GEOLOGIC MAP OF DUGWAY PROVING GROUND AND ADJACENT AREAS, TOOELE COUNTY, UTAH

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UTAH GEOLOGICAL SURVEY
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SCALE: 1:75,000

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

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GEOLOGIC MAP OF DUGWAY PROVING GROUND AND ADJACENT AREAS, TOOELE COUNTY, UTAH

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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 40º 30′ N. latitude, (2) the entire southern Cedar Mountains north to 40º 30′ N. latitude, including part of the Cedar Mountain Wilderness Area, and (3) the southeastern strip between DPG and 40º 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 km^2) 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 blanketed 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 Kowallis, 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 Tooele 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 stratigraphy in the Oquirrh Mountains/Bingham mine. The map area straddles the hinterland metamorphic belt and the Sevier fold-thrust belt, parts of the Cordilleran orogenic belt (Triassic to Eocene) (DeCelles, 2004). The age of the Granite Peak intrusion was long in doubt, but is now shown to be Late Jurassic (149 Ma) (Clark and others, 2009), similar to other granitic plutons in western Utah in the Newfoundland Mountains, and at Crater Island, Pilot Range, Gold Hill, and Notch Peak (Hintze and Kowallis, 2009; Miller and others, in preparation). This retroarc magmatism was associated with Jurassic deformation that included minor thrusting and folding in the hinterland area of western Utah, eastern Nevada, and central Idaho (Miller, 1991; DeCelles, 2004). The Sevier belt is an area of folds and thrust faults in central Utah to eastern Nevada that developed from the Early Cretaceous to Eocene (roughly 145 to 50 Ma) (DeCelles, 2004; DeCelles and Coogan, 2006; Yonkee and Weil, 2011). Typically brittle thrusts of the Sevier belt merge westward and downward with ductile shear zones associated with metamorphic rocks in the hinterland (Miller, 1991; Camilleri and others, 1997). Some of the westernmost exposed thrust faults in this part of the Sevier belt are present in the map area, including the Wig Mountain thrust, Cedar thrust, and Cochran Spring backthrust. However, the extent of these faults or others in the subsurface is not known. The Onaqui fault (Armin and Moore, 1981), also called the Faust fault by Tooker (1983) and Faust tear by Morris (1987), probably accommodated slip at the Manning Canyon decollement. Several Sevier-related oblique-slip faults and folds were mapped in the Cedar Mountains near Wildcat and Rydalch Canyons, Cochran Spring, and Post Hollow. Low-angle normal faults near Wide Hollow and the Buckhorn fault (Dugway Range) are likely related to subsequent extensional collapse of the Sevier belt (Eocene-Oligocene? in age) (see, for example, Constenius, 1996; Constenius and others, 2003).

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 ranges from about 42 to 38 Ma in age. Older Tertiary sedimentary strata (unit Tso) 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 $^{40}Ar/^{39}Ar$ 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 no 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). The lake generally increased in size (transgressive phase) from about 30,000 to 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 bouguer 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 bouguer 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 Waddell (1968), Bolke and Sumsion (1978), Stephens and Sumsion (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 fluorite 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).

Qai **Alluvial silt** (Holocene to upper Pleistocene?) – Silt, clay, some sand, and minor gravel deposited by streams and sheet wash within former lagoonal areas related to Lake Bonneville shorelines at south and west margin of Cedar Mountains and on Wildcat Mountain; bottom of lagoonal basins may include some unexposed, thin, fine-grained lacustrine deposits; thickness less than about 40 feet (12 m).

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.

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.

Channels associated with the Old River Bed delta are present on DPG. Two types of channel systems were mapped—younger sand channels (Qasd) and older gravel channels (Qagd), described below. We mapped only the main channels that were directly related to the Old River Bed delta, and depicted unit Qasd solely as lines, and unit Qagd as polygons. This channel mapping was simplified and modified somewhat from unpublished archeological survey reports prepared by the Desert Research Institute for the Directorate of Environmental Programs, U.S. Army DPG, and by Page (2008).

Qasd **Alluvial sand of Old River Bed delta** (lower Holocene to uppermost Pleistocene) – Sand and silt, locally with gravel, present in "exposed/eroded channels" (exposed due to deflation of mudflat surfaces) on mudflats north and west of Granite Peak, and in "buried/uneroded channels" (buried by eolian sand and silt) extending between the Old River Bed and the mudflats of the southern Great Salt Lake Desert; associated with alluvial gravel of Old River Bed delta (unit Qagd); 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).

Qagd **Alluvial gravel of Old River Bed delta** (upper Pleistocene) – Coarse sand and gravel, dominated by volcanic clasts, present in topographically inverted "gravel channels" on mudflats north of Granite Peak; these "gravel channels" have a distinct morphology—straight to curved, digitate, and with abrupt bulbous ends; associated with alluvial sand of Old River Bed delta (unit Qasd); formed by a river delta that originated as overflow from the Sevier basin along the Old River Bed during the late regressive phases of Lake Bonneville, prior to 11,000 and after 12,500 ^{14}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) – Windblown 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) – Windblown 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.

Qdg **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/IPobp, Qlg/PIPo, 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 & NMGRL (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 $^{40}Ar/^{39}Ar$ age of 7.78 ± 0.05 Ma on sanidine (UGS & NMGRL, 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; $^{40}Ar/^{39}Ar$ age of 8.20 ± 0.05 Ma on sanidine (UGS & NMGRL, 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, NMGRL, 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 Krahulec (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; $^{40}Ar/^{39}Ar$ 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; $^{40}Ar/^{39}Ar$ 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 lahars and less common tuffs; lava flows are porphyritic to aphanitic, and phenocrysts include feldspar, quartz, and biotite; lahars 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; erupted from local vents mapped as unit Tiac, described below; $^{40}Ar/^{39}Ar$ ages of 38.17 ± 0.47 and 40.66 ± 0.45 (groundmass) and 41.73 ± 0.24 Ma (hornblende) (UGS & NMGRL, 2009b); exposed thickness to 1200 feet (370 m).

Tiac **Andesitic intrusions of southern Cedar Mountains (Devils Postpile, Six Horse Pass, Tabbys Peak)** (Eocene) – Dark-gray porphyritic to aphanitic andesitic intrusions associated with local vents for extrusive calc-alkaline volcanic rocks (unit Tac); locally contains phenocrysts of feldspar, hornblende, and lesser biotite; columnar jointing of exposures common—subvertical for Devils Postpile and Tabbys Peak, and horizontal for Six Horse Pass; Devils Postpile was previously called Moronis Postpile (Maurer, 1970); $^{40}Ar/^{39}Ar$ ages of 39.55 ± 0.22 Ma (groundmass) from Devils Postpile and 40.61 ± 0.78 Ma (groundmass) from Tabbys Peak (UGS & NMGRL, 2009b); exposures to 1600 feet (490 m) across.

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 and 27.13 ± 0.05 Ma on K-feldspar (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 19.14 ± 0.08 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 Sheeprock 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 cliffy 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):

PIPofm **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.

ℙobm **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 (*Triticites, Pseudofusulinella*); 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.

ℙobw **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.

ℙobp **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 Cedar thrust faults; 4150 feet (1265m) thick at southern Cedar Mountains.

ℙowc **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.

Mmc **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.

Mgb **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.

Mh **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).

MISSISSIPPIAN TO CAMBRIAN ROCK UNITS OF NORTHERN DUGWAY RANGE, WIG MOUNTAIN, CAMELS BACK RIDGE, SIMPSON BUTTES

Mo **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.

Mw **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 slopes 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.

Mj **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.

D€d **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).

Dg **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 cliffy 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.

Dss **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.

Dsi **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.

Dsy **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.

Sl **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 cliffy 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.

Oes **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 (Floride 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.

O€u **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.

Op **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.

€n **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.

€ou **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.

€ob **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.

€l **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 ledgy interval; 900 feet (275 m) thick at Camels Back Ridge.

€tl **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 ledgy 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.

€pc **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.

€pm **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);

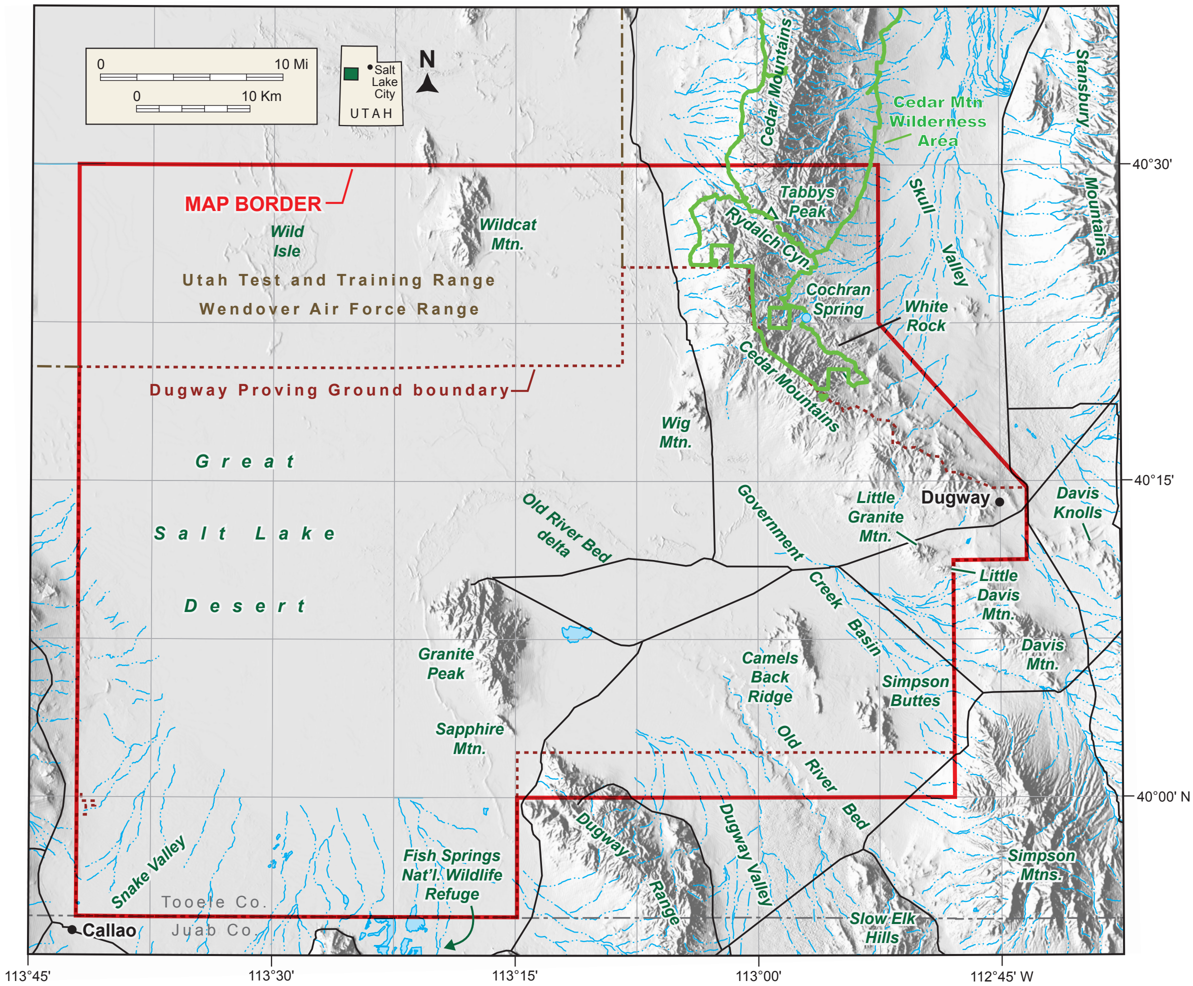

Figure 1. *Primary geographic features associated with Dugway Proving Ground and adjacent areas.*

Maurer (1970)

Time-stratigraphic unit		Cochran Spring section Feet (Meters)	Overall Feet (Meters)	Oquirrh Formation unit
PERMIAN	Wolfcampian	340+ (104+)	1935+ - 2750 (590+ - 838)	Unit 5
PENNSYLVANIAN	Virgilian	2762 (842)	2762 - 3000 (842 - 915)	Unit 4
PENNSYLVANIAN	Desmoines.-Missourian	2556 (779)	2556 - 3000+ (779 - 915+)	Unit 3
PENNSYLVANIAN	Morrowan - Atokan	715 (218)	715 - 1400 (218 - 427)	Unit 2
MISS.	? Chest.	434 (132)	434 (132)	Unit 1
Total Thickness		6807 (2075)	8402+ - 10,584+ (2562+ - 3229+)	

This Map

Oquirrh Group	Cochran Spring section Feet (Meters)	Overall Feet (Meters)	Sample Numbers	Time-stratigraphic unit		
Freeman Peak and Curry Peak Formations	2713 (827)	3500 (1065)	— D-60 — D-75 D-69	Wolfcampian	L	PERMIAN
Bingham Mine Formation	1000 (305) fault	2700 (825)	— D-76 D-68 — D-52 D-57 — D-71	Misso.-Virgil.	u	PENNSYLVANIAN
Butterfield Peaks Formation	fault 2660 (811)	4150 (1265)	— D-70	Atokan-Desmoinesian	m	PENNSYLVANIAN
West Canyon Limestone	500 (150)	500-800 (150-245)	— D-50	Morrowan	L	PENNSYLVANIAN
Total	6873 (2095)	11,000 (3355)				

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).*

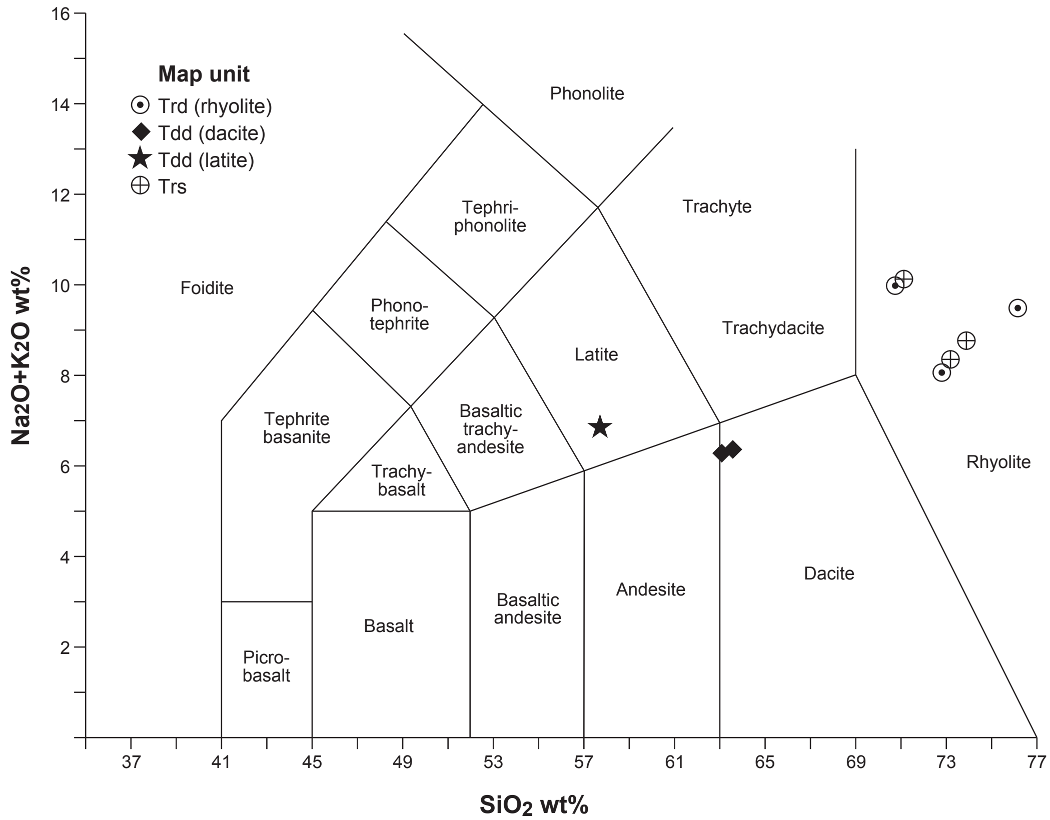

Figure 3. *Total alkali-silica classification plot (after LeBas and others, 1986) for Tertiary dikes and volcanic rocks of the Granite Peak and Sapphire Mountain area.*

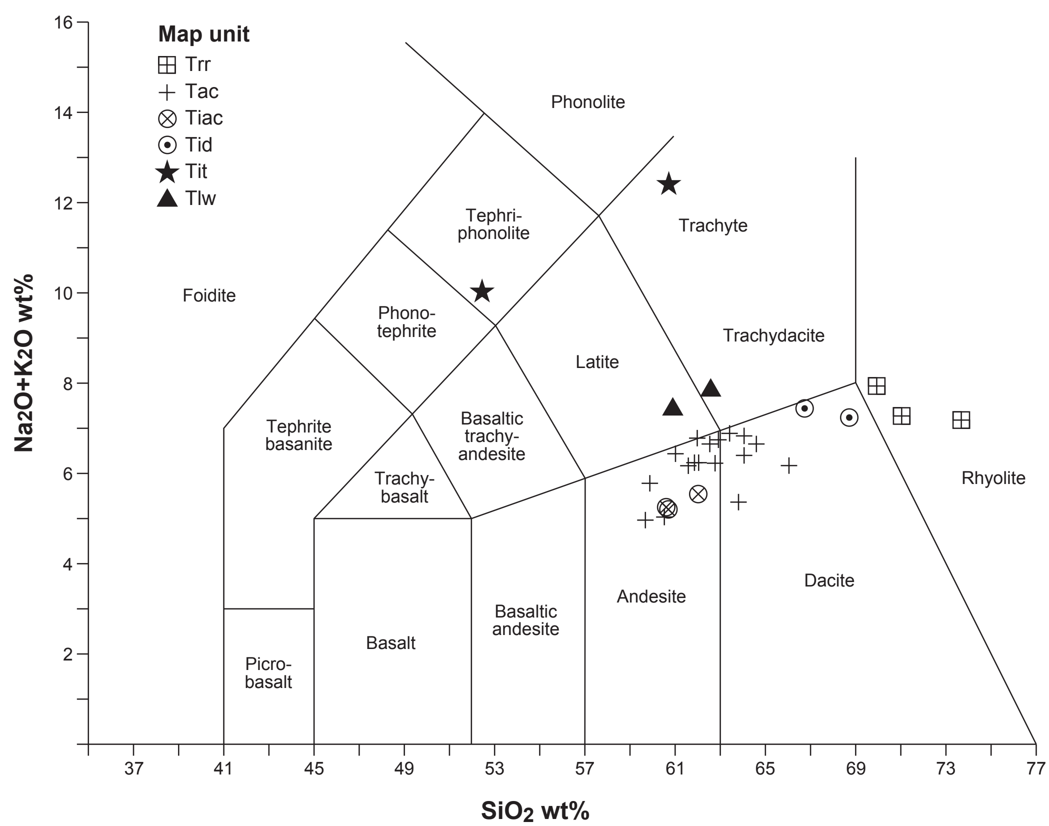

Figure 4. *Total alkali-silica plot (after LeBas and others, 1986) for extrusive and intrusive rocks from southern Cedar Mountains and northern Dugway Range.*

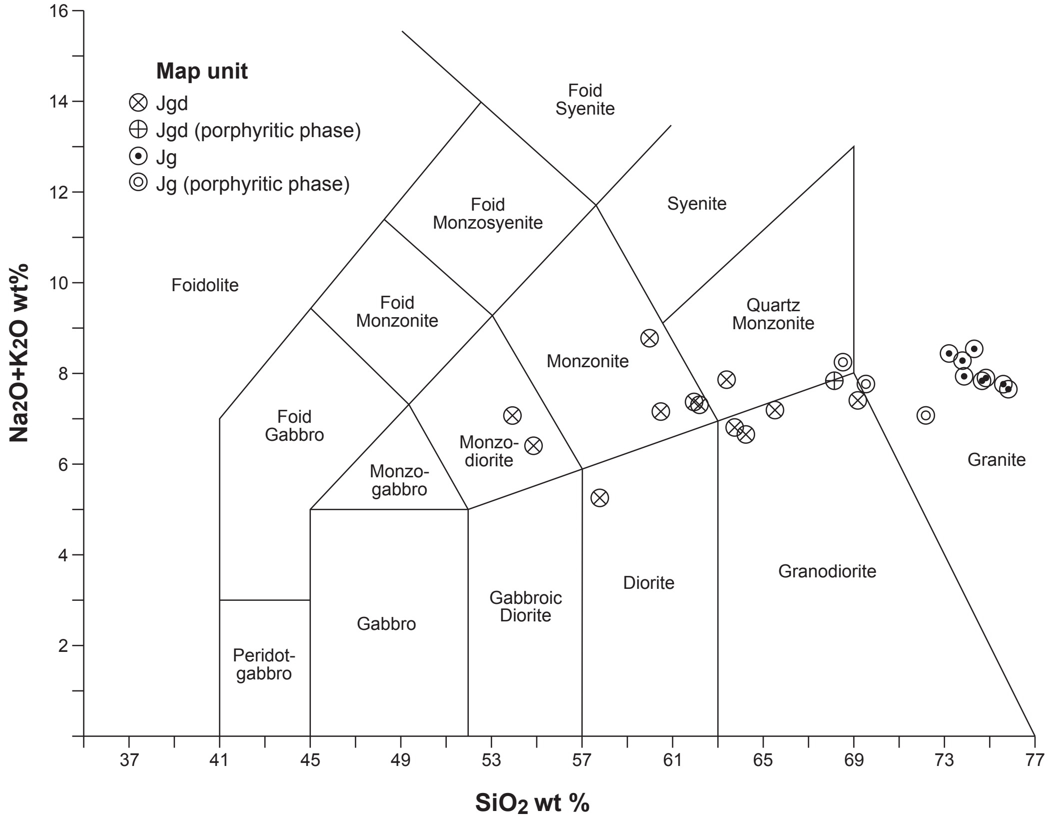

Figure 5. *Total alkali-silica plot (after Middlemost, 1994) with field names for plutonic rocks of Granite Peak.*

Table 1. *Ages and elevations of major shorelines of Lake Bonneville in Dugway Proving Ground and adjacent areas.*

Lake Cycle and Phase	Shoreline (map symbol)	Age (Rounded to 1000 years)		
		radiocarbon years B.P.	calibrated years B.P.[1]	Elevation feet (meters)
Lake Bonneville				
Transgressive Phase	Stansbury (S)	21[2]	25	4450-4480 (1357-1366)
	Bonneville (B)	15	18	5220-5262 (1591-1604)
flood				
Regressive Phase	Provo (P)	15-12.5[3, 4, 5]	18-15	4860-4880 (1482-1488)

[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).

[5] Oviatt (2015).

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

Field ID	Lab ID	Material dated	UTM E*	UTM N*	Zone	Altitude**	^{14}C age (years)	^{14}C Error	Cal min***	Cal mean	Cal max***	7.5' Quadrangle	Reference
WCM-L53-01	Beta-267663	Organic sediment	299765	4483650	12	1295-1318	8300	50	9133	9287	9440	Wildcat Mountain	Madsen and others (2015)
WCM-L54-01	Beta-206215	Organic sediment	300138	4479844	12	1295-1318	8590	80	9436	9646	9856	Wildcat Mountain	Madsen and others (2015)
WCM-L53-03	Beta-267665	Organic sediment	299765	4483650	12	1295-1318	8740	50	9556	9729	9901	Wildcat Mountain	Madsen and others (2015)
DPGNE-T21	Beta-282098	Plant material	319384	4448189	12	1295-1318	8790	40	9627	9874	10120	Dugway Proving Ground NW	Madsen and others (2015)
DPGNW-14	Beta-131594	Plant material	316823	4452807	12	1295-1318	8800	40	9665	9900	10134	Dugway Proving Ground NW	Oviatt and others (2003); Madsen and others (2015)
DPGSE-3A	Beta-131592	Plant material	324603	4442724	12	1295-1318	8850	40	9745	9952	10158	Dugway Proving Ground SE	Oviatt and others (2003); Madsen and others (2015)
WCMNW-L10-01	Beta-234836	Organic sediment	290324	4480874	12	1295-1318	8880	60	9744	9967	10190	Wildcat Mountain NW	Madsen and others (2015)
WCM-L54-06	Beta-236937	Shell (Lymnaeidae)	300138	4479844	12	1295-1318	8890	50	9785	9988	10190	Wildcat Mountain	Madsen and others (2015)
WCMNW-L2-01	Beta-179084	Organic sediment	287692	4485305	12	1295-1318	8890	60	9767	9982	10196	Wildcat Mountain NW	Madsen and others (2015)
WCM-L54-03	Beta-234838	Organic sediment	300138	4479844	12	1295-1318	8910	50	9795	9999	10203	Wildcat Mountain	Madsen and others (2015)
WCM-L54-09	Beta-237011	Shell (Physa)	300138	4479844	12	1295-1318	8940	40	9916	10060	10204	Wildcat Mountain	Madsen and others (2015)
WCM-L54-04	Beta-234839	Organic sediment	300138	4479844	12	1295-1318	8980	50	9919	10078	10237	Wildcat Mountain	Madsen and others (2015)
DPGSE-2E	Beta-137105	Plant material	328059	4437155	12	1295-1318	8990	110	9707	10053	10399	Dugway Proving Ground SE	Oviatt and others (2003); Madsen and others (2015)
GPNE-10	Beta-221778	Plant material	298712	4449251	12	1295-1318	9010	40	9948	10048	10147	Granite Peak NE	Madsen and others (2015)
DPGNW-T9	Beta-282097	Plant material	316747	4444762	12	1295-1318	9080	50	10176	10280	10383	Dugway Proving Ground NW	Madsen and others (2015)
WCM-L54-02	Beta-234837	Organic sediment	300138	4479844	12	1295-1318	9090	60	10170	10323	10476	Wildcat Mountain	Madsen and others (2015)
DPGNW-5H	Beta-124300	Plant material	312665	4456464	12	1295-1318	9170	80	10204	10377	10549	Dugway Proving Ground NW	Oviatt and others (2003); Madsen and others (2015)
GPNE-3	Beta-250000	Plant material	299004	4457321	12	1295-1318	9200	60	10238	10376	10514	Granite Peak NE	Madsen and others (2015)
WCM-L54-05	Beta-234840	Organic sediment	300138	4479844	12	1295-1318	9210	60	10240	10392	10543	Wildcat Mountain	Madsen and others (2015)
GPNE-11	Beta-250001	Plant material	300509	4454589	12	1295-1318	9250	60	10257	10413	10569	Granite Peak NE	Madsen and others (2015)
WCMNW-L51-01	Beta-267658	Organic sediment	299658	4476470	12	1295-1318	9260	50	10275	10422	10569	Wildcat Mountain NW	Madsen and others (2015)
DPGSE-3C	Beta-135253	Shell (Anodonta)	324603	4442724	12	1295-1318	9330	50	10304	10499	10694	Dugway Proving Ground SE	Oviatt and others (2003); Madsen and others (2015)
GPNE-6	Beta-234320	Plant material	301998	4454537	12	1295-1318	9330	90	10256	10501	10745	Granite Peak NE	Madsen and others (2015)
DPGNW-5I	Beta-124301	Plant material	312665	4456464	12	1295-1318	9350	100	10249	10657	11064	Dugway Proving Ground NW	Oviatt and others (2003); Madsen and others (2015)
DPGSE-1G	Beta-119850	Plant material	326196	4441641	12	1295-1318	9420	120	10297	10700	11103	Dugway Proving Ground SE	Oviatt and others (2003); Madsen and others (2015)
DPGNW-5G	Beta-124299	Plant material	312665	4456464	12	1295-1318	9450	40	10572	10814	11056	Dugway Proving Ground NW	Oviatt and others (2003); Madsen and others (2015)
GPNE-7B	Beta-238667	Plant material	299326	4453728	12	1295-1318	9450	90	10439	10769	11099	Granite Peak NE	Madsen and others (2015)
DPGNW-5F	Beta-124298	Plant material	312665	4456464	12	1295-1318	9470	90	10505	10806	11107	Dugway Proving Ground NW	Oviatt and others (2003); Madsen and others (2015)
WCMNW-L12-01	Beta-154760	Shell (unid. snails)	288434	4483326	12	1295-1318	9480	60	10572	10826	11080	Wildcat Mountain NW	Madsen and others (2015)
GPNE-5A	Beta-120190	Plant material	307710	4452944	12	1295-1318	9520	40	10680	10880	11080	Granite Peak NE	Oviatt and others (2003); Madsen and others (2015)
GPNE-7C	Beta-248473	Plant material	299326	4453729	12	1295-1318	9530	60	10607	10857	11106	Granite Peak NE	Madsen and others (2015)
WCMNW-L5-01	Beta-120199	Shell (unid. snails)	290014	4479465	12	1295-1318	9640	60	10775	10984	11193	Wildcat Mountain NW	Madsen and others (2015)
DPGNW-11C	Beta-135876	Plant material	318818	4450769	12	1295-1318	9660	50	10786	10995	11203	Dugway Proving Ground NW	Madsen and others (2015)
WCMNW-L52-01	Beta-267661	Organic sediment	299508	4473725	12	1295-1318	9680	50	10792	11005	11217	Wildcat Mountain NW	Madsen and others (2015)
DPGNW-1D	Beta-120189	Shell (Lymnaeidae)	309803	4457312	12	1295-1318	9710	60	10793	11017	11241	Dugway Proving Ground NW	Oviatt and others (2003); Madsen and others (2015)
GPNE-7A	Beta-231555	Plant material	300115	4453471	12	1295-1318	9750	40	11110	11176	11241	Granite Peak NE	Madsen and others (2015)
DPGSE-1F	Beta-121825	Plant material	326196	4441641	12	1295-1318	9770	50	11105	11182	11259	Dugway Proving Ground SE	Oviatt and others (2003); Madsen and others (2015)
WCMSW-3	Beta-248475	Plant material	294082	4468753	12	1295-1318	9800	60	11102	11218	11333	Wildcat Mountain SW	Madsen and others (2015)
WCM-L54-07	Beta-236938	Shell (Physa)	300138	4479844	12	1295-1318	9830	60	11162	11278	11393	Wildcat Mountain	Madsen and others (2015)
DPGNW-5C	Beta-119847	Plant material	312665	4456464	12	1295-1318	9850	90	10904	11302	11699	Dugway Proving Ground NW	Oviatt and others (2003); Madsen and others (2015)
WCMNW-L18-03	Beta-263307	Organic sediment	289940	4477165	12	1295-1318	9870	50	11199	11297	11395	Wildcat Mountain NW	Madsen and others (2015)
DPGSE-2B	Beta-135251	Plant material	328059	4437155	12	1295-1318	9880	40	11213	11301	11389	Dugway Proving Ground SE	Oviatt and others (2003); Madsen and others (2015)
DPGNW-12A	Beta-144237	Plant material	318687	4451198	12	1295-1318	9920	80	11201	11453	11704	Dugway Proving Ground NW	Oviatt and others (2003); Madsen and others (2015)
DPGSE-3B	Beta-135252	Shell (Anodonta)	324603	4442724	12	1295-1318	9950	90	11208	11484	11760	Dugway Proving Ground SE	Oviatt and others (2003); Madsen and others (2015)
WCM-L54-08	Beta-236939	Shell (Lymnaeidae)	300138	4479844	12	1295-1318	9960	50	11244	11432	11619	Wildcat Mountain	Madsen and others (2015)
GPNE-8A	Beta-238669	Plant material	298869	4457120	12	1295-1318	10000	40	11274	11487	11700	Granite Peak NE	Madsen and others (2015)
WCMNW-L18-01	Beta-179083	Organic sediment	289898	4477519	12	1295-1318	10000	80	11240	11526	11811	Wildcat Mountain NW	Oviatt and others (2003); Madsen and others (2015)
WCMNW-L51-02	Beta-267659	Organic sediment	299658	4476470	12	1295-1318	10030	50	11294	11528	11762	Wildcat Mountain NW	Madsen and others (2015)
DPGNW-11B	Beta-144507	Plant material	318818	4450769	12	1295-1318	10060	90	11271	11620	11969	Dugway Proving Ground NW	Madsen and others (2015)
GPNE-9	Beta-221779	Plant material	298426	4453818	12	1295-1318	10130	80	11360	11710	12060	Granite Peak NE	Madsen and others (2015)
WCMNW-L21-01	Beta-267657	Organic sediment	289898	4477519	12	1295-1318	10140	50	11411	11725	12038	Wildcat Mountain NW	Madsen and others (2015)
DPGNW-11A	Beta-144506	Plant material	318818	4450769	12	1295-1318	10170	80	11404	11762	12120	Dugway Proving Ground NW	Oviatt and others (2003); Madsen and others (2015)
DPGSE-1B	Beta-123082	Plant material	326196	4441641	12	1295-1318	10180	50	11628	11851	12074	Dugway Proving Ground SE	Oviatt and others (2003); Madsen and others (2015)
DPGNW-11E	Beta-144508	Plant material	318818	4450769	12	1295-1318	10220	60	11642	11900	12158	Dugway Proving Ground NW	Oviatt and others (2003); Madsen and others (2015)
WCMNW-L18-02	Beta-263305	Organic sediment	289832	4477461	12	1295-1318	10220	80	11506	11943	12380	Wildcat Mountain NW	Madsen and others (2015)
WCMNW-L51-03	Beta-267660	Organic sediment	299658	4476470	12	1295-1318	10250	50	11762	12062	12362	Wildcat Mountain NW	Madsen and others (2015)
GPNE-8B	Beta-238668	Plant material	298869	4457120	12	1295-1318	10290	50	11829	12105	12381	Granite Peak NE	Madsen and others (2015)
WCMNW-L18-04	Beta-263308	Organic sediment	289940	4477165	12	1295-1318	10320	60	11839	12122	12404	Wildcat Mountain NW	Madsen and others (2015)
GPNW-4A	Beta-248474	Plant material	290623	4457285	12	1295-1318	10460	60	12111	12337	12562	Granite Peak NW	Madsen and others (2015)
WCM-L53-02	Beta-267664	Organic sediment	299765	8365044	12	1295-1318	10570	40	12422	12541	12659	Wildcat Mountain	Madsen and others (2015)
WCMNW-L10-02	Beta-237010	Shell (unid. snails)	290324	4480874	12	1295-1318	10570	60	12403	12545	12687	Wildcat Mountain NW	Madsen and others (2015)
WCMSE-1A	Beta-168834	Shell (unid. snails)	302960	4466682	12	1295-1318	10590	40	12428	12555	12682	Wildcat Mountain SE	Madsen and others (2015)
GPNW-4B	Beta-249999	Shell (Gyraulus)	290623	4457285	12	1295-1318	10720	60	12571	12651	12730	Granite Peak NW	Madsen and others (2015)
DPGSE-1C	Beta-121823	Plant material	326196	4441641	12	1295-1318	10830	60	12661	12739	12816	Dugway Proving Ground SE	Oviatt and others (2003); Madsen and others (2015)
WCMNW-L29-03	Beta-263310	Shell (Helisoma)	289604	4477210	12	1295-1318	10980	60	12721	12861	13000	Wildcat Mountain NW	Madsen and others (2015)
DPGSE-1A	Beta-119848	Plant material	326196	4441641	12	1295-1318	11010	40	12742	12871	12999	Dugway Proving Ground SE	Oviatt and others (2003); Madsen and others (2015)
WCMSE-1B	Beta-251958	Plant material	302464	4466094	12	1295-1318	11020	60	12738	12886	13034	Wildcat Mountain SE	Madsen and others (2015)
WCMSE-1C	Beta-251959	Plant material	303026	4466269	12	1295-1318	11050	60	12764	12913	13061	Wildcat Mountain SE	Madsen and others (2015)
WCMNW-L29-05	Beta-154761	Shell (unid. snails)	290032	4478905	12	1295-1318	11080	70	12777	12931	13084	Wildcat Mountain NW	Madsen and others (2015)
WCMNW-L29-04	Beta-263311	Shell (Lymnaeidae)	289604	4477210	12	1295-1318	11090	60	12799	12940	13080	Wildcat Mountain NW	Madsen and others (2015)
DPGNW-11D	Beta-131590	Plant material	318818	4450769	12	1295-1318	11440	50	13153	13280	13406	Dugway Proving Ground NW	Madsen and others (2015)
WCMNW-L18-05	Beta-307887	Organic sediment	289820	4477430	12	1295-1318	11580	40	13302	13394	13486	Wildcat Mountain NW	Madsen and others (2015)
WCMNW-L52-02	Beta-267662	Organic sediment	299508	4473725	12	1295-1318	12430	50	14198	14552	14905	Wildcat Mountain NW	Madsen and others (2015)
WCMNW-L29-01	Beta-263307	Organic sediment	289760	4477180	12	1295-1318	12900	60	15189	15423	15656	Wildcat Mountain NW	Madsen and others (2015)
WCMNW-L21-02	Beta-267657	Organic sediment	289898	4477519	12	1295-1318	13550	60	16106	16335	16564	Wildcat Mountain NW	Madsen and others (2015)
DPGNW-5B	Beta-119846	Charcoal	312665	4456464	12	1295-1318	14140	140	16743	17171	17598	Dugway Proving Ground NW	Madsen and others (2015)
DPGSE-1E	Beta-121824	Charcoal	326196	4441641	12	1295-1318	25180	120	28888	29221	29553	Dugway Proving Ground SE	Madsen and others (2015)
CRROS6-BIO****	Beta-188004	shell	341450	4447620	12	~1326	30600	260	34053	34531	35009	Camels Back Ridge NE	Parsons (2004)

*UTM coordinates using NAD83 calculated from latitude/longitude measurements in Oviatt (1999), Oviatt and Madsen (2000), 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 3. *Summary of $^{40}Ar/^{39}Ar$ age analyses from Dugway Proving Ground and adjacent areas.*

Map Number	Sample Number	Map Unit	Rock Name	7.5' Quadrangle	Latitude (N) NAD27	Longitude (W) NAD27	Age + 2sd (Ma)[1]	Material Dated	Laboratory[2]	Comments	Reference
Trd1	GP081605-6c	Trd	Rhyolite	Granite Peak	40°08'3.7"	113°17'4.9"	7.78 ± 0.05	sanidine	NMGRL	single-crystal laser fusion	UGS & NMGRL, 2007
Trs1	SM071405-11	Trs	Rhyolite	Granite Peak SE	40°03'55.4"	113°16'18.5"	8.20 ± 0.05	sanidine	NMGRL	single-crystal laser fusion	UGS & NMGRL, 2007
Jg2	GP102605-1	Jg	Granite	Granite Peak	40°09'58.2"	113°15'56.2"	13.69 ± 0.12	muscovite	NMGRL	step heating, plateau age	UGS & NMGRL, 2007
Jgd1	GP102605-3	Jgd	Monzonite	Granite Peak SE	40°05'16.2"	113°16'45.9"	15.97 ± 0.04	biotite	NMGRL	step heating, plateau age	UGS & NMGRL, 2007
Jg2	GP102605-1	Jg	Granite	Granite Peak	40°09'58.2"	113°15'56.2"	19.14 ± 0.08	K-feldspar	NMGRL	integrated age	UGS & NMGRL, 2009a
Jgd1	GP102605-3	Jgd	Monzonite	Granite Peak SE	40°05'16.2"	113°16'45.9"	27.13 ± 0.05	K-feldspar	NMGRL	integrated age	UGS & NMGRL, 2009a
Tac3	D-17	Tac	Andesite	Tabbys Peak SW	40°18'39.6"	112°56'36.3"	38.17± 0.47	groundmass concentrate	NMGRL	furnace step-heat	UGS & NMGRL, 2009b
Tid2	D-4	Tid	Dacite	Tabbys Peak SW	40°19'17.9"	112°54'01.1"	38.69 ± 0.10	sanidine	NMGRL	laser total fusion	UGS & NMGRL, 2009b
Trr2	D-48	Trr	Rhyolite	Tabbys Peak	40°25'10.8"	112°58'38.3"	39.18 ± 0.06	sanidine	NIGL	laser total fusion	UGS & NIGL, 2012
Tiac1	D-6	Tiac	Andesite	Wig Mountain	40°20'03.3"	113°01'42.2"	39.55 ± 0.22	groundmass concentrate	NMGRL	furnace step-heat	UGS & NMGRL, 2009b
Tid1	FM083105-1	Tid	Dacite	Camels Back Ridge NE	40°12'08"	112°50'16"	39.56 ± 0.10	biotite	NMGRL	integrated age	UGS & NMGRL, 2009a
Tiac2	D-40	Tiac	Andesite	Tabbys Peak	40°27'47.7"	112°59'13.8"	40.61 ± 0.78	groundmass concentrate	NMGRL	furnace step-heat	UGS & NMGRL, 2009b
Tac5	D-42	Tac	Andesite	Wig Mountain NE	40°26'55.3"	113°01'57.8"	40.66 ± 0.45	groundmass concentrate	NMGRL	furnace step-heat	UGS & NMGRL, 2009b
Tid1	FM083105-1	Tid	Dacite	Camels Back Ridge NE	40°12'08"	112°50'16"	40.95 ± 0.32	hornblende	NMGRL	step-heating, plateau age	UGS & NMGRL, 2009a
Tac1	D-7	Tac	Andesite	Wig Mountain	40°21'37.8"	113°00'04.0"	41.73 ± 0.24	hornblende	NMGRL	furnace step-heat	UGS & NMGRL, 2009b

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.

2. NIGL is the Nevada Isotope Geochronology Laboratory, Las Vegas, Nevada

NMGRL reported unreliable age data for samples D-2, D-15, D-25, D-47, as samples were too felsic for good groundmass concentrate analysis and/or were unable to separate any other datable mineral phases.

See UGS & NMGRL (2007, 2009a, 2009b), UGS & NIGL (2012) for complete presentation of data.

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

Map Number	Sample Number	Map Unit	Rock Name	7.5' Quadrangle	Latitude (N) NAD27	Longitude (W) NAD27	Weighted Average $^{238}U/^{206}Pb$ Age Mean (Ma)
Jgd1	GP102605-3	Jgd	Granodiorite	Granite Peak	40°05'16.2"	113°16'45.9"	149.8 ± 1.3
Jg1	GP081605-9	Jg	Granite porphyry	Granite Peak	40°07'40"	113°18'23"	148.8 ± 1.3

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.*

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

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).

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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.

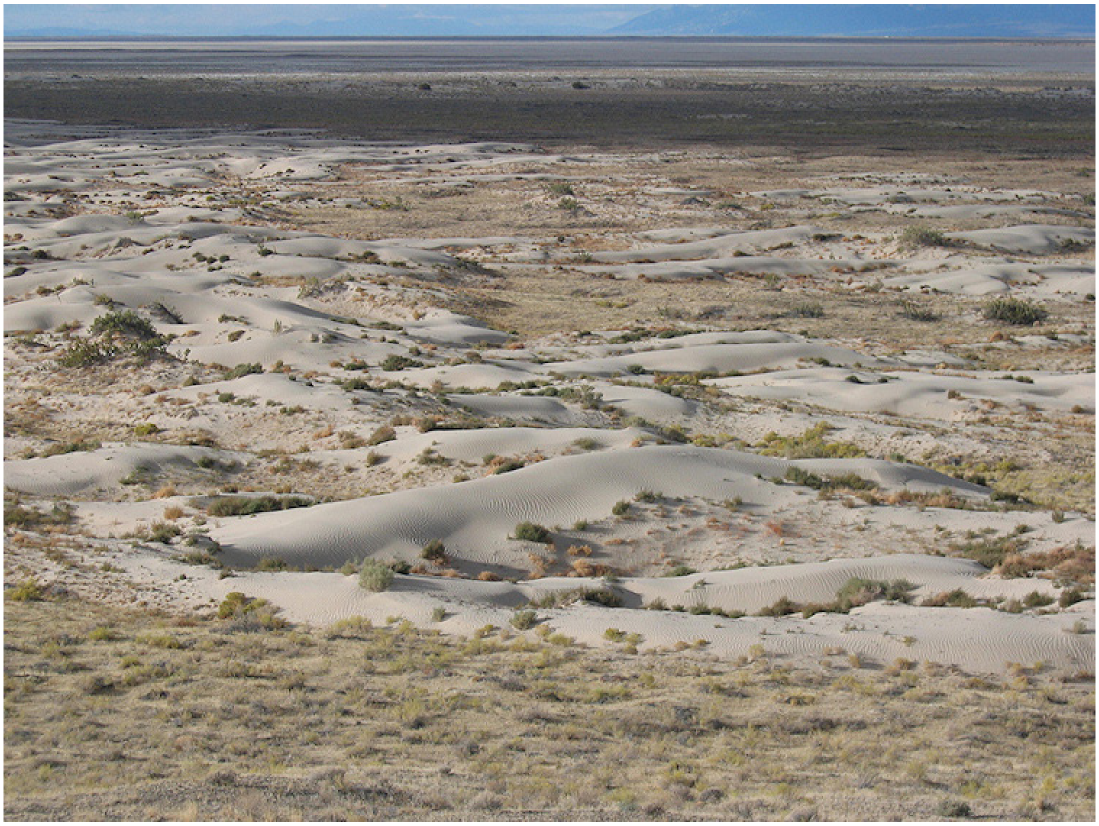
View west of the southern Cedar Mountains, mudflats, and Granite Peak.

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.