Preliminary Geologic Map of the Cedarville 30’ × 60’ Quadrangle, Modoc County, California

Scale 1:100,000

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Introduction

Geologic mapping in the Cedarville 30’ × 60’ quadrangle has been minimal relative to most other areas in California. The regional geologic map, compiled by Gay and Aune (1958), sets out the essential geologic framework. It was published in connection with compilation of the geologic map of California at scale 1:250,000 by the California Geological Survey. Regional groundwater investigations by the California Department of Water Resources (1963) provided additional mapping in select basins in the general region. The first geologic synthesis of the Modoc Plateau and adjacent Cascades in northeastern California, which includes the Cedarville area, was written by G.A. Macdonald (1966). Subsequent to these pioneering reconnaissance efforts, the Cedarville area has been systematically mapped in recent years at 1:62,500 with a few local maps at 1:24,000 (Figure 1). Support has come primarily from the California Geological Survey, the U.S. Forest Service, the U.S. Geological Survey, and Stanford University. This Cedarville 100k geologic map integrates these maps at 1:100,000 scale and is one of many such maps in the revised editions of the Geologic Map of California.

Compilation

The Preliminary Geologic Map of the Cedarville 30’ × 60’ Quadrangle was largely compiled from original, unpublished mapping by Thomas Grose, completed during field seasons between 2003 and 2009. Grose and Egger completed additional independent and collaborative mapping in the Warner Range at a scale of 1:24,000 and 1:48,000 during field seasons between 2004 and 2010, utilizing and enhancing mapping by Martz (1970) and Duffield et al. (1976). In this time period, Anne Egger also completed detailed geologic mapping in the hills north of the Hays Canyon Range and along the western range front of the Hays Canyon Range, completed reconnaissance geologic mapping of surrounding areas, compiled data from exploratory drill holes and well logs in the Surprise Valley, and conducted numerous geochemical and geochronological analyses on rocks from this region. The geologic investigations and mapping conducted by Thomas Grose and Anne Egger were enriched by other more focused investigations. Fault scarps within the surprise valley were mapped first by Hedel (1980; 1981; 1984) and were later subjected to greater scrutiny by Bryant (1990). More recently, Egger et al. (2010) utilized seismic reflection profiling from Lerch et al. (2010) to identify numerous intrabasin faults within the Surprise Valley. Additional geochronological and geochemical analyses of predominantly late Miocene and Pliocene lava flows were also completed by Carmichael et al. (2006).

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Figure 1. Index map showing the 15' quadrangles within the Alturas 30' × 60' quadrangle and sources used for the compilation. See References Cited.
Physiography

The Cedarville 30’ × 60’ quadrangle in northeastern California is underlain predominantly by volcanic rocks and spans two major geologic provinces. In the eastern part of the quadrangle, the Warner Range and Surprise Valley mark the western margin of the Basin and Range extensional province. West of the Warner Range lie Goose Lake Valley and the Devils Garden Plateau, both part of the relatively unextended Modoc Plateau. These four second-order geologic provinces are delineated herein on the basis of lithology, structure, and physiography (Figure 2). They are summarized below, as they occur from east to west across the map.

Surprise Valley

The northern half of the Surprise Valley graben occurs in the eastern one-quarter of the Cedarville 30’ × 60’ map area. The valley margin is marked by a spectacular, active, normal fault scarp – the trace of the Surprise Valley fault (Hedel, 1984; Personius et al., 2009; Egger, 2014). The flat valley floor is about 4,500 feet (about 1,370 meters) in elevation and is the result of deposition of sediments eroded from the Warner Range since uplift began along the Surprise Valley fault ca. 12 Ma. During the Pleistocene, the valley hosted Lake Surprise, a pluvial lake that reached a maximum elevation of 1567 m (176 m above the present-day playa) at 15.19 ± 0.18 ka (Ibarra et al., 2014). Currently, the valley is occupied by three ephemeral lakes, of which two (the upper and middle lakes) are located in the Cedarville quadrangle. Along the western margin of Surprise Valley, modern alluvial fans from the steep front of the Warner Range grade eastward into lake sediments. Thermal springs in various stages of activity are present throughout the valley, primarily at locations of fault intersections and interactions (Egger et al., 2014). To the east, fine alluvium and eolian sand sheets lap up on subhorizontal, moderately faulted basalt flows of the Miocene-Pliocene Vya Group (Carmichael et al., 2006), which occur as part of regional flow sequences widespread to the east and north in Nevada and Oregon.

Warner Range

The most significant physiographic feature in the Cedarville map area is the Warner Range (Figure 2), formed by approximately 8 km of dip-slip along the Surprise Valley fault on the east side of the range and flexure on the west (Egger and Miller, 2011). Motion across the southern ~¾ of the range-bounding Surprise Valley fault produces a highly asymmetric east-west topographic profile with a steep eastern flank and gentle western slope. In the northern part of the Range, however, offset along the Surprise Valley fault dies out, the topographic asymmetry is reversed, and the west side, displays abrupt relief along a west-dipping normal fault. The reversal of topographic and structural asymmetry coincides spatially with the Fandango Valley, a northwest-southeast trending accommodation fault zone.

The oldest rocks in the quadrangle, late Eocene in age, are exposed at the base of the eastern flank of the Warner Range. Among several peaks above 8,000 feet (about 2,400 meters), the highest elevation in the range within the Cedarville Quadrangle is Mount Bidwell at 8,297 feet (2,529 meters).

Goose Lake Valley

The southern half of Goose Lake Valley lies within the Cedarville map extent, between the Devils Garden Plateau and the Warner Range. It is approximately 25 mi. (~40 km) in north-south dimension, and it tapers in width from about 10 mi. (~16 km.) southward to zero where the Devils Garden Plateau is in contact with the Warner Range. The valley floor is flat at about 4,700 ft. (~1,430 m.) elevation. Goose Lake is shallow and intermittently dry. Quaternary lake clays are ubiquitous, and alluvium is concentrated along the eastern and southern margins of the basin. Pre-Quaternary rocks consist of horizontal layers of
Figure 2. Map of the Cedarville 30' x 60' Quadrangle, showing geographic features and second-order geologic provinces (outlined in green).
tuff and volcaniclastic rocks of the Alturas Formation (Grose, 2009), over which thin layers of Devils Garden Basalt may occur in down-faulted sections buried by Quaternary sediments of the Valley (Grose, 2005a).

The western margin of Goose Lake Valley is a faulted and eroded escarpment of basalt flows that is about 100 ft (about 30 m) high at its southernmost end and 1,000 ft (about 300 m) at the northern extent of the quadrangle. The eastern margin, in contrast, is marked by a major normal fault zone that bounds the Warner Range horst. At the north end, this range front is abrupt, with relief of 3,000 ft (about 900 m), with no geomorphic indications of Quaternary activity. Southward, the fault zone becomes less well defined with less relief. It appears to die out at Fandango Valley.

The southern end of Goose Lake Valley is a source area of the North Fork of the Pit River. Here the valley fill consists of alluvium rich in obsidian pebbles derived entirely from the Warner Range, and lake and shoreline deposits that record changing levels of Goose Lake. These sediments 1) create and control the location of a natural dam that impounds Goose Lake, and 2) produce headward erosion by gullies at the headwaters of the Pit River drainage system. In modern times, the source of the Pit River is located in the southeastern quadrant of T45N, R19E located within the Davis Creek 15’ quadrangle extent (Grose, 2005a). The Quaternary deposits in this area of the natural dam of Goose Lake are believed to be quite thin, as is evident from several nearby outcrops of barely eroded resistant basalt flows which sustain the valley floor.

**Devils Garden Plateau**

The Devils Garden Plateau covers the western half of the map area, and its southern margin coincides roughly with the southern margin of the map. Elevations vary less than 600 ft (about 200 m) from 5,600 ft (about 1,700 m) in the east to 5,000 ft (about 1,500 m) in the west. This relatively level surface is a constructional basaltic field with numerous thin, intertonguing lava flows locally derived from numerous small and mid-sized shield volcanoes. The topographic relief of the modern surface as well as the interflow surfaces is remarkably low, which indicates uniformly high fluidity of the lavas, homogeneity of flow type, and lack of erosion between flow emplacements. The modern ground surface, however, is interrupted by the ubiquitous occurrence of several hundred north- to northwest-trending linear ridges which are rarely more than 100 ft (about 30 m) high. These ridges are the result of late Pliocene and Quaternary normal faulting. The surface drainage is barely integrated, and consists of shallow streams connecting ephemeral shallow basins and reservoirs. The streams are rarely incised more than 70 ft (about 20 m). The surface drainage divide between the Klamath and Pit rivers trends inconspicuously in a northeast-southwest zone across the Plateau from the north-central part of the map to the southwest corner of the map.

The eastern margin of the Devils Garden Plateau is marked by an eroded and faulted escarpment that exposes pyroclastic rocks underlyng the thin basalt flows. Quaternary alluvium and lake sediments of Goose Lake Valley occur to the east. In the southeast corner of the Plateau, the strata of the Plateau lap up on an irregular surface cut into older volcanic rocks of the Warner Range (Grose, 2005a). Here the Alturas Formation appears to be missing between the basalts and the much older volcanic rocks due to both faulting and erosion. The western and northern margins of the Plateau lie some distance outside the boundary of the Cedarville 100K map (McKee et al., 1983).

In contrast to surrounding areas, the Devils Garden in the Cedarville 100K map region exhibits a uniformly monotonous topography that belies the geologic complexity and variability of the many eruptive centers, flow sequences, and faults “hidden” in the terrain.
Formations

Bedrock exposed in the Cedarville 100K map area are Neogene volcanic rocks that include 1) lava flows, domes, and plugs, 2) pyroclastic rocks, welded and non-welded, and 3) volcanlastic sedimentary rocks. Surficial formations include alluvium, lake beds, landslides, and sand sheets. All of the formations in the map area are layered and most are locally derived from a wide variety of eruptive centers such as shield and stratovolcanoes, and possibly calderas.

There is a great difference in the lithologies, structures, and ages of the formations in the western half of the Cedarville 100K map area, which is dominated by the Devils Garden Plateau, relative to the formations in the eastern half, which includes the Warner Range and Surprise Valley. The Devils Garden is a distinct volcanic province composed of two major lithologies: 1) an underlying thick and uniform silicic tuff of regional extent, the Miocene Alturas Formation, and 2) the overlying, very thin, interfingering flows of the Late Miocene – Pliocene Devils Garden Basalt that are sourced locally from many small volcanoes and several large shields within the Devils Garden Plateau.

The Alturas Formation is exposed in several erosional windows in the flows at widely spaced locations on the Plateau as well as along the margins of the Plateau. The tuff is white and fine-grained and mostly massive. Along the northern margin of the Plateau, the Alturas Formation tuff includes interbedded silicic and intermediate welded layers. The contact with the overlying basalt section is generally smooth and bedding-parallel, indicating a low-relief surface over which the basalt flowed.

The Devils Garden Basalt is an olivine tholeiite, high in aluminum and low in potassium (McKee et al., 1983; Carmichael et al., 2006). Its distinctive texture varies from diktytaxitic to dense and aphyric to sparsely microporphyrctic with olivine and calcic plagioclase. Flows display dense cores and vesicular flow breccia margins. Individual flows are generally less than 16 ft (about 5 m) thick. The basalt section in total varies from less than 100 ft (about 30 m) to over 300 ft (about 90 m), and it thickens toward local shield volcanoes. In the vicinity of vents, dikes, and plugs, the basalt is reddened with oxidation and is scoriaceous, glassy, and more variable in texture, structure, and thickness. Regionally, the flow-on-flow sequence of the Plateau becomes thicker and less uniformly bedded to the north. An outstanding characteristic of the Devils Garden Basalt is that the numerous eruptive sources of different types and sizes exert little influence on the topography. This indicates that the terrain, as well as the viscosity and lithology of eruptive products, were relatively uniform throughout the Plateau region during their several million years of accumulation in the Late Miocene and Pliocene.

The geologic formations exposed in the Warner Range are older and more variable than those described above in the Devils Garden. More than 14,750 ft (about 4,500 m) of complexly layered volcanic, volcanlastic, and sedimentary rocks of latest Eocene to mid-Miocene age are well exposed in the simple west-tilted section that makes up the Warner Range (Duffield and McKee, 1986; Duffield et al., 1976; Egger and Miller, 2011). The isolated exposure of these older rock units renders it critical in paleogeographic interpretations in the northwest Basin and Range province (Egger et al., 2009). The base of the section consists of Eocene basalt flows and breccias. They are overlain by more than 10,000 ft. (about 3,000 m) of lava flows, pyroclastic rocks, and sedimentary rocks that have been divided into several local formations (Egger et al., 2009). This section was previously assigned to the Lower Cedarville Formation of Russell (1928). Within this complex section, the selectively well-studied Steamboat Formation of sandstone and conglomerate (Early Oligocene) has yielded a few isolated boulders of granitic and metamorphic basement-derived rocks dated radiometrically to be mainly Early Cretaceous and Middle Jurassic (Egger et al., 2009). The section in the Warner Range also contains several andesitic plugs and stratovolcanoes as well as silicic domes, some of which include massive obsidian and associated lenticular welded tuff layers. In the range west of the village of Cedarville, a thick andesitic tuff breccia (Cedar Pass Complex), dated 24-27 Ma (mid-Oligocene), represents a very large pyroclastic source area (Colgan et al., 2011; Egger and Miller, 2011; Grose, 2005a). In the more northerly part of the range, in the Sugar Hill and High Grade districts (Keats, 1985), most of the rocks are silicic
and intermediate complexes of layered sequences with intrusive domes and plugs, ranging from 9 to 14 Ma (mid to late Miocene). These large areas and volumes of silicic pyroclastic rocks are interpreted on the basis of lithologic correlations and field relationships to indicate caldera sources of the extensive Alturas Formation that occurs to the west and southwest (Grose, 2009).

The geologic formations east of the Warner Range in the Surprise Valley consist of Miocene and Pliocene basalt flows and Quaternary sediments. The basalt is assigned to the Vya Group which is dated 4 to 8 Ma (Carmichael et al., 2006). It is lithologically and chronologically correlative with the Devils Garden Basalt, though it probably was not continuous with it across the area of the Warner Range (Egger and Miller, 2011). Underlying the basalt are limited exposures of silicic tuffs of Oligocene age. The graben of Surprise Valley is filled with at least 5,000 ft (about 1,525 m) of alluvium and playa lake sand and clay (Woods, 1974; Egger et al., 2010). Surficial formations consist of unconsolidated alluvium, lake beds, and windblown sand.

**Structure**

Major tectonic domains correspond to the second order geologic provinces within the map area.

The Devils Garden Plateau is a region of horizontal strata with little structural relief. Numerous north-south to northwest-southeast – trending, high-angle normal faults with minor displacement (less than 100 ft, 30 m) slice through the Plateau. The faults are pervasive, spaced 0.5–1.5 miles apart, with lengths of 1–6 miles (2-10 km). Commonly the faults are associated with fractures, some of which are open (rifts), that tend to form a conjugate pattern with the axis of greatest tensional stress oriented east-west. These fractures are clearly visible on air photos through linear alignment of trees. In the field, however, the fractures are hardly recognizable because opposite sides of the fracture are rarely offset and the fracture zones are filled in with soil and vegetation that are a product of increased weathering and surface water penetration. This expression of relatively uniform and active jointing in close association with Pliocene and Quaternary faulting in flat-lying, resistant lava flows indicates an active regional tensional stress field that covers about 1,000 square mi. (about 2,600 square km). This stress field continues to the south in the Alturas Basin where it is not readily detectable in the easily eroded tuff of the Alturas Formation.

The faults appear to be spatially and genetically unrelated to numerous eruptive centers that occur throughout the Plateau. One notable exception is a northwest-southeast – trending fault 10 mi (about 16 km) long that localizes at least 12 basaltic cinder cones and plugs that occurs in the central part of the South Mountain 15’ quadrangle (Grose, 2004a).

Goose Lake Valley is a graben east of the Devils Garden Plateau. The contact between the two provinces is a normal fault zone that displaces the Plateau lavas downward likely a few hundred meters, although the subsurface structure and stratigraphy below the Quaternary sediments of the valley are unknown. The east side of the is delineated by a major Quaternary normal fault that bounds the Warner Range and increases in vertical displacement to over 3,000 ft (about 915 m) at the Oregon state line. The range-front fault north of the intersection with the NW-trending Fandango fault zone shows no geomorphic evidence of geologically recent activity, though several hot springs line the range front. The faults on both west and east margins of Goose Lake Valley gradually die out toward the south end of the valley.

The most prominent structure in the Cedarville 100K map region is the north-south – trending horst of the Warner Range. The east side is defined by the Surprise Valley fault. This fault is characterized by fresh scarps in modern alluvium, thermal springs, and many other features typical of Late Quaternary activity (Hedel, 1984) on normal faults along range margins in the Basin and Range province. The fault is interpreted to dip east somewhat less than 40 degrees, and have dip-slip displacement of 5 mi (about 8 km) with a vertical component of dip-slip (throw) of about 3 mi (about 4.5 km) (Lerch et al., 2008; Egger and Miller, 2011). The displacement decreases northward and splays into
northwest- and northeast- trending segments, and the topographic relief decreases and becomes more diffuse. Farther south the west flank is much less faulted and is mainly a homoclinal with low dip into the Alturas Basin (Grose, 2009). Structures within the Warner Range are truncated by marginal faults. Those structures are 1) homoclinal with west dip less than 30 degrees and declining to the west in the section south of the Fandango fault and 2) homoclinal with low east dip to horizontal north of the Fandango fault. The reversal of dip of stratigraphy within the Range is accommodated along the Fandango fault. Also, the zone of active mountain-margin faulting transfers from the east side to the west side along the Fandango fault zone.

East of the great Warner Range horst is the Surprise Valley, a deep half-graben within the extent of this quad. The Surprise Valley fault marks the western margin of the Valley. In contrast, the eastern margin, though parallel to the western margin, has topographic relief of only a few hundred meters between Quaternary sediments and sub-horizontal lava flows. There are several buried normal faults (Athens et al., 2015; Egger et al., 2010); a few hot springs suggest active faulting, but fault scarps and other tectonic geomorphic features so well displayed along the west side of the Valley are lacking.

In summary, all of the tectonic structures within the Cedarville 30’ × 60’ quadrangle indicate that the area has been extending generally east-west or east-northeast—west-southwest during the Neogene, overprinting the Oligocene to Miocene Cascade volcanic arc. The region is still tectonically active.
Description of Map Units

[Approximate stratigraphic relationships]

Quaternary Sedimentary Deposits

af  **Artificial fill**

Qa  **Alluvium** (Holocene)—Sand, gravel, and silt. Locally rich in obsidian pebbles and granules derived from erosion of abundant obsidian domes and beds. Deposited locally along streams and extensively along the flanks of the Warner Range and across bajadas in Surprise Valley. Occurs on the Devils Garden Plateau in rare and thin deposits, usually less than several meters thick. In contrast, alluvial thickness in the Surprise Valley graben may exceed several hundred meters. Qa grades laterally into, and is in facies relationship with, several other Quaternary units, such as Qc, Qt, Qf, Qls, and lake deposits.

Qc  **Colluvium** (Holocene)—Gravel, sand, silt. Deposited by slope wash and creep locally at base of mountains and ridges in Surprise Valley and rather extensively on the floor of Fandango Valley within the Warner Range. Commonly grades into alluvium.

Ql  **Lake deposits** (Holocene)—Silt, clay, and sand of modern lakes, mainly Goose Lake and ephemeral lakes in Surprise Valley. Many small ephemeral lakes occur on the Devils Garden Plateau that have thin, modern deposits. May interstratify with or grade into alluvial deposits.

Qe  **Sand, dunes and sheets** (Holocene)—Low amplitude. Mostly arrested. Localized.

Qhs  **Hot spring deposits** (Holocene)—Hot spring deposits, mostly travertine. Interbeds with lake deposits of ancient Lake Surprise. Occurs at one hot spring cluster about 9.7 km (6 mi) N30E of Cedarville.

Qf  **Alluvial fan** (Holocene)—Boulder, gravel, and sand deposits in fan shape. Originates where canyons abruptly change to lower gradient valley floor surfaces, usually at traces of fault scarps. Best developed along active margins of the Warner Range. Grades into Qa, Qc, and various lake beds.

Qls  **Landslide deposits** (Holocene to Pleistocene)—Usually associated with seismic shaking of unstable and steep fault scarps in the Warner Range and slope failure in soft pyroclastic rocks. An uncommonly large mass (13 km² or 5 mi²) occurs on the active east slope of Mount Bidwell along the northern continuation of the Surprise Valley fault. Three distinct slump masses comprise a slide complex east of Fandango Pass. In the eastern part of Surprise Valley, slides occur where fault scarp s of massive basalt flows are underlain by incompetent tuffs.

Qoa  **Older alluvium** (Pleistocene?)—Gravel and sand. Somewhat older and high-level, dissected by modern Sand Creek, and preserved at one locality near southeast corner of the map.

Qol  **Older lake deposits** (Holocene to Pleistocene)—Lake gravel, sand and silt of lake high stands. May include thin local interbeds of alluvium or tuffaceous sediments.

Qof  **Older fan deposits** (Pleistocene?)—Alluvial gravel and sand preserved locally in extensive fan deposits.

Qpd  **Delta deposits in ancient Lake Surprise** (Late Pleistocene)—Gravel and sand. Remnant of large delta of Late Pleistocene Lake Surprise occurring at north end of Surprise Valley.
Quaternary Volcanic Rocks

Qbwb  **Basalt of Badger Well** (Pleistocene)—Olivine tholeiitic basalt. Dark gray to black, variously dikttytaxitic to aphanitic and dense, sparsely microporphyritic with olivine <2 mm. Widespread horizontal flows sourced from a small shield volcano located 1.6 km (1.0 mi) west of the west-central margin of the map; dated at 0.98 ± 0.16 Ma (K-Ar) (Grose and Travis, 2006).

Tertiary Bedrock: Devils Garden Plateau

(Listed based on source and/or field association, and in general from youngest to oldest, though facies relationships are common.)

Tdgb  **Devils Garden Basalt** (Late Pliocene to Miocene)—Lava flows of high-alumina, low potassium olivine tholeiitic basalt. Light gray to black, variously dikttytaxitic to aphanitic, dense to vesicular, sparsely microporphyritic with olivine <2 mm and plagioclase. Occurs as widespread horizontal flows concordantly over most of the Devils Garden, overlying the pyroclastic and volcaniclastic rocks of the Alturas Formation. Flows are derived from many large multiple-vent shield volcanoes of low relief, small single-vent volcanoes, and cinder cones. Ranging in age from 8 to 3 Ma, but mostly 4-3 Ma (Carmichael et al., 2006), and generally becoming younger westward and southward. A major reference is McKee et al. (1983). Overlain in places by younger basalt flows derived from the Medicine Lake volcano complex to the west. ⁴⁰Ar/³⁹Ar age at Loc. 27 is 4.31 ± 0.18 (Carmichael et al., 2006). K-Ar age at Loc. 6 is 9.5 ± 2.0 Ma (McKee et al., 1983).

Tbi  **Basaltic plugs and dikes** (Late Pliocene and (?) Miocene)—Black, aphanitic basalt; dense to vesicular with local cinders. Occurs as plugs, dikes, and cinder vents in a 10 km² (4 mi²) area just north of Alturas. Probably part of a larger intrusive-extrusive cluster which includes five medium-sized volcanoes, occurring to the northwest (Tmrb).

Tmrb  **Basalt of Mahogany Ridge** (Late Pliocene or (?) Miocene)—Basalt lava flows. Dark gray to black, sparsely microporphryritic with olivine and plagioclase, mostly aphanitic and dense, locally slightly dikttytaxitic. Comprise five low, small- to medium-sized shield volcanoes that erupted through Ta and that may have sourced Tdgb or largely pre-dated Tdgb (as a kipuka).

Trmb  **Basalt of Rail Mountain** (Pliocene and (or) late Miocene)—Basalt lava flows. Dark gray to black, dikttytaxitic, moderately microporphryritic with olivine and plagioclase. May represent a remnant of a large shield that collapsed in summit vent area. A kipuka surrounded by Tdgb flows.

Thbb  **Basalt of Hidden Basin Volcano** (Pliocene and (or) late Miocene)—Basalt lava flows. Similar to Trmb of Rail Mountain about 8 km (5 mi) to the south. This volcano preserves a summit pit crater with reddened agglutinate, scoria and cinders, and radial dips outward.

Tmwbh  **Basalt of Mowitz Butte volcanoes** (Pliocene and (or) late Miocene)—Basalt lava flows. Petrographically similar to basalts of Rail Mountain and Hidden Basin volcano in line to the south. The two Mowitz Butte volcanoes are large cones atop the larger Mowitz Butte shield volcano.

Tmsb  **Basalt of Mowitz shield volcano** (Pliocene and (or) late Miocene)—Basalt lava flows. Similar to Tmhb, Thbb, and Trmb. The shield covers 64 km² (25 mi²) and is at the north end of a line
of small basaltic shields that trend about N10W. Younger basalt flows of Tdgb and Qbwb lap up on the margin of the Mowitz shield.

**Tbsb** Basalt of Bird Spring (Pliocene and (or) late Miocene)—Basalt lava flows. Dark gray to black, variously dikttytaxitic to aphanitic, dense to vesicular, microporphryritic with olivine and plagioclase. Appears to occur as flows among a large cluster (termed the Blue Mountain Group) of small-to-large shields and cones of units Tmbb, Trbb, Ttrb, and Tcub and probably sourced from them. Probably interbeds with and overlies Tdgb.

**Trcb** Basalt of Rock Creek (Pliocene and (or) late Miocene)—Basalt lava flows. Lithologically similar and probably equivalent to Tdgb. Appears to be ponded by surrounding higher elevations of volcanoes and older (?)s flows of Tdwb on the south.

**Ttrb** Basalt of Timbered Ridge (Pliocene and (or) late Miocene)—Basalt lava flows. Olivine basalt similar to Tbrb and Tmbb. Erupted from two coalescing medium-sized shields in the Blue Mountain Group.

**Tbrb** Basalt of Bird Spring Ridge (Pliocene and (or) late Miocene) —Basalt lava flows. Olivine basalt similar to other basalts in the Blue Mountain Group. Occurs in a medium-sized, moderately-eroded shield.

**Tbmb** Basalt of Blue Mountain (Pliocene and (or) late Miocene)—Basalt lava flows. Dark gray to black, aphanitic to moderately dikttytaxitic, sparsely mafic andesite flows. Flow-on-flow sequence comprises highest shield in the region. Moderately eroded. 5.4 ± 0.9 (K-Ar) at Location 3 (Steele Swamp).

**Tnmb** Basalt of North Mountain (Pliocene and (or) late Miocene?)—Basalt lava flows; similar in composition to basalt of other volcanoes on the Devils Garden. North Mountain is a low-relief circular shield covering about 13 km² (5 mi²).

**Twrb** Basalt of Whittemore Ridge (Pliocene and (or) late Miocene)—Basalt lava flows. Petrographically similar to basalts of nearby volcanoes. Derived from Whittemore Ridge, an elongate north-south shield covering about 10.4 km² (4 mi²). Dated at 5.9 ± 0.7 Ma by the K-Ar method (McKee et al., 1983).

**Ttmb** Basalt of Timbered Mountain (Pliocene and (or) late Miocene)—Basalt lava flows. Dark gray to black, aphanitic to slightly dikttytaxitic, dense to variously vesicular, locally reddened in vent areas, but overall remarkably uniform lithologically. Derived from more than thirteen cinder and flow vents that are roughly aligned north-northeasterly. Covering about 83 km² (32 mi²), Timbered Mountain is the largest shield within the California portion of the Devils Garden. On the basis of erosion, its age should be comparable to adjacent shields, i.e. 5.5-6.0 Ma.

**Tcmb** Basalt of Crowder Mountain (Pliocene and (or) late Miocene)—Basalt lava flows; petrographically similar to Ttmb. Flows derived from at least four vents aligned north-south on a medium-sized shield that covers about 13 km² (8 mi²).

**Tdvb** Basalt of Dry Valley (Pliocene and (or) late Miocene)—Basalt lava flows. Similar to Tdgb, though less dikttytaxitic (or more aphanitic) with rare mafic andesite flows. Probably stratigraphically equivalent to Tdgb. Lies conformably on near-planar surface of Ta and irregularly overlies (?) Tcub. K-Ar whole rock of 6.7 ± 2.5 Ma (McKee et al., 1983).

**Tcub** Basalt Volcano (Pliocene to(? late Miocene)—Multiple basaltic volcanoes roughly within northwest-southeast zone within the Devils Garden. Black, aphanitic basaltic lava flows uncommonly associated with cinders, agglutinate, agglomerate, and dikes. Usually <2 km (1 mi) in diameter, relatively steep-sided, and frequently isolated by younger flows of the Devils
Garden basalt (Tdbg). Moderately eroded and probably of significantly different ages, Miocene and Pliocene. One large cinder cone is K-Ar dated at 8.7 ± 0.4 Ma (McKee et al., 1983).

**Tjbb**  
**Basalt of Jack's Butte** (Miocene)—Basalt lava flows. Dark gray to black, similar to basalts of Tcub, Ttmb and others, though denser and less diktytaxitic. Flows are exposed on the moderately-eroded, small isolated shield. May include mafic andesite and andesite.

**Tcfb**  
**Basalt flows of Crowder Flat** (Miocene)—Basalt lava flows; petrographically similar to Tdvb, but less diktytaxitic and more aphanitic and dense. The flows in composite exceed 100 m (328 ft) in thickness, cover over 100 km² (40 mi²), are moderately eroded, and are locally derived from several small volcanoes, plugs, and dikes. The formation is somewhat older than Tdvb but may be coeval with the lower flows of Tdrb.

**Tmma**  
**Andesite of Muldoon Mountain** (Miocene)—Light gray, aphanitic and platy andesite interbedded with basalt. Slightly diktytaxitic; occurs as a large volcano that appears to be associated with a large silicic volcanic complex.

**Tfpt**  
**Domes and welded tuff of Fitzwater Point** (Miocene)—Silicic to andesitic welded tuff, glassy flows, domes, plugs, and breccia that comprise a large pyroclastic complex. It may be a major source (caldera?) of the regionally extensive Alturas Formation.

**Tdrb**  
**Basalt of Dorris Reservoir** (Pliocene and (or) Miocene)—Dark gray to black lavas; moderately microporphyritic with plagioclase and lesser olivine and pyroxene; variously diktytaxitic to dense and aphanitic; subophitic. Contains xenoliths up to a few meters in diameter of medium-crystalline, black, dense olivine-plagioclase-pyroxene peridotite. Flows generally less than 15 m (50 ft) thick, extending for several km² as a stray flow entirely interbedded within Ta, 15 to 30 m below the Ta/Tdbg contact. Source unknown. K-Ar age of 7.8 ± 4.0 Ma (McKee et al,1983) 2 km from southern map extent along Hwy. 299.

**Tcrt**  
**Tuff and volcaniclastic rocks of City Rock** (Miocene)—White to gray, silicic; mostly fine to lapilli with minor tuff breccias, lahars, and thin pyroclastic flows. In part locally derived from vents in City Rock area. Gradational with and interbedded with the Alturas Formation (Ta).

**Ta**  
**Alturas Formation** (Pliocene to Miocene)—White, light gray, tan; fine- to coarse-grained tuff and volcaniclastic rocks with minor pumice lapilli. Massive and variously bedded. Increasing lake clays and fluvial volcanic sandstones in upper part (Collins, 1999). The Alturas Formation is extensively exposed in the Alturas Basin which lies immediately south of the Devils Garden, and is sporadically exposed in several windows and fault scarps in and surrounding the Devils Garden. The Formation represents a thick regional pyroclastic infilling of the Alturas Basin that extends under the basalt flow sequences of the Devils Garden Plateau. The age of the Alturas Formation ranges from about 16 to 5 Ma on the basis of radiometric data. The enormous volume of tuff in the Alturas Formation is probably derived from little known and enigmatic silicic eruptive complexes occurring in the northern part of the Warner Range.
Tertiary Bedrock: Warner Range and Surprise Valley

(Listed based on source and/or field association, and in general from youngest to oldest, though facies relationships are common.)

Tb  **Basalt and andesite volcanoes** (Pliocene and (or) late Miocene)—Light gray to black lava flows, rubble, tuff and dikes. Variously dipping layers in two volcanoes that occur in a north-south zone of several volcanoes that display plugs, dikes, and vent facies and proximal flows and tuffs of the Tfcb unit and probably the Ttab unit as well.

Tffb  **Basalt of Fender Flat** (Pliocene and (or) late Miocene)—Dark gray basalt lava flows with unusual rusty red weathering; sparsely finely microporphyritic with olivine and plagioclase. Appear to be local flows, horizontal, filling a small 3.2 km² (2 mi²) fault-bound valley. Source is unknown.

Tau  **Andesite** (Pliocene and (or) late Miocene)—Light to dark gray andesite lavas, moderately finely microporphyritic with euhedral pyroxene phenocrysts, irregularly finely crystalline texture with local glomeroporphyritic clots with microcavities. May include partially assimilated xenoliths. Occurs in one small area on west flank of Warner Range.

Tcsa  **Basaltic andesite of Cold Spring** (Pliocene and (or) late Miocene)—Light to dark gray, aphanitic, stony, dense basaltic andesite; locally platy and moderately finely porphyritic with plagioclase. Occurs as a 2.6 km² (1.0 mi²) remnant with low west dip on Tsht.

Tvgb  **Basalt of the Vya Group** (Pliocene to Late Miocene)—Low-K, high-Al olivine tholeiites. Gray to black, diktytaxitic, sparsely microporphyritic with olivine and plagioclase. Individual flows are 1 to 10 m. thick; entire flow-on-flow sequence is locally over 200 m thick. Occurs as near-horizontal flow along eastern side of Surprise Valley and in adjacent Nevada and Oregon, and ranges in age from 8 to 3 Ma (Carmichael et al., 2006). Coeval with the Devils Garden Basalt and Basalt of the Alturas Plateau that occur west of the Warner Range, but not physically continuous with them. 40Ar/39Ar ages ranging from 4.28 ± 0.16 to 7.33 ± 0.06 (Carmichael et al., 2006).

Ttbb  **Basalt of Two Buttes** (Miocene and(?) Pliocene)—Dark gray basalt lava flows, variously porphyritic with olivine, pyroxene, and plagioclase up to a few mm locally. Flows <6 m (10 ft) to >50m (164 ft) thick, interbedded with basaltic andesite and sourced from a large (18 km², 11 mi²) shield with at least three summit vents.

Tsvr  **Rhyolite domes and flows** (Pliocene and(?) Miocene)—Light gray, hyaline to phenocryst-poor, with local obsidian. Occur in three small areas, possibly genetically related to local hot springs. Or may be a facies of Tsvt.

Tsvt  **Tuffs and volcaniclastic rocks of Surprise Valley** (Pliocene and(?) Miocene)—Fine-grained to lapilli, vitric crystal tuff, non-welded, interbedded with thin to thick (<0.4 m, 1 ft) layers of conglomerate, sandstone and siltstone with tuffaceous matrix. Interbedded with overlying basalt flows of Tsvb through several tens of meters, where the units apparently grade into one another. Base of Tsvt unit is not exposed; thickness is unknown. Occurs in the eastern part of Surprise Valley.

Tmba  **Andesite of Mount Bidwell** (mid-Miocene)—Light gray, aphanitic, dense andesitic lavas with few basalt interflows. Occurs as thin remnant in summit area of Mount Bidwell with low northeast dip.

Tsht  **Pyroclastic rocks of Sugar Hill** (late Miocene)—Siliceous to intermediate tuff, massive to variously bedded and textured, non-welded to welded, mostly fine grained, locally with coarse
chaotic breccia. Locally intruded by obsidian domes (do) and co-eruptive thick glassy flow masses. Interpreted to represent part of a much larger silicic caldera complex that occurs to the north and northwest (unit Tfpt). Regional correlations suggest that it may also be a major source of the voluminous pyroclastic deposits of the Alturas Formation. K-Ar ages range from 7.3 ± 0.3 Ma (Duffield and McKee, 1986) to 10.2 ± 0.3 Ma (McKee et al., 1983).

**Tmr** Rhyolite flows and domes (Miocene)—Rhyolitic domes and flows, often including obsidian carapaces, that range in age from 7 to 15 Ma (Duffield and McKee, 1986). Rhyolites are generally light gray and phenocryst-poor

**Tib** Tuff breccia (Miocene?)—White, red, brown and yellow tuff breccias, altered and mineralized in places. Appear to be breccia pipes within the tuff complex center of the High Grade District.

**Tovi** Hypabyssal intrusions (Miocene?)—Phenocryst-rich hypabyssal intrusive rocks within the Cedar Pass volcanic complex. Phenocrysts consist almost entirely of hornblende and plagioclase crystals, 2-5 mm in size with rare hornblende crystals up to 2-3 cm in size.

**Ttab** Basalt and andesite flows and breccias, undifferentiated (Miocene?)—Basalt and andesite lava flows and breccias, undifferentiated. Light to dark gray, variously sparsely to moderately porphyritic mainly with plagioclase and minor pyroxene and olivine. Massive to discontinuous bedding. Contact with overlying Alturas Formation (Ta) reveals considerable relief along two spurs from ancestral Warner Highlands to the east. Unknown thickness and internal structure. May be a facies of Tfcb.

**Tfcb** Basalt of Franklin Creek (Miocene?)—Medium to dark gray, moderately porphyritic with labradorite phenocrysts, intergranular, with minor fine olivine, pyroxene, and magnetite. Comprises a complex of flows with plugs and dikes derived from several local volcanoes that together define a north-south zone of distinctive erosional relief. Overall the complex has a low west dip and appears to represent a line of distinct basaltic and andesitic eruptive centers. The unit Ttab may be a southern continuation of Tfcb.

**Tvc** Andesite and welded rhyolite ash-flow tuff (Miocene?)—Compose unit with lower welded tuff 100 m to 300 m thick, a middle section of andesite flows 130 m to 350 m thick, and an upper section somewhat similar to the lower section but less welded and thinner, 30 to 60 m thick. This complex unit may expand northward into large mass of tuff breccia Tovc. K-Ar ages are 25.4 Ma and 26.3 Ma from ash-flow tuffs (Duffield and McKee, 1986).

**Ti** Silicic to intermediate shallow intrusive rocks, undifferentiated (Miocene?)—Plugs, dikes, massive sills(?) and laccoliths(?) occurring in several areas within the High Grade volcanic complex. Probably the sources of the surrounding, thick pyroclastic and lava flows.

**Thiu** High Grade volcanic complex, undifferentiated (mid Miocene)—Silicic to intermediate pyroclastic products and lava flows in a thick section punctuated by intrusions (including Ti). Possibly ponded within a volcanotectonic depression. Associated with local epithermal gold mineralization in breccias and veins. K-Ar ages are 12.1 ± 0.6 and 13.6 ± 0.6 Ma (Keats, 1985).

**Tmbb** Basalt of Mount Bidwell (Miocene)—Gray to black, aphanitic to diktytaxitic, flow-on-flow sequence of laterally continuous andesitic lava flows, 240 m (800 ft) thick, horizontal to low northeast dip.

**Tfpm** Basalt of Fandango Peak (Miocene)—Gray to black, aphanitic to sparsely microporphyritic with olivine and plagioclase, moderately diktytaxitic to dense. Over 600 m (2000 ft) thick flow-on-flow section that may be correlative with Tmbb. May be sourced in part from vents along a summit ridge.

**Tfpv** Pyroclastics of Fandango Valley (Miocene)—White to gray, mostly fine-grained and variously bedded with minor beds of lapilli tuff. Barely exposed.
Tpvu **Volcanics of New Pine Creek, undifferentiated** (Miocene)—Silicic to andesitic lava flows and tuffs of New Pine Creek, undifferentiated. Occurs as a thick crudely layered sequence with a low to moderate eastward dip. Complexly intruded with plugs and dikes. Probably continuous with Tmbt.

Tmbt **Tuffs of Mount Bidwell** (mid Miocene)—White, mostly fine-grained, silicic, finely bedded to massive, variously welded to non-welded tuffs. Section contains limited intermediate lava flows. This thick complex unit appears peripheral to the huge High Grade silicic center (Thiu). One K-Ar age is 14.4 ± 0.6 Ma (Keats, 1985).

Tovb **Basalt of Bald Mountain** (late Oligocene)—Thin (10-20 m) but continuous basalt lava flow capping Bald Mountain and dated at 24.47 +/- 0.34 Ma (Colgan et al., 2011).

Tbwmnb **Basalt of Buck Mountain** (Oligocene)—Medium to dark gray, sparsely to finely plagioclase-phyric basalt lava flows; intergranular and rarely diktytaxitic. Mafic andesite flows also occur in the flow sequence in places. Maximum thickness of 427 m (1400 ft) represents a remnant of a more extensive flow sequence that was deposited on a low-relief surface cut on flows and tuffs of Tfbtf. Dips are low to the west (<6 degrees). May be equivalent to Tppa.

Tppa **Andesite and basalt of Payne Peak** (Oligocene)—Andesite and basalt lava flows. Medium to dark gray, moderately to finely porphyritic with plagioclase and clinopyroxene and lesser olivine; intergranular to subophitic; seriate pyroxene. Maximum thickness of less than 244 m (800 ft); erosional remnant of more extensive flows lying unconformably on moderate-relief surface cut on horizontal to low west dipping Tctb tuff breccia. May be correlative with Tbwmnb unit six miles to the north.

Tovc **Cedar Pass volcanic complex** (Oligocene)—Medium gray pyroclasts in white to light gray fine tuffaceous matrix. Pyroclasts are <20 cm (6 in) in size, abundantly finely porphyritic andesite with plagioclase and pyroxene and minor hornblende phenocrysts. Unit contains lava blocks up to 3 or more meters (10 ft) in unsorted breccia intervals irregularly interbedded with finer tuffs, minor welded tuffs, and lava flows. It is essentially a massive poorly bedded pyroclastic flow breccia section over 600 m (2000 ft) that dips generally less than 20 degrees west. It appears to be a facies of the Tfbtf unit and to be sourced from an eruptive breccia center located just south of the map. K-Ar age of 26.6 ± 1.1 (Duffield and McKee, 1986), and 40Ar/39Ar age of 27.07 ± 0.225 (Carmichael et al., 2006), 26.35 ± 0.11 Ma near the middle of the sequence and 26.64 ± 0.8 Ma near base of the sequence in field area (Colgan et al., 2011).

Tfbtf **Tuffs and flows of Fort Bidwell, undifferentiated** (Oligocene)—Complexly interbedded silicic to intermediate tuffs, non-welded, and thin to thick flows, lenticular to tabular, with local sills suspected. This heterogeneous and complex unit is probably a part of a very thick regional pyroclastic deposit that is identified locally as Tpvu and Tmbt. Several radiometric ages reported, ranging from a K-Ar age of 28.7 ± 1.1 at Loc. 16 (Duffield and McKee, 1986) to a 40Ar/39Ar age of 25.70 ± 0.94 at Loc. 35, 27.83 ± 0.21 Ma near the exposed base, and 27.14 ± 0.08 near the contact with Tovc (Colgan et al., 2011).

Tdct **Tuff of Davis Creek** (Oligocene)—Fine-grained andesitic tuff, undifferentiated, poorly exposed beneath alluvium. May be correlative with Ta occurring along east margin at south end of Goose Lake Valley. K-Ar age of 28.8 ± 1.1 reported by Duffield and McKee (1986).

Tcpr **Breccia of Cedar Pass** (Oligocene)—Dark greenish gray, sparsely finely plagioclase-phyric pyroclastic deposits in micro-to-cryptocrystalline matrix, andesitic, massive, oxidized with dark minerals converted to opaque oxides. Tectonically brecciated in numerous shear zones. Crudely circular mass suggests intrusive breccia plug.
Tlw  **Lost Woods Formation** (Oligocene)—Andesitic and basaltic lahars, sedimentary rocks (sandstone, shale and conglomerate) and interbedded lava flows, 300-1000 m thick. The entire unit is conspicuously red-weathering. Lahars comprise beds ~2-3 m thick, with a sandy to pebbly matrix and poorly sorted subangular to angular clasts averaging ~10 cm but reaching 40 cm. Andesite and basalt flows are less than 4 m thick and include porphyritic plagioclase basalt and hornblende andesite. Sedimentary successions have conglomerate lenses, sandstones and shales, and contain abundant fossil wood.

Tdc  **Deep Creek Formation** (Oligocene)—Poorly-exposed, slope-forming unit consisting mostly of fine-grained tuffs, up to 400 m thick. Includes highly altered and silicified breccia with a green matrix.

Tscc  **Steamboat Formation, Cougar Cliffs Member** (Oligocene to late Eocene)—Massive, cliff-forming andesitic lahars and debris flows, 250-350 m thick, with mostly subangular clasts up to 1 m in size. Poorly sorted, and generally matrix supported. Matrix consists mostly of mud, minor ash, and abundant mm-sized hornblende and plagioclase crystals. Clasts are predominantly andesite with purple-grey, aphanitic groundmass, 1-2 mm plagioclase and larger hornblende phenocrysts. The unit forms prominent cliffs south of Simpsons Canyon, but the unit becomes thinner and less resistant to the north. Locally, thinly-bedded conglomerates, sandstones and siltstones are interlayered with the lahars.

Tsbn  **Steamboat Formation, Badger’s Nose Member** (Oligocene to late Eocene)—Primarily fine-grained volcaniclastic sediments, including a lacustrine shale with abundant leaf fossils of late Eocene-early Oligocene age (Myers, 2006).

Tmrv  **McCulley Ranch Formation** (late Eocene)—Fractured and deeply weathered andesitic debris flows interbedded with andesite flows, minimum thickness of ~650 m. Near the top of the unit, Axelrod (1966) reports a K-Ar age of 40.8 +/- 3.0 Ma (corrected) on plagioclase from an andesite flow, suggesting an Eocene age for the entire sequences.
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Figure 3. Map of the Cedarville 30' × 60' quadrangle showing the locations of volcanic rocks dated by radiometric methods. Numbers correspond to Location Numbers in Table 1.
Table 1. K-Ar and 40Ar/39Ar ages of volcanic rocks within the Cedarville 30’x60’ quadrangle. Location Number refers to Figure 2 and geologic map.

<table>
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<tr>
<th>Location Number</th>
<th>Sample</th>
<th>Rock Type</th>
<th>Map Unit</th>
<th>Latitude (North)</th>
<th>Longitude (West)</th>
<th>Method</th>
<th>Age</th>
<th>Source</th>
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<td>Basalt</td>
<td>Tfsvb</td>
<td>41.5845</td>
<td>120.0307</td>
<td>40Ar/39Ar</td>
<td>4.28 ± 0.16</td>
<td>Carmichael et al., 2006</td>
</tr>
<tr>
<td>25</td>
<td>SV92</td>
<td>Basalt</td>
<td>Tdgb</td>
<td>41.5011</td>
<td>120.6300</td>
<td>40Ar/39Ar</td>
<td>4.31 ± 0.18</td>
<td>Carmichael et al., 2006</td>
</tr>
<tr>
<td>26</td>
<td>SV96</td>
<td>Basaltic andesite</td>
<td>Tctb</td>
<td>41.5090</td>
<td>120.2583</td>
<td>40Ar/39Ar</td>
<td>27.07 ± 0.225</td>
<td>Carmichael et al., 2006</td>
</tr>
<tr>
<td>27</td>
<td>07-C-19</td>
<td>Andesite lava</td>
<td>Tfbtf</td>
<td>41.5881</td>
<td>120.2728</td>
<td>40Ar/39Ar</td>
<td>25.727 ± 0.045</td>
<td>Colgan et al., 2011</td>
</tr>
<tr>
<td>28</td>
<td>07-C-6</td>
<td>Olivine basalt</td>
<td>Tfbtf</td>
<td>41.6091</td>
<td>120.2403</td>
<td>40Ar/39Ar</td>
<td>27.14 ± 0.08</td>
<td>Colgan et al., 2011</td>
</tr>
<tr>
<td>29</td>
<td>AE05WR03</td>
<td>Basalt</td>
<td>Tfbtf</td>
<td>41.5783</td>
<td>120.2241</td>
<td>40Ar/39Ar</td>
<td>27.49 ± 0.33</td>
<td>Colgan et al., 2011</td>
</tr>
<tr>
<td>30</td>
<td>H08-57</td>
<td>Ashflow tuff</td>
<td>Tfbtf</td>
<td>41.6057</td>
<td>120.2462</td>
<td>40Ar/39Ar</td>
<td>26.642 ± 0.077</td>
<td>Colgan et al., 2011</td>
</tr>
<tr>
<td>31</td>
<td>JC07WR303</td>
<td>Ashflow tuff</td>
<td>Tfbtf</td>
<td>41.6135</td>
<td>120.2615</td>
<td>40Ar/39Ar</td>
<td>26.35 ± 0.11</td>
<td>Colgan et al., 2011</td>
</tr>
<tr>
<td>32</td>
<td>JC08WR405</td>
<td>Basalt</td>
<td>Tfbtf</td>
<td>41.6090</td>
<td>120.2317</td>
<td>40Ar/39Ar</td>
<td>27.83 ± 0.21</td>
<td>Colgan et al., 2011</td>
</tr>
<tr>
<td>33</td>
<td>WR07AE40</td>
<td>Basalt</td>
<td>Tfbtf</td>
<td>41.7041</td>
<td>120.2501</td>
<td>40Ar/39Ar</td>
<td>25.70 ± 0.94</td>
<td>Colgan et al., 2011</td>
</tr>
</tbody>
</table>

Latitude and longitude coordinates for Colgan et al. (2011) locations are in NAD27. Coordinate systems used by Carmichael et al. (2006), Duffield and McKee (1986) and McKee et al. (1983) are not specified but assumed to be NAD27. Locations for Axelrod (1966) were given according to PLSS; coordinates are approximate.

^aCorrected age – published age of 40.0 ± 3.0 used 4.72 x 10^-30 as the decay constant for K.

All ages are in Ma; error from Colgan et al., 2011 is reported as 2σ, all others reported as 1σ.

Ar/39Ar dates calculated relative to Fish Canyon Tuff sanidine = 28.02 Ma.
Table 2. Terminology used in the description of volcanic rocks.

<table>
<thead>
<tr>
<th>Porphyritic volcanic rock features</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Abundantly porphyritic</td>
<td>--</td>
<td>phenocrysts &gt;20% (volume)</td>
</tr>
<tr>
<td>Moderately porphyritic</td>
<td>--</td>
<td>phenocrysts 5-20%</td>
</tr>
<tr>
<td>Sparsely porphyritic</td>
<td>--</td>
<td>phenocrysts &lt;5%</td>
</tr>
<tr>
<td>Coarsely porphyritic</td>
<td>--</td>
<td>phenocrysts &gt;5 mm (size)</td>
</tr>
<tr>
<td>Finely porphyritic</td>
<td>--</td>
<td>phenocrysts 1-5 mm</td>
</tr>
<tr>
<td>Microporphyritic</td>
<td>--</td>
<td>phenocrysts &lt;1 mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Volcanic rock names</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Basalt</td>
<td>--</td>
<td>&lt;52% SiO₂ (weight %)</td>
</tr>
<tr>
<td>Basaltic andesite</td>
<td>--</td>
<td>52-57%</td>
</tr>
<tr>
<td>Andesite</td>
<td>--</td>
<td>57-63%</td>
</tr>
<tr>
<td>Dacite</td>
<td>--</td>
<td>63-68%</td>
</tr>
<tr>
<td>Rhyodacite</td>
<td>--</td>
<td>68-72%</td>
</tr>
<tr>
<td>Rhyolite</td>
<td>--</td>
<td>&gt;72%</td>
</tr>
</tbody>
</table>

**Example** - *sparsely finely olivine porphyritic basaltic andesite; abundantly coarsely plagioclase, sanidine porphyritic dacite.*