddish, clayey, calcareous matrix (possible breccia pipe); blocks are chiefly limestone and siltstone of the Woodman Formation, but in places include fragments of limestone from the Ochre Mountain Limestone and Joana Limestone (Staatz, 1972); age unknown, assumed Tertiary; Staatz (1972) mapped as intrusive breccia; circular exposure is about 500 feet (150 m) in diameter.

Trd

Rhyolitic dikes of Granite Peak (Miocene) – Grayish-orange, weathering to dark-yellowish-brown, porphyritic rhyolite with phenocrysts of feldspar and biotite; cross-cuts granite (unit Jg), granodiorite (unit Jgd), and pegmatite dikes; prior K-Ar age of about 13 Ma (Moore and McKee, 1983), new 40Ar/39Ar age of 7.78 ± 0.05 Ma on sanidine (UGS & NMGR, 2007); dikes probably related to rhyolite of Sapphire Mountain; width to 30 feet (10 m).

Trs

Rhyolite of Sapphire Mountain (Miocene) – Pale-red, weathering to dark-yellowish-brown and moderate-red, porphyritic rhyolite lava flow; contains about 10% phenocrysts of quartz, sanidine, and minor biotite in an aphanitic groundmass; locally includes flow breccia; forms cliffy exposures on Sapphire Mountain; 40Ar/39Ar age of 8.20 ± 0.05 Ma on sanidine (UGS & NMGR, 2007); exposed thickness is 450 feet (140 m).

Tlw

Latitic rocks of Wildcat Mountain (Eocene?) – Dark- to moderate-gray and pale-red latite lava flows and dark-gray trachydacite intrusions associated with local vents; exposed on west side of Wildcat Mountain; rocks are porphyritic to aphanitic and locally vesicular; blocky exposures commonly draped with lacustrine gravel and eolian sand; no age data obtained; previously mapped as Tertiary basalt and basaltic andesite (?) (Moore and Sorensen, 1979); mostly mapped as stacked units Qlg/Tlw and Qes/Tlw?, and queried in exposures that were not directly inspected; exposed thickness up to 120 feet (40 m).

Tdd

Dacitic dikes of Granite Peak (Eocene?) – Medium-gray to medium-dark-gray porphyritic dacite dikes on northwest side of mountain; only one such dike is mapped; uncommon, unmapped latite dikes are also present; cross-cuts granite (unit Jg), granodiorite (unit Jgd), and pegmatite dikes; no age data; width to 30 feet (10 m).

Tit

Trachytic intrusions of northern Dugway Range (Eocene?) – Gray to reddish-brown aphanitic to porphyritic trachyte and tephriphonolite (previously called rhyodacite by Staatz, 1972); locally with phenocrysts of quartz, plagioclase, biotite, and amphibole; locally vesicular, highly oxidized and devitrified; occurs as plugs along Buckhorn fault; also includes small areas of flow breccia and associated tuffs (see Staatz and Carr, 1964; Staatz, 1972; Kelley and others, 1987; Kelley and Yambrick, 1988; Klatt, 2006); age estimate of 36? Ma (Lindsey, 1979), UGS obtained unreliable radiometric age (Lisa Peters, NMGR, written communication, 2008); exposures to 1400 feet (430 m) across.
**Trr**  Rhyolite of Rydalch Canyon area (Eocene) – Light-gray and very pale orange rhyolitic ash-flow tuff and intrusion exposed south and east of Rydalch Canyon in southern Cedar Mountains; contains about 25% phenocrysts of feldspar, quartz, hornblende, and biotite; Ken Krahluc (UGS, verbal communication, 2013) reported that the central part of the outcrop area (at sample Trr2) may be a stock; forms slopes, rounded knobs, and cliffs; \(^{40}\text{Ar}/^{39}\text{Ar}\) age of 39.18 ± 0.06 Ma (sanidine) (UGS & NIGL, 2012); exposed thickness to 650 feet (200 m).

**Tid**  Dacitic intrusions of White Rock and Little Granite Mountain (Eocene) – Light-gray, weathering to white and yellowish-gray, porphyritic dacite with phenocrysts (~25%) of plagioclase, quartz, biotite, and amphibole (0.5–2 mm long average); groundmass is intergrowth of plagioclase, potassium feldspar, and quartz (Maurer, 1970; Moore and Sorensen, 1977); forms isolated, rounded, steep-walled exposures; \(^{40}\text{Ar}/^{39}\text{Ar}\) ages of 38.69 ± 0.10 Ma (sanidine) for White Rock and 39.56 ± 0.10 Ma (biotite) and 40.95 ± 0.32 Ma (hornblende) for Little Granite Mountain (UGS & NMGRL, 2009a, 2009b); exposures to 9500 feet (2900 m) across.

**Tac**  Andesitic and dacitic rocks of southern Cedar Mountains (Eocene) – Dark- to light-gray and pale-red lava flows interlayered with laharas and less common tuffs; lava flows are porphyritic to aphanitic, and phenocrysts include feldspar, quartz, and biotite; laharas contain clasts of intermediate volcanic rocks up to 4 feet (1 m) across; variously welded ash-flow tuffs contain phenocrysts of feldspar, hornblende, and biotite; calc-alkaline affinities are similar to those of Oligocene-Eocene rocks in the region (Clark, 2015); forms slopes to cliffs; exposed thickness is 12 feet (3.7 m).

**Tso**  Older Tertiary strata (Eocene) – One area southwest of Dugway (English Village) of grayish-orange, very pale orange, and moderate-orange-pink lacustrine limestone that is locally oncolitic, moderately crystalline, and indistinctly to thin bedded; underlain by small exposure of moderate-reddish-orange tuffaceous sandstone; poorly exposed on flank of gravel-covered area; U-Pb detrital zircon age of similar strata to east at Davis Knolls and Vernon Hills is 46.77 ± 1.28 Ma and 38.70 ± 0.28/– 0.62 Ma (UGS & AtoZ, 2013; Clark and others, 2012, in review); exposed thickness is 12 feet (4 m).

**JURASSIC TO NEOPROTEROZOIC? ROCK UNITS OF GRANITE PEAK**

Granite Peak (elevation 7082 feet [2159 m]) is the highest point of an unnamed mountain of largely granitic rock on Dugway Proving Ground. This mountain is informally known as Granite Mountain and Granite Peak Mountain. Refer to the geologic map by Clark and others (2009). Geochemical and age data for Jurassic rocks are presented in Clark (2015), figure 5, tables 3 and 4, Christiansen and Vervoort (2009), and UGS & NMGRL (2007, 2009a). Rock names are from the total alkali-silica classification diagram of Middlemost (1994).

**Jgu**  Foliated granodiorite and granite of Granite Peak, undivided (Late Jurassic) – Foliated granodiorite (unit Jgd) with sills and dikes of granite (unit Jg) exposed in the central and western part of mountain; exposed thickness is 400 feet (120 m).

**Jgd**  Foliated granodiorite of Granite Peak (Late Jurassic) – Medium-light-gray to medium-gray granodiorite with variable chemical composition (decreasing silica) to quartz monzonite, monzonite, diorite, and monzodiorite; primary minerals include plagioclase > quartz > alkali-feldspar > biotite > amphibole > muscovite (Fowkes, 1964; Christiansen and others, 2007b; Jensen and others, 2007); rock is weakly to strongly foliated, contains uncommon dark xenoliths and local large feldspar crystals; cut by numerous unmapped, white, beryl-bearing pegmatite dikes in various forms (Fowkes, 1964; Clark and others, 2009) as much as 100 feet (30 m) thick; also cut by minor aplite dikes, quartz veins, and younger dikes (units Trd, Tdd); granodiorite is believed to be altered upper part of granite intrusion (unit Jg) (Clark and Christiansen, 2006; Christiansen and others, 2007b; Jensen and others, 2007); forms rounded to rugged exposures; some fault and fracture zones in granodiorite and associated granite (unit Jg) are mineralized with hematite and lesser amounts of base metal-bearing minerals; Jensen and others (2007) and Clark and others (2009) provided isotopic data on granodiorite; U-Pb zircon age determination of...
149.8 ± 1.3 Ma (intrusion age; table 4) (Clark and Christiansen, 2006; Christiansen and others, 2007b; Jensen and others, 2007; Christiansen and Vervoort, 2009); \(^{40}\)Ar/\(^{39}\)Ar ages of 15.97 ± 0.04 Ma on biotite (cooling and possibly unroofing ages; table 3) (Clark and others, 2009; UGS & NMGRL, 2009a); exposed thickness is about 2000 feet (600 m).

**Jg**

Granite of Granite Peak (Late Jurassic) – White (leucocratic) granite that weathers to pale-orange and moderate-yellowish-brown; primary minerals include quartz > plagioclase > alkali-feldspar > muscovite > biotite (Fowkes, 1964; Christiansen and others, 2007b; Jensen and others, 2007); locally includes dark schistose inclusions and large potassium feldspar crystals; generally weakly foliated, except in northeastern exposures where strong flow foliation exists in upper part near contact with foliated granodiorite; cut by a few pegmatite and aplite dikes, quartz veins, and younger dikes (units Trd, Tdd); forms rounded to rugged exposures; Jensen and others (2007) and Clark and others (2009) provided isotopic data on granite; U-Pb zircon age determination of 148.8 ± 1.3 Ma (intrusion age; table 4) (Clark and Christiansen, 2006; Christiansen and others, 2007b; Jensen and others, 2007; Christiansen and Vervoort, 2009); \(^{40}\)Ar/\(^{39}\)Ar ages of 13.69 ± 0.12 Ma on muscovite and 15.97 ± 0.04 Ma on K-feldspar (cooling and possibly unroofing ages; table 3) (Clark and others, 2009; UGS & NMGRL, 2009a); exposed thickness is 1400 feet (425 m).

**PzZm**

Metasedimentary rocks of Granite Peak (Paleozoic? or Neoproterozoic?) – Metasedimentary rocks composed of schist with minor quartzite, and marble with lesser schist intruded by granodiorite (unit Jgd) and leucogranite (unit Jg) sills and dikes at the south end of the mountain; approximately 60% metasedimentary rocks and 40% intrusions; forms ledges to cliffs; metasedimentary rocks may correspond to part of the Paleozoic section, to part of the Neoproterozoic McCoy Creek Group or Trout Creek Sequence of the southern Deep Creek Range (see Rodgers, 1989), or, less likely, to Neoproterozoic units of the Sheprock Mountains (Christie-Blick, 1982); locally cut by pegmatite and aplite dikes and quartz veins; in fault contact with granodiorite (unit Jgd); exposed thickness is 2300 feet (700 m).

**PERMIAN TO MISSISSIPPIAN ROCK UNITS OF SOUTHERN CEDAR MOUNTAINS, WILDCAT MOUNTAIN, LITTLE DAVIS MOUNTAIN**

**Psl**

Sandstone, limestone, and dolomite (Lower Permian, Leonardian) – Light-brown to pale-red sandstone that weathers to dark brown, interbedded with moderate-gray cherty limestone and dolomite that weathers to light gray, and some calcareous sandstone in lower part; bedding is thin to thick to indistinct, forming ledgy and clifftop outcrops; sandstone is slightly calcareous with fine to medium sand and tabular cross-bedding; limestone and lesser dolomite are finely crystalline and locally bioclastic, with black chert in nodules and thin beds; contains *Parafusulina* (fusulinid) fossils near base indicating a Leonardian age (table 5); Maurer (1970) mapped as Permian unnamed formation; similar stratigraphic interval is present to the north in the Grassy and Hogup Mountains (Doelling, 1964; Miller and others, in preparation); top not exposed, and incomplete thickness is 2000 feet (600 m) at southern Cedar Mountains; Maurer (1970) reported a measurement of 3953 feet (1205 m) north of map area where this unit underlies Grandeur Member of the Park City Formation.

**PiPo**

Oquirrh Group, undivided (Lower Permian, Leonardian? to Lower Pennsylvanian, Morrowan?) – Mapped as undivided unit in Wildcat Mountain because the stratigraphic and structural relationships to Oquirrh strata in the southern Cedar Mountains is unclear; only reconnaissance mapping was conducted there due to access restrictions, exposed (incomplete) thickness is about 1500 feet (460 m).

Oquirrh Group of the southern Cedar Mountains herein includes Lower Permian and Pennsylvanian formations of the Bingham Sequence after Laes and others (1997) (see figure 2), also see Clark and others (2012) and Constenius and others (2011):

**PiPoPofm**

Oquirrh Group, Freeman Peak-Curry Peak and Bingham Mine Formations, undivided (Lower Permian, Wolfcampian, and Upper Pennsylvanian, Virgilian) – Combined unit in two areas of Cedar Mountains: (1) along Cedar thrust, north of Rydalch Canyon, and (2) small exposure on southwest margin, south of Orme and Bitter Springs.

**Pofc**

Oquirrh Group, Freeman Peak and Curry Peak Formations, undivided (Lower Permian, Wolfcampian) – Medium- to dark-gray, weathering to yellowish-gray, calcareous, fine-grained sandstone and siltstone with uncommon very pale orange, medium-gray and pale-red orthoquartzite and sandy limestone; laminated to thick-bedded unit breaks into chips and plates forming rounded hills and slopes with occasional ledges; “worm trail” markings common on bedding planes in lower part of unit; also contains *Schwagerina* and *Triticites cf. T. meeki* (fusulinids) that indicate a middle to early Wolfcampian age (table 5); contact of Curry Peak and underlying Bingham Mine Formation is an unconformity to the
east (Welsh and James, 1961) but no obvious break here; corresponds to most of Maurer’s (1970) Unit 4 and Unit 5 (figure 2); 3500 feet (1065 m) thick at southern Cedar Mountains.

Oquirrh Group, Bingham Mine Formation (Upper Pennsylvanian, Virgilian-Missourian) – Very pale orange to pale-red calcareous sandstone with lesser medium-gray sandy limestone; thin- to medium-bedded, forming ledges and slopes; fossils include brachiopods, bryozoans, and fusulinids (Trititites, Pseudo fusulinella); fusulinids indicate a Virgilian to Missourian age (table 5); corresponds to upper part of Maurer’s (1970) Unit 3 and lower part of Unit 4 (figure 2); 2700 feet (825 m) thick at southern Cedar Mountains.

Oquirrh Group, Butterfield Peaks Formation and West Canyon Limestone, undivided (Middle to Lower Pennsylvanian, Desmoinesian-Morrowan) – Combined unit mapped in small exposures of southern Cedar Mountains.

Oquirrh Group, Butterfield Peaks Formation (Middle to Lower Pennsylvanian, Desmoinesian-Morrowan) – Medium- to dark-gray, sandy limestone, cherty limestone, and fossiliferous limestone interbedded with light-brown calcareous sandstone and quartzite; thin- to very thick bedded, forming ledges, cliffs, and slopes of a cyclic character; lower part forms ledgy escarpment; limestone is finely crystalline to bioclastic; gray, yellow-brown, and black chert occurs as spherical nodules and semi-bedded masses; contains sandy laminae and horizontally flattened concretionary structures; overall clastic percentages increase upsection; fossils include Chaetetes and Syringopora (colonial corals), rugose corals, fusulinids (Fusulina, Fusulinella, Beedeina, Millerella), brachiopods, and bryozoans; fusulinids indicate a Desmoinesian to Atokan age (our table 5; Maurer, 1970); corresponds to Maurer’s (1970) Unit 2 and most of Unit 3 (figure 2); queried in small exposure between Wig Mountain and CAMELS BACK RIDGE, SIMPSON BUTTES

Oquirrh Group, West Canyon Limestone (Lower Pennsylvanian, Morrowan to Upper Mississippian?) – Medium- to dark-blue-gray and brown-gray limestone and fossiliferous limestone with sparse chert; weathers to gray and yellow-brown; thin- to medium-bedded, forming ledges and slopes; formation is limestone interval at base of Oquirrh Group; conodont sample has large age range (table 5); corresponds to Maurer’s (1970) Unit 1 (figure 2); 500 to 800 feet (150–245 m) thick at southern Cedar Mountains.

Manning Canyon Formation (Lower Pennsylvanian? to Upper Mississippian) – Gray to black, fissile, slope-forming shale with lesser light-brown and multicolored quartzite and uncommon brownish-gray, carbonaceous limestone; typically forms dark shaley slopes littered with quartzite fragments; crops out in southern Cedar Mountains and near Little Davis Mountain; interval of regional decollement; probably 1500 to 2000 feet (450–600 m) thick in southern Cedar Mountains (Maurer, 1970), but base not exposed, and small exposures near Little Davis Mountain are both not in contact and are in fault contact with the Great Blue Limestone.

Great Blue Limestone (Upper Mississippian) – Medium- to dark-gray, typically medium- and thick-bedded, finely crystalline limestone and fossiliferous limestone that forms rugged ledges; black and gray chert locally common as nodules or beds; no obvious shaley intervals; fossils include colonial and rugose corals, crinoids, and bryozoan fragments; southwestern exposures at Little Davis Mountain are silicified; incomplete thicknesses of 2440 feet (745 m) at southern Cedar Mountains (Maurer, 1970) and 1200 feet (370 m) at Little Davis Mountain.

Humbug Formation (Upper Mississippian) – Yellow-brown and gray sandstone and quartzite, and medium-to dark-gray limestone mostly in middle part; forms slopes and ledges; sandstone weathers to brown and maroon, is fine to medium grained, thin to medium bedded; limestone is thin to medium bedded with numerous thin horizontal black chert stringers, and locally common corals and brachiopods; crops out in one area near Wide Hollow along Cochran Spring thrust, southern Cedar Mountains; base not exposed, incomplete thickness is 1014 feet (310 m) (Maurer, 1970).

Ochre Mountain Limestone (Upper Mississippian) – At northern Dugway Range, medium-gray limestone and a few interbeds of dark-gray dolomite; thin to thick bedded and locally cherty; horn corals locally common; forms ledgy exposures (Staatz, 1972); at Wig Mountain, medium- to dark-gray limestone and fossiliferous limestone with uncommon black nodular chert; medium- to thick-bedded, forming rugged ledges and cliffs; isolated exposure north of Wig Mountain contains brachiopods and numerous large crinoid columnals; incomplete thicknesses of 700 feet (200 m) at northern Dugway Range (Staatz, 1972), and 600 feet (180 m) at Wig Mountain.

Woodman Formation (Upper to Lower Mississippian) – At northern Dugway Range, upper part thin-
bedded, light-gray silty limestone with a 20-foot-thick (6 m), brown-weathering quartzite near base, and lower part of thin-bedded, reddish-brown, calcareous siltstone; forms ledges with some ledges; Staatz (1972); Wig Mountain exposures of very pale orange calcareous sandstone and siltstone, medium-gray cherty limestone, fossiliferous limestone, and sandy limestone; black chert in nodules and beds; very thin to thin bedded; complete thicknesses of 785 feet (240 m) at northern Dugway Range (Staatz, 1972) and 1000 feet (300 m) at Wig Mountain.

**Joana Limestone** (Lower Mississippian) – Moderate-gray limestone and fossiliferous limestone that is fine grained, locally with some chert; thin to very thick bedded and forms ledges; Staatz (1972) mapped as Madison Limestone equivalent in northern Dugway Range; unconformably overlies Guilmette Formation; complete thicknesses of 315 feet (95 m) at northern Dugway Range (Staatz, 1972) and 300 feet (90 m) in limited exposures at Wig Mountain.

**Devonian-Cambrian dolomite** (Upper Devonian? to Middle Cambrian?) – Two isolated exposures where formation determination is unclear; includes small exposure on mud flat between the Old River Bed and northern Dugway Range of moderate-gray to moderate-brown dolomite that weathers to light brown, dark brown and pale red with common near-vertical fractures; exposed thickness 25 feet (8 m); queried in single outcrop on Goodyear Road near western DPG border (Baker Strong Point or Black Point area) that was not accessible; exposed thickness roughly 50 feet (15 m).

**Guilmette Formation** (Upper to Middle Devonian) – At northern Dugway Range, exposures of light-to-dark-gray, commonly sandy-textured dolomite; upper part contains interbedded light-gray limestone and brown-weathering gray to white dolomitic quartzite, middle part is thick to very thick bedded and contains some medium-bedded gray limestone, and lower part contains interbedded brown-weathering dolomitic and calcareous quartzite; *Amphipora* (stromatoporoid) fossils common in some dolomite beds of middle part; forms clifffy and ledgy outcrops; Staatz (1972) mapped as Hanauer Formation, Gilson Dolomite, and Goshoot Formation (local names not used on this map); at Wig Mountain, moderate-gray to moderate-brown, thick- to very thick bedded dolomite; local laminated surface appearance; includes ~40-foot-thick (~12 m), dark-reddish-brown quartzite at top of formation; queried at Camels Back Ridge in faulted section where is moderate- to dark-gray, finely to moderately crystalline dolomite that locally weathers brownish gray and is thin to thick bedded and forms ledges; Devonian strata were apparently depositionally thinned near the Stansbury uplift (Rigby, 1959); incomplete thicknesses of 2180 feet (660 m) at northern Dugway Range (Staatz, 1972) and about 500 feet (150 m) at Camels Back Ridge, and complete thickness is 400 to 800 feet (120–250 m) at Wig Mountain.

**Simonson Dolomite and Sevy Dolomite, undivided** (Middle to Lower Devonian) – Combined unit at Wig Mountain; moderate gray, thin- to medium-bedded dolomite; weathers to very light and light gray with laminated surface appearance; lighter colored, more distinctly bedded, and less resistant than adjacent formations; unconformable with underlying Laketown; thickness is 100 feet (30 m) at Wig Mountain.

**Simonson Dolomite** (Middle Devonian) – At northern Dugway Range, gray to black dolomite that is very thick bedded, crystalline, and sandy-textured; forms less resistant ledges than overlying Guilmette Formation; Staatz (1972) mapped as Engelmann Formation (local name not used on this map); at Camels Back Ridge, light- to dark-gray, finely to moderately crystalline dolomite that locally weathers brownish gray; local zones of chert; thin to very thick bedded, forming cliffs and ledges; incomplete thicknesses of 1080 feet (330 m) at northern Dugway Range (Staatz, 1972) and about 500 feet (150 m) at Camels Back Ridge.

**Sevy Dolomite** (Lower Devonian) – Moderate-gray, finely crystalline dolomite that weathers to light gray with a laminated surface appearance; thin to medium bedded in ledges and slopes; unconformity between Sevy and underlying Laketown; thickness is about 250 feet (75 m) at Camels Back Ridge.

**Laketown Dolomite** (Silurian) – At Wig Mountain, light- to dark-gray, weathers to light- and moderate-brown, very thick bedded dolomite commonly with small open vugs, local black chert, laminated appearance, and case hardening; thinner bedded interval (roughly 50 feet [15 m] thick) with dark-brown and light-gray dolomite is about 500 feet (150 m) above base; formation generally clifffy and indistinctly bedded; at Camels Back Ridge, moderate- to dark-gray, finely to moderately crystalline dolomite that locally weathers to light and moderate brown and light gray, and that contains some intervals of light gray dolomite; contains gray and red chert in beds, masses and nodules, and rust-colored case hardening; mostly very thick bedded, forming cliffs and ledges; to south, Hintze (1980) separated into several members corresponding to formations of Staatz and Carr (1964); complete thickness is 1800 feet (550 m) at Wig Mountain and incomplete thickness is about 500 feet (150 m) at Camels Back Ridge.
Ely Springs Dolomite (Upper Ordovician) – At Wig Mountain, moderate-gray, thin- to medium-bedded dolomite that weathers to moderate brown and light gray; forms more distinct and less resistant beds between enclosing formations; at Camels Back Ridge, includes upper part (Flordie Member of Hintze, 1980) and lower part (lower member) not mapped separately; upper part is very light gray, finely crystalline dolomite with indistinct to medium bedding; lower part is cherty, resistant, moderate-gray dolomite at top underlain by brown-weathering, less resistant, thin-bedded dolomite; both parts are thin to thick bedded, forming ledges, cliffs, and slopes; unconformity with underlying units associated with the Tooele arch (Hintze, 1959) where Eureka Quartzite and Pogonip Group are not present; complete thicknesses of 300 feet (90 m) at Wig Mountain and 250 feet (75 m) at Camels Back Ridge.

Lower Ordovician and Upper-Middle Cambrian strata, undivided (Lower Ordovician? to Upper-Middle Cambrian?) – Combined unit in Simpson Buttes due to lack of access; gray-, brown-, and pink-weathering, thin- to very thick bedded dolomite and limestone; may correspond to parts of Pogonip Group, Notch Peak Formation, Orr Formation, Lamb Dolomite, and Trippe Limestone; exposed thickness about 2300 feet (700 m) at Simpson Buttes.

Pogonip Group, undivided (Middle-Lower Ordovician to Upper Cambrian?) – Upper part of dark-gray and moderate-gray, finely to moderately crystalline dolomite, underlying moderate-gray intraformational conglomerate with siltstone and limestone; thin to medium bedded, forming ledges and slopes; exposed in low hills west of Camels Back Ridge; may include part of Kanosh Shale? and underlying formations are described by Hintze (1980); incomplete thickness up to 150 feet (45 m) at Camels Back Ridge.

Notch Peak Formation (Lower Ordovician? to Upper Cambrian) – At Wig Mountain, exposures are moderate-gray dolomite that weathers to light and moderate brown and gray brown, locally with a mottled appearance; locally sandy, with dark brown laminae, and calcite rods; thin to very thick bedded; at Camels Back Ridge, moderate to dark-gray, finely to moderately crystalline dolomite, with some intervals that are light gray, tan, and light pink (some up to several feet/meters thick); medium to very thick bedded, cliff and ledge forming; locally includes pisolites, calcite rods, and Girvanella (algae); corresponds to Dugway Ridge Formation of Staatz and Carr (1964); incomplete thicknesses of 1000 feet (300 m) at Wig Mountain and about 500 feet (150 m) at Camels Back Ridge.

Orr Formation, upper part (Upper Cambrian) – Very light gray to light-gray, finely to moderately crystalline dolomite and limestone, and green and light-brown shale; commonly medium to thick bedded; forms less resistant and lighter colored interval between Notch Peak Formation and Big Horse Limestone that likely includes (in descending order) Sneakover Limestone Member, Corset Spring Shale Member, Johns Wash Limestone Member, and Candland Shale Member; corresponds to Fera Limestone of Staatz and Carr (1964); 200 feet (60 m) thick at Camels Back Ridge.

Orr Formation, Big Horse Limestone Member (Upper Cambrian) – Moderate-gray to tan-gray, finely to moderately crystalline limestone with some intervals weathering to light tan, pink, and mottled; medium to very thick bedded, resistant interval forming cliffs and ledges; locally dolomitized; corresponds to Straight Canyon Formation of Staatz and Carr (1964); 425 feet (130 m) thick at Camels Back Ridge.

Lamb Dolomite (Upper? to Middle Cambrian) – Upper part is less resistant, mostly very thin to thin bedded and commonly rusty and pink weathering, and consists of ledges of moderate-gray oolitic and silty limestone and flat-pebble conglomerate, underlain by moderate-gray dolomite and limestone with rusty-colored blebs and layers; lower part of more resistant gray dolomite that locally weathers to mottled gray, pink gray, and light brown, is moderately to coarsely crystalline, contains intervals of Girvanella (algae), and forms a thin- to very thick bedded ledge interval; 900 feet (275 m) thick at Camels Back Ridge.

Trippe Limestone (Middle Cambrian) – Upper part is moderate-gray, laminated and nodular limestone, shale, intraformational conglomerate, and light-tan-weathering dolomite that is laminated to medium bedded; lower part is light- to moderate-gray, locally mottled, laminated to very thick bedded limestone; unit forms generally less resistant and ledge interval between Lamb Dolomite and Pierson Cove Formation; corresponds to upper part of Fandangle Limestone of Staatz and Carr (1964); 700 feet (215 m) thick at Camels Back Ridge.

Pierson Cove Formation (Middle Cambrian) – Moderate-gray limestone and silty limestone with some light-gray dolomite interbeds; thin to very thick bedded forming ledges to cliffs; unit locally dolomitized; corresponds to lower part of Fandangle Limestone of Staatz and Carr (1964); incomplete thickness about 800 feet (245 m) at Camels Back Ridge.

Prospect Mountain Quartzite (Lower Cambrian) – White to tan, resistant, thick-bedded quartzite with local thin beds of olive-green, micaceous shale and lenses of quartz-pebble conglomerate (Staatz, 1972);
Figure 1. Primary geographic features associated with Dugway Proving Ground and adjacent areas.

Figure 2. Comparison of Oquirrh strata nomenclature and map units of the southern Cedar Mountains. Maurer (1970) provided thicknesses for his units measured in the Cochran Spring section and overall estimates. Our work indicated the Cochran Spring section is incomplete and provide revised thickness estimates. The stratigraphy used in this map for the Lower Permian (Wolfcampian) and Pennsylvanian formations is based on that of the Oquirrh Mountains/Bingham mining district (see Laes and others, 1997).
Figure 3. Total alkali-silica classification plot (after LeBas and others, 1986) for Tertiary dikes and volcanic rocks of the Granite Peak and Sapphire Mountain area.

Figure 4. Total alkali-silica plot (after LeBas and others, 1986) for extrusive and intrusive rocks from southern Cedar Mountains and northern Dugway Range.
Table 1. Ages and elevations of major shorelines of Lake Bonneville in Dugway Proving Ground and adjacent areas.

<table>
<thead>
<tr>
<th>Lake Cycle and Phase</th>
<th>Shoreline (map symbol)</th>
<th>Age (Rounded to 1000 years)</th>
<th>Elevation feet (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>radiocarbon years B.P.</td>
<td>calibrated years B.P.</td>
</tr>
<tr>
<td>Lake Bonneville</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transgressive Phase</td>
<td>Stansbury (S)</td>
<td>21(^2)</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Bonneville (B)</td>
<td>15</td>
<td>18</td>
</tr>
<tr>
<td>flood</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regressive Phase</td>
<td>Provo (P)</td>
<td>15-12.5(^3,4,5)</td>
<td>18-15</td>
</tr>
</tbody>
</table>

\(^1\) Calendar calibration using OxCal \(^14\)C calibration and analysis software (v. 4.2) (Bronk Ramsey, 2009) using the INTCAL13 calibration curve (Reimer and others, 2013).

\(^2\) Oviatt and others (1990). Stansbury high and low.

\(^3\) Miller and others (2013).

\(^4\) Godsey and others (2011).

Table 2. Radiocarbon ages from Dugway Proving Ground and adjacent areas.

<table>
<thead>
<tr>
<th>Field ID</th>
<th>Lab ID</th>
<th>Material dated</th>
<th>UTM E</th>
<th>UTM N</th>
<th>Zone</th>
<th>Altitude**</th>
<th>Age (cal years)</th>
<th>1 sigma</th>
<th>2sigma</th>
<th>Cal孵</th>
<th>Cal孵孵</th>
<th>Cal孵孵孵</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>VGCMNW-L1-01</td>
<td>Beta-267953</td>
<td>Organic sediment</td>
<td>369705</td>
<td>448358</td>
<td>12</td>
<td>125-131.89</td>
<td>8300</td>
<td>50</td>
<td>9133</td>
<td>3087</td>
<td>9460</td>
<td>Wildcat Mountain</td>
<td>Madsen and others (2015)</td>
</tr>
<tr>
<td>VGCMNW-L2-01</td>
<td>Beta-267955</td>
<td>Organic sediment</td>
<td>369705</td>
<td>448358</td>
<td>12</td>
<td>125-131.89</td>
<td>7840</td>
<td>50</td>
<td>9596</td>
<td>3092</td>
<td>9901</td>
<td>Wildcat Mountain</td>
<td>Madsen and others (2015)</td>
</tr>
<tr>
<td>VGCMNW-L2-03</td>
<td>Beta-267957</td>
<td>Organic sediment</td>
<td>369705</td>
<td>448358</td>
<td>12</td>
<td>125-131.89</td>
<td>8740</td>
<td>40</td>
<td>9627</td>
<td>3074</td>
<td>10130</td>
<td>Dugway Proving Ground NW</td>
<td>Madsen and others (2015)</td>
</tr>
<tr>
<td>VGCMNW-L2-05</td>
<td>Beta-267952</td>
<td>Organic sediment</td>
<td>369705</td>
<td>448358</td>
<td>12</td>
<td>125-131.89</td>
<td>10590</td>
<td>40</td>
<td>10239</td>
<td>3079</td>
<td>10514</td>
<td>Dugway Proving Ground NW</td>
<td>Madsen and others (2015)</td>
</tr>
<tr>
<td>VGCMNW-L2-06</td>
<td>Beta-267951</td>
<td>Organic sediment</td>
<td>369705</td>
<td>448358</td>
<td>12</td>
<td>125-131.89</td>
<td>11210</td>
<td>40</td>
<td>10544</td>
<td>3086</td>
<td>10714</td>
<td>Dugway Proving Ground NW</td>
<td>Madsen and others (2015)</td>
</tr>
<tr>
<td>VGCMNW-L2-07</td>
<td>Beta-267959</td>
<td>Organic sediment</td>
<td>369705</td>
<td>448358</td>
<td>12</td>
<td>125-131.89</td>
<td>11360</td>
<td>50</td>
<td>10757</td>
<td>3099</td>
<td>10303</td>
<td>Wildcat Mountain</td>
<td>Madsen and others (2015)</td>
</tr>
<tr>
<td>VGCMNW-L2-08</td>
<td>Beta-267960</td>
<td>Organic sediment</td>
<td>369705</td>
<td>448358</td>
<td>12</td>
<td>125-131.89</td>
<td>11920</td>
<td>50</td>
<td>11080</td>
<td>3099</td>
<td>10504</td>
<td>Wildcat Mountain</td>
<td>Madsen and others (2015)</td>
</tr>
<tr>
<td>VGCMNW-L2-09</td>
<td>Beta-267961</td>
<td>Organic sediment</td>
<td>369705</td>
<td>448358</td>
<td>12</td>
<td>125-131.89</td>
<td>12450</td>
<td>50</td>
<td>11293</td>
<td>3099</td>
<td>10704</td>
<td>Wildcat Mountain</td>
<td>Madsen and others (2015)</td>
</tr>
<tr>
<td>VGCMNW-L2-10</td>
<td>Beta-267962</td>
<td>Organic sediment</td>
<td>369705</td>
<td>448358</td>
<td>12</td>
<td>125-131.89</td>
<td>12950</td>
<td>50</td>
<td>11596</td>
<td>3099</td>
<td>10904</td>
<td>Wildcat Mountain</td>
<td>Madsen and others (2015)</td>
</tr>
<tr>
<td>VGCMNW-L2-12</td>
<td>Beta-267964</td>
<td>Organic sediment</td>
<td>369705</td>
<td>448358</td>
<td>12</td>
<td>125-131.89</td>
<td>14050</td>
<td>50</td>
<td>12233</td>
<td>3099</td>
<td>11304</td>
<td>Wildcat Mountain</td>
<td>Madsen and others (2015)</td>
</tr>
<tr>
<td>VGCMNW-L2-14</td>
<td>Beta-267966</td>
<td>Organic sediment</td>
<td>369705</td>
<td>448358</td>
<td>12</td>
<td>125-131.89</td>
<td>14960</td>
<td>50</td>
<td>12697</td>
<td>3099</td>
<td>11704</td>
<td>Wildcat Mountain</td>
<td>Madsen and others (2015)</td>
</tr>
</tbody>
</table>

**UTM coordinates using NAD83 calculated from latitude/longitude measurements in Oviatt (1999), Oviatt and Madsen (2000), and Oviatt and Madsen (2001), to nearest 0.1 or 0.01 minutes of a degree and rounded off to nearest 100 m (for 0.1 min.) or 10 m (0.01 min.)

**Altitudes in m; most altitudes are approximate and within the range of 1295-1318 m

***Calibrated ages determined using CALIB7.0 (http://calib.qub.ac.uk/calib/); INTCAL13; Reimer and others, 2013; ages are reported to the nearest year as output from CALIB7.0, but should be rounded to the nearest 100 yr for comparisons

****Parsons sample collected from borehole/monitoring well 056B_MW01 at depth of 29 feet
<table>
<thead>
<tr>
<th>Map Number</th>
<th>Sample Number</th>
<th>Map Unit</th>
<th>Rock Name</th>
<th>Latitude (N)</th>
<th>Longitude (W)</th>
<th>Age + 2sd (Ma)</th>
<th>Material Dated</th>
<th>Laboratory</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trd1</td>
<td>GP071405-11</td>
<td>Trd</td>
<td>Rhyolite</td>
<td>40°08'3.7&quot;</td>
<td>113°17'4.9&quot;</td>
<td>7.78 ± 0.05</td>
<td>sanidine</td>
<td>NMGRRL</td>
<td></td>
</tr>
<tr>
<td>Trd2</td>
<td>GP071405-23</td>
<td>Trd</td>
<td>Rhyolite</td>
<td>40°05'16.2&quot;</td>
<td>113°15'56.2&quot;</td>
<td>13.69 ± 0.12</td>
<td>biotite</td>
<td>NMGRRL</td>
<td></td>
</tr>
<tr>
<td>Tac3</td>
<td>GP102605-1</td>
<td>Tac</td>
<td>Monzonite</td>
<td>40°26'55.3&quot;</td>
<td>113°01'57.8&quot;</td>
<td>40.66 ± 0.45</td>
<td>groundmass</td>
<td>NMGRRL</td>
<td></td>
</tr>
<tr>
<td>Tac3</td>
<td>GP102605-3</td>
<td>Tac</td>
<td>Monzonite</td>
<td>40°18'39.6&quot;</td>
<td>112°56'36.3&quot;</td>
<td>38.17 ± 0.47</td>
<td>groundmass</td>
<td>NMGRRL</td>
<td></td>
</tr>
<tr>
<td>Tac3</td>
<td>GP102605-5</td>
<td>Tac</td>
<td>Andesite</td>
<td>40°25'10.8&quot;</td>
<td>112°59'13.8&quot;</td>
<td>40.61 ± 0.78</td>
<td>groundmass</td>
<td>NMGRRL</td>
<td></td>
</tr>
<tr>
<td>Tac3</td>
<td>GP102605-11</td>
<td>Tac</td>
<td>Andesite</td>
<td>40°19'17.9&quot;</td>
<td>112°54'01.1&quot;</td>
<td>40.19 ± 0.08</td>
<td>groundmass</td>
<td>NMGRRL</td>
<td></td>
</tr>
<tr>
<td>Tac3</td>
<td>GP102605-13</td>
<td>Tac</td>
<td>Andesite</td>
<td>40°17'38.6&quot;</td>
<td>112°56'38.3&quot;</td>
<td>39.18 ± 0.06</td>
<td>groundmass</td>
<td>NMGRRL</td>
<td></td>
</tr>
<tr>
<td>Tac3</td>
<td>GP102605-22</td>
<td>Tac</td>
<td>Andesite</td>
<td>40°22'03.3&quot;</td>
<td>112°51'01.1&quot;</td>
<td>39.56 ± 0.10</td>
<td>groundmass</td>
<td>NMGRRL</td>
<td></td>
</tr>
<tr>
<td>Tac3</td>
<td>GP102605-25</td>
<td>Tac</td>
<td>Andesite</td>
<td>40°25'10.8&quot;</td>
<td>112°59'13.8&quot;</td>
<td>40.61 ± 0.78</td>
<td>groundmass</td>
<td>NMGRRL</td>
<td></td>
</tr>
<tr>
<td>Tac3</td>
<td>GP102605-32</td>
<td>Tac</td>
<td>Andesite</td>
<td>40°22'03.3&quot;</td>
<td>112°51'01.1&quot;</td>
<td>39.56 ± 0.10</td>
<td>groundmass</td>
<td>NMGRRL</td>
<td></td>
</tr>
<tr>
<td>Tac3</td>
<td>GP102605-45</td>
<td>Tac</td>
<td>Andesite</td>
<td>40°25'10.8&quot;</td>
<td>112°59'13.8&quot;</td>
<td>40.61 ± 0.78</td>
<td>groundmass</td>
<td>NMGRRL</td>
<td></td>
</tr>
<tr>
<td>Tac3</td>
<td>GP102605-50</td>
<td>Tac</td>
<td>Andesite</td>
<td>40°19'17.9&quot;</td>
<td>112°54'01.1&quot;</td>
<td>40.19 ± 0.08</td>
<td>groundmass</td>
<td>NMGRRL</td>
<td></td>
</tr>
<tr>
<td>Tac3</td>
<td>GP102605-58</td>
<td>Tac</td>
<td>Andesite</td>
<td>40°17'38.6&quot;</td>
<td>112°56'38.3&quot;</td>
<td>39.18 ± 0.06</td>
<td>groundmass</td>
<td>NMGRRL</td>
<td></td>
</tr>
<tr>
<td>Tac3</td>
<td>GP102605-90</td>
<td>Tac</td>
<td>Andesite</td>
<td>40°22'03.3&quot;</td>
<td>112°51'01.1&quot;</td>
<td>39.56 ± 0.10</td>
<td>groundmass</td>
<td>NMGRRL</td>
<td></td>
</tr>
<tr>
<td>Tac3</td>
<td>GP102605-92</td>
<td>Tac</td>
<td>Andesite</td>
<td>40°25'10.8&quot;</td>
<td>112°59'13.8&quot;</td>
<td>40.61 ± 0.78</td>
<td>groundmass</td>
<td>NMGRRL</td>
<td></td>
</tr>
<tr>
<td>Tac3</td>
<td>GP102605-98</td>
<td>Tac</td>
<td>Andesite</td>
<td>40°22'03.3&quot;</td>
<td>112°51'01.1&quot;</td>
<td>39.56 ± 0.10</td>
<td>groundmass</td>
<td>NMGRRL</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1. Results for Jgd1 and Jg2 are considered cooling ages rather than intrusion ages.
2. NMGRL is the New Mexico Geochronology Research Laboratory, Socorro, New Mexico.
3. NMGRRL reported unreliable age data for samples D-2, D-4, D-6, D-7, as samples were too felsic for good groundmass concentrate analysis and/or were unable to separate any other datable mineral phases.

### Table 4. Summary of U-Pb zircon age analyses from Granite Peak.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Map Unit</th>
<th>Rock Name</th>
<th>7.5' Quadrangle</th>
<th>Latitude (N) NAD27</th>
<th>Longitude (W) NAD27</th>
<th>Weighted Average $^{238}$U/$^{206}$Pb Age Mean (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jgd1</td>
<td>GP102805-3</td>
<td>Jgd</td>
<td>Granite Peak</td>
<td>40°05'16.2&quot;</td>
<td>113°16'45.9&quot;</td>
<td>149.8 ± 1.3</td>
</tr>
<tr>
<td>Jg1</td>
<td>GP081605-9</td>
<td>Jg</td>
<td>Granite porphyry</td>
<td>40°07'40&quot;</td>
<td>113°18'23&quot;</td>
<td>148.8 ± 1.3</td>
</tr>
</tbody>
</table>

Notes:
- Analyses performed by Eric H. Christiansen (Brigham Young University) and Jeffrey D. Vervoort (Washington State University).
- Analyses by laser ablation-inductively coupled mass spectrometry.
- See Christiansen and Vervoort (2009) for complete presentation of data.

### Table 5. Fossil identifications and ages from Dugway Proving Ground and adjacent areas.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Map Unit</th>
<th>Rock Type</th>
<th>7.5' Quadrangle</th>
<th>Latitude (N) NAD27</th>
<th>Longitude (W) NAD27</th>
<th>Fossil Type</th>
<th>Fauna</th>
<th>Preservation &amp; Abrasion</th>
<th>Calcareous Algae Present</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-77</td>
<td>Psl</td>
<td>biomicrite wackestone</td>
<td>Wig Mountain NE</td>
<td>40°24'05.2&quot;</td>
<td>113°02'06.2&quot;</td>
<td>fusulinid</td>
<td>Parafusulina</td>
<td>Poor</td>
<td>None</td>
<td>early Leonardian</td>
</tr>
<tr>
<td>D-74</td>
<td>Psl</td>
<td>biomicrite wackestone</td>
<td>Wig Mountain NE</td>
<td>40°29'06.5&quot;</td>
<td>113°07'07.3&quot;</td>
<td>fusulinid</td>
<td>Parafusulina, Schwagerina</td>
<td>Poor</td>
<td>None</td>
<td>Leonardian</td>
</tr>
<tr>
<td>D-60</td>
<td>Pofc</td>
<td>silicified shale</td>
<td>Wig Mountain NE</td>
<td>40°23'25.8&quot;</td>
<td>113°01'16.8&quot;</td>
<td>fusulinid</td>
<td>Schwagerina longisimoidea</td>
<td>Poor</td>
<td>None</td>
<td>middle Wolfcampian</td>
</tr>
<tr>
<td>D-69</td>
<td>Pofc</td>
<td>biomicrite wackestone</td>
<td>Tabbys Peak</td>
<td>40°27'48.0&quot;</td>
<td>112°59'49.6&quot;</td>
<td>fusulinid</td>
<td>Triticites cf. T. meeki</td>
<td>Good</td>
<td>None</td>
<td>early Wolfcampian</td>
</tr>
<tr>
<td>D-75</td>
<td>Pofc</td>
<td>biomicrite mudstone</td>
<td>Tabbys Peak</td>
<td>40°28'10.9&quot;</td>
<td>112°58'46.9&quot;</td>
<td>fusulinid</td>
<td>Triticites cf. T. meeki</td>
<td>Fair</td>
<td>None</td>
<td>early Wolfcampian</td>
</tr>
<tr>
<td>D-76</td>
<td>IPobm</td>
<td>biomicrite wackestone</td>
<td>Tabbys Peak</td>
<td>40°29'53.8&quot;</td>
<td>112°56'41.1&quot;</td>
<td>fusulinid</td>
<td>Triticites</td>
<td>Fair</td>
<td>None</td>
<td>Virgilian</td>
</tr>
<tr>
<td>D-68</td>
<td>IPobm</td>
<td>biomicrite wackestone</td>
<td>Tabbys Peak</td>
<td>40°23'37.1&quot;</td>
<td>112°59'45.3&quot;</td>
<td>fusulinid</td>
<td>Triticites</td>
<td>Fair</td>
<td>None</td>
<td>Virgilian</td>
</tr>
<tr>
<td>D-52</td>
<td>IPobm</td>
<td>biomicrite wackestone</td>
<td>Tabbys Peak SW</td>
<td>40°20'17.8&quot;</td>
<td>112°59'13.6&quot;</td>
<td>fusulinid</td>
<td>Pseudofusulinella, Triticites</td>
<td>Fair</td>
<td>None</td>
<td>early Virgilian</td>
</tr>
<tr>
<td>D-57</td>
<td>IPobm</td>
<td>biosparite packstone</td>
<td>Tabbys Peak SW</td>
<td>40°19'31.0&quot;</td>
<td>112°58'13.0&quot;</td>
<td>fusulinid</td>
<td>Triticites cullomensis</td>
<td>Good</td>
<td>None</td>
<td>early Virgilian</td>
</tr>
<tr>
<td>D-71</td>
<td>IPobm</td>
<td>biomicrite mudstone</td>
<td>Tabbys Peak</td>
<td>40°23'05.6&quot;</td>
<td>112°59'05.3&quot;</td>
<td>fusulinid</td>
<td>Triticites</td>
<td>Good</td>
<td>None</td>
<td>Missourian</td>
</tr>
<tr>
<td>D-78</td>
<td>IPobm</td>
<td>biomicrite wackestone</td>
<td>Tabbys Peak SW</td>
<td>40°20'04.3&quot;</td>
<td>112°58'34.9&quot;</td>
<td>fusulinid</td>
<td>Triticites</td>
<td>Fair</td>
<td>None</td>
<td>Missourian</td>
</tr>
<tr>
<td>D-70</td>
<td>IPobp</td>
<td>biomicrite wackestone</td>
<td>Tabbys Peak</td>
<td>40°23'08.4&quot;</td>
<td>112°58'34.7&quot;</td>
<td>fusulinid</td>
<td>Beedeina</td>
<td>Fair</td>
<td>Fragments</td>
<td>early Desmoinesian</td>
</tr>
<tr>
<td>D-50</td>
<td>IPowc</td>
<td>crinoidal packstone</td>
<td>Tabbys Peak</td>
<td>40°22'38.9&quot;</td>
<td>112°57'57.4&quot;</td>
<td>conodont</td>
<td>Adetognathus lautus</td>
<td>-</td>
<td>-</td>
<td>latest Mississippian</td>
</tr>
</tbody>
</table>

Notes:
- Fusulinids identified by A.J. Wells (independent).
- Conodonts identified by S.R. Ritter (Brigham Young University).
ledge- to cliff-forming unit; present in footwall of Buckhorn fault in northern Dugway Range; incomplete thickness of 450 feet (140 m).

ACKNOWLEDGMENTS

We thank the following U.S. Army Dugway Proving Ground personnel for logistical and technical assistance with this project: Rachel Quist, Jason Raff, John Woofinden (retired), and also Carl Mandelco, Carl Jorgensen, and Kathy Callister for the Granite Peak mapping project. Thanks to Kathy Vaux and Roger Cannon (U.S. Air Force) who provided reconnaissance access to Wildcat Mountain. Jeff Fitzmayer (Parsons) and David Madsen (Desert Research Institute) provided logistical, technical, and field assistance. Adolph Yankee (Weber State University), Eric Christiansen (Brigham Young University), and Douglas Stoeser (U.S. Geological Survey) provided technical assistance for the Granite Peak mapping. Eric Christiansen (Brigham Young University) and Jeff Vervoort and Garret Hart (Washington State University) performed the U-Pb zircon age and isotopic analyses of rocks from Granite Peak, while Eric and his student Bryce Jensen conducted petrographic and geochemical analyses. The New Mexico Geochronology Research Laboratory and Nevada Isotope Geochronology Laboratory conducted the $^{40}$Ar/$^{39}$Ar dating. Barbara Nash (University of Utah) and Elmira Wan (USGS) conducted analyses of basaltic ash. The late John Welsh contributed to the understanding of Permian-Pennsylvanian strata of this region. A.J. Wells (independent paleontologist) identified fusulinids and reviewed Maurer’s fusulinid data. Scott Ritter (Brigham Young University) identified conodonts from Pennsylvania strata. We thank UGS colleagues Robert Biek, Grant Willis, Kent Brown, Paul Kuehne, Buck Ehler, and Carl Ege for contributions to the Granite Peak and Sapphire Mountain area mapping. Dave Miller and Victoria Langenheim (both USGS) provided insights on structure and geophysics. UGS staff Robert Biek, Grant Willis, Robert Ressetar, and Michael Hylland reviewed and improved this map over several stages, Jon King and Christian Hardwick provided some technical assistance, while James Parker, Lori Douglas, Jay Hill, Basia Matyjasik, and Buck Ehler assisted in preparation of the map and figures. Kent Brown (UGS) compiled the GIS data.

REFERENCES


Miller, D.M., Felger, T.J., and Langenheim, V.E., in preparation, Geologic map of the Newfoundland Mountains 30’ x 60’ quadrangle and part of the adjacent Wells 30’ x 60’ quadrangle, Box Elder County, Utah: Utah Geological Survey Map, scale 1:62,500.


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


Oviatt, C.G., 1991, Quaternary geology of Fish Springs Flat, Juab County, Utah: Utah Geological Survey Special Study 77, 16 p., 1 plate, scale 1:50,000.


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


Pan-American Center for Earth and Environmental Studies (PACES), 2012, North American Gravity and Magnetic
Geologic map of Dugway Proving Ground and adjacent areas, Tooele County, Utah


Sack, D., 1993, Quaternary geologic map of Skull Valley, Tooele County, Utah: Utah Geological Survey Map 150, 16 p., 1 plate, scale 1:100,000.


PHOTO GALLERY

View northwest of the Old River Bed (broad swale in center of photo), with northern Dugway Range (left) and Granite Peak (right) in background.

View of Upper and Middle Cambrian formations on the east flank of Camels Back Ridge, includes from top to bottom Notch Peak Formation, Orr Formation, Lamb Dolomite.
Southern Cedar Mountains with view to the east of lava flows and other volcanic rocks (unit Tac) in foreground and White Rock (unit Tid) in middle ground.

View southeast of Little Granite Mountain (unit Tid) with well-developed Provo shoreline notch near middle and lower part of mountain.
View southwest of Camels Back Ridge.

Southwest margin of Cedar Mountains with Devils postpile (unit Tiac) and co-author Charles (Jack) Oviatt.
View south of southern Cedar Mountains from near Tabbys Peak. The rocks here are predominantly Oquirrh Group strata and Tertiary volcanic rocks.

View west of the southern Cedar Mountains, mudflats, and Granite Peak.
View northeast of Tabbys Peak (unit Tiac) and Rydalch Canyon of the southern Cedar Mountains.

View northwest of the southern Cedar Mountains near Cane Springs with volcanic rocks (unit Tac) and underlying Oquirrh Group strata.
Volcanic rocks above (unit Tac) and Oquirrh Group strata below, near Cane Springs, southern Cedar Mountains.

View southwest of part of Wig Mountain (foreground), mudflats and Granite Peak (middle ground), and northern Dugway Range and Deep Creek Mountains (background).
View of dune field (unit Qed) on west side of southern Cedar Mountains.

Beds of Oquirrh Group, Butterfield Peaks Formation in Wildcat Canyon, southern Cedar Mountains.