Preliminary Geologic Map of the Alturas 30’ x 60’ Quadrangle, Lassen and Modoc Counties, California

Scale 1:100,000

By

Thomas L.T. Grose[1], Anne E. Egger[2], and Matt D. O’Neal[3]

Digital Preparation by

Matt D. O’Neal[3], Collette K. Gantenbein[3], Karen Toman-Sager[3], Carlos I. Gutierrez[3], Daniel J. Wills[3], and Benjamin Middendorf[3]

2016



[1]Colorado School of Mines
[2]Central Washington University
[3]California Geological Survey

STATE OF CALIFORNIA
EDMUND G. BROWN JR.
GOVERNOR

THE NATURAL RESOURCES AGENCY
JOHN LAIRD
SECRETARY FOR RESOURCES

DEPARTMENT OF CONSERVATION
MARK NECHODOM
DIRECTOR

CALIFORNIA GEOLOGICAL SURVEY
JOHN G. PARRISH, Ph.D.
STATE GEOLOGIST



CALIFORNIA GEOLOGICAL SURVEY
JOHN G. PARRISH, Ph.D.
STATE GEOLOGIST

Copyright © 2016 by the California Department of Conservation. All rights reserved. No part of this publication may be reproduced without written consent of the California Geological Survey.

The Department of Conservation makes no warranties as to the suitability of this product for any particular purpose.

Table of Contents

Introduction 4

PHYSIOGRAPHY 5
Surprise Valley 5
Warner Range 7
Alturas Basin 7
Manzanita Range 7
Central Volcanoes 7
Hayden Hill Upland 7
Big Valley 8
Stone Coal Valley 8
FORMATIONS 8
STRUCTURE 9

Compilation 4

Description of Map Units 11

SURFICIAL DEPOSITS 11
VOLCANIC ROCKS 12
Volcanic Units Associated with a Source Volcano 12
Probable Large Eruptive Centers 15
Multiple Local and Regional Sources 16

References Cited 23

Plate

Preliminary Geologic Map of the Alturas 30’ x 60’ Quadrangle, Lassen and Modoc Counties, California ..... (see PDF)

Figures

Figure 1. Index map showing boundaries of 7.5’ quadrangles within the Alturas 30’ x 60’ Quadrangle and sources used in this compilation. 5

Figure 2. Map of the Alturas 30’ x 60’ Quadrangle showing geographic features, second-order geologic provinces, and source volcanoes 6

Figure 3. Map of the Alturas 30’ x 60’ Quadrangle showing the sample collection locations of volcanic rocks dated by radiometric methods 25

Tables

Table 1. K-Ar ages of volcanic rocks within the Alturas 30’ x 60’ Quadrangle, California 26

Table 2. Terminology used in the description of volcanic rocks. 27

Preliminary Geologic Map of the Alturas 30’ x 60’ Quadrangle, Lassen and Modoc Counties, California

By: Thomas L.T. Grose[1], Anne E. Egger[2] and Matt D. O’Neal[3]

Introduction

Geologic mapping in the Alturas 30’ x 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 Alturas area, was written by G.A. Macdonald (1966). Subsequent to these pioneering reconnaissance efforts, the Alturas area has been systematically mapped in recent years at scale 1:62,500 with a few local maps at scale 1:24,000 (Figure 1). Support has come primarily from the California Geological Survey, the U.S. Forest Services, and the U.S. Geological Survey. This Alturas 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 Alturas 30’ x 60’ Quadrangle, California*** was primarily compiled from original, unpublished mapping by Thomas Grose that was completed during field seasons between 2003 and 2008.

Additional mapping in the Warner Range at a scale of 1:24,000 took place during field seasons between 2004 and 2009 and was compiled from field mapping by Wendell Duffield (Duffield et al., 1976). Geologic maps of the Dorris Reservoir, Eagle Peak, Eagleville, Little Juniper Reservoir, Shields Creek, Soup Creek, and Warren Peak 7.5' quadrangles were combined and published at the 1:24,000 scale by Anne Egger (2010); the same mapping was published at 1:50,000 by Egger and Miller (2011).

The following sources of detailed geologic mapping were also used in the compilation: Bowens, 1998; Garman, 1991; Obernyer, 2002 (Figure 2). The individual maps were scanned and digitized with minor to moderate modifications to produce this seamless digital map.

[1] Colorado School of Mines
[2] Central Washington University
[3] California Geological Survey

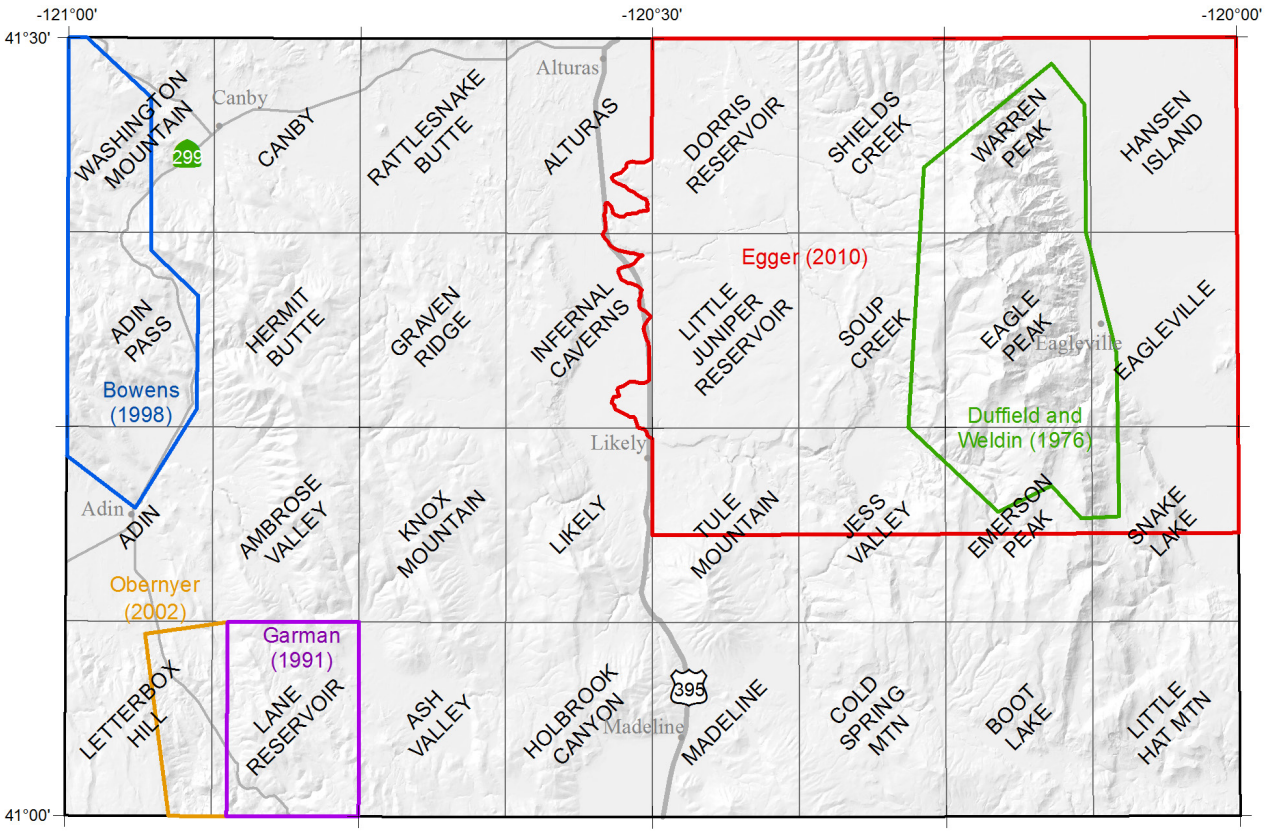


Figure 1. Index map showing the 7.5’ quadrangles within the Alturas 30' x 60' quadrangle and sources used for the compilation. See References Cited.

Physiography

The Alturas 30’ x 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 lies the relatively unextended Modoc Plateau. Within the map area, several second-order geologic provinces are delineated herein on the basis of lithology, structure, and physiography (Figure 2). They are summarized below from east to west across the map.

Surprise Valley

The southern half of Surprise Valley graben occurs in the eastern part of the Alturas map. 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 middle and lower lakes) are located in the Alturas 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).

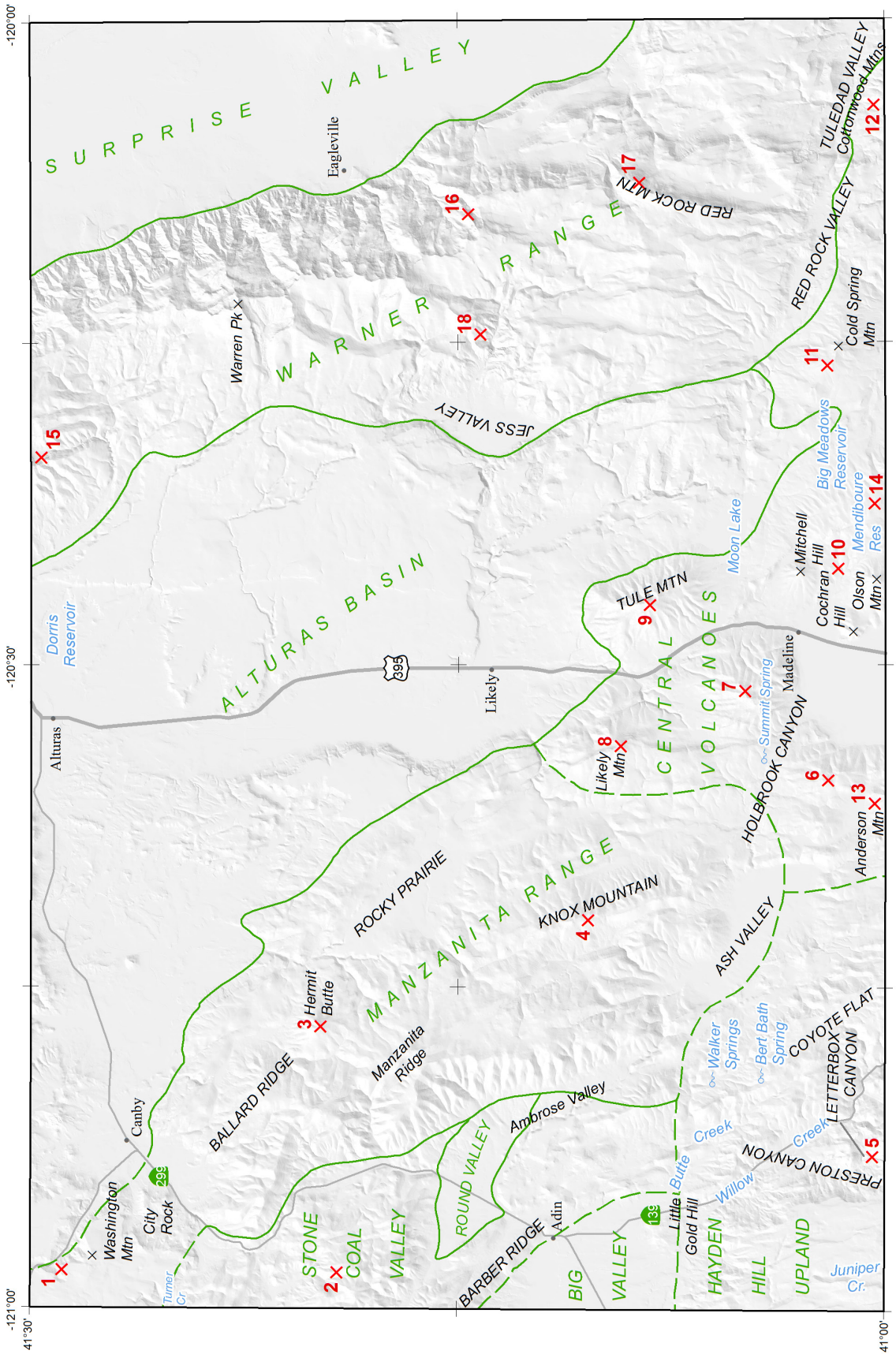


Figure 2. Map of the Alturas 30' x 60' Quadrangle, showing geographic features, second-order geologic provinces (outlined in green), and source volcanoes (in red; numbers refer to unit entries in Description of Map Units, below).

Warner Range

The most significant physiographic feature in the Alturas region 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). The range-bounding Surprise Valley fault produces a highly asymmetric profile over the 10-15 km width of the range with a steep eastern flank and gentler western slope. The oldest rocks in the quadrangle, late Eocene in age, are exposed on the east flank of the Warner Range. Among many peaks above 8,000 feet (about 2,400 meters), the highest elevation in the range within the Alturas Quadrangle is Eagle Peak at 9,897 feet (3,017 meters).

Alturas Basin

West of the Warner Range, the large and low-relief terrain of the physiographic and structural Alturas basin (Figure 2) is shaped primarily by erosion of soft tuffaceous rocks by the Pit River and its south fork. Elevations range from about 4,300 feet (about 1,300 meters) in the Canby area in the northwest corner of the map to about 5,000 feet (about 1,500 meters) along the eastern margin of the basin. The basin narrows gradually in a south-southeasterly direction and ends where central volcanoes come in direct contact with the layered rocks in the southern part of the Warner Range. The physiographic margin of the basin coincides with the west-flowing South Fork of the Pit River east of the village of Likely. The basin widens to the north and includes the Warm Springs Valley in the Canby area. Just beyond the northern border of the map, the physiographic Alturas Basin ends at the erosional edge of horizontal basalt lava flows of the Devils Garden Plateau.

The eastern part of the Alturas basin is dominated by the Alturas Plateau, capped by sub-horizontal basalt flows that range in age from 2.8 to 4.6 Ma (Carmichael et al., 2006). A low-amplitude vent about nine miles southeast of the city of Alturas, herein named the Fitzhugh volcano, appears to be a source for the highly fluid lava flows of the Plateau.

Manzanita Range

On the wide west flank of the Alturas Basin, a series of heavily forested, northwest-trending ridges collectively define a moderate-relief volcanic upland of elevation 6,500 to 7,300 feet (about 1,980 to 2,230 meters), which is herein named for the highest ridge called Manzanita (Figure 2). The ridges are sustained by resistant lava flows that appear to be repeated by longitudinal faulting and that dip gently into the Alturas Basin. Small shields and stratovolcanoes, such as Hermit Butte and Knox Mountain, occur at higher elevations. They appear to be both conformably within the volcanic section as well as unconformably atop the section. The Manzanita Range merges gradually, irregularly, and rather inconspicuously into a cluster of central volcanoes to the south, into the Hayden Hill Upland to the southwest, into Big Valley and Round Valley to the west, and into the Stone Coal Valley to the northwest.

Central Volcanoes

Several mid to late Miocene volcanoes averaging 8-10 km in diameter control the landscape in the south-central part of the Alturas 30’ x 60’ quadrangle. Likely Mountain is the highest at 7,376 feet (2,248 meters) followed by Tule Mountain at 7,098 feet (2,163 meters). These consist of basaltic andesite lavas with arc affinities (Colgan et al., 2011). Other more diffuse eruptive centers, herein named Northwest Madeline and Holbrook Canyon, and satellite volcanoes of the giant McDonald Peak – Three Peaks center that occurs mostly south of the map (Grose et al, 2014) make up this central volcano cluster.

Hayden Hill Upland

The northeastern part of what is termed herein the Hayden Hill Upland (Figure 2) occurs in the southwestern corner of the Alturas 30’ x 60’ quadrangle. The Upland merges into the Central Volcanoes

to the east and into the Manzanita Range to the northeast. It is bounded on the north by an irregular, east-west trending slope that gives way to the nearly flat floor of Big Valley 1,000 feet (about 300 meters) lower. Elevations in the Upland vary from 5,500 to about 6,400 feet (about 1,680 to 1,950 meters) in moderate relief of northwest-trending canyons incised into faulted, complexly layered and intruded volcanic rocks. Hayden Hill proper was truncated by open-pit gold mining in the 1990s.

Big Valley

The eastern extremity of the large Big Valley physiographic province and the similar but smaller Round Valley and Ash Valley occur in the western part of the Alturas 30’ x 60’ quadrangle (Figure 2). These valleys have surfaces that range from anomalously flat to low and rolling slopes eroded into fine-grained tuff with few stretches of thin alluvium. Outcrops are few. The valley margins vary from sharp and linear to gradual. The valleys are mostly surrounded by thick, east-tilted sequences of lava flows and pyroclastic rocks. The valleys are unusual and their origins are enigmatic compared to other valleys in the region: they could be either tectonic or volcanic. More age determinations on tilted units and detailed field mapping could resolve the origins of these valleys.

Stone Coal Valley

The Stone Coal Valley is an area of irregular hills and valleys with random pattern set between adjacent linear ridges and drained by the Pit River (Figure 1). Elevations range from 4,600 to 6,000 feet (about 1,400 to 1,830 meters). A very thick, silicic, complexly deformed and intruded sequence of rocks crops out in the Valley. Some of the tuffaceous beds are dark in color, fossiliferous and organic-rich, resembling coal (for which the valley is named). Several plugs and domes have intruded the complex. The localized great thickness and variety of structures and rocks in combination with the landforms strongly suggest that the Stone Coal Valley is the site of a deeply eroded volcanotectonic depression or a caldera (Bowens, 1998 and Bowens and Grose, 2001).

Drainages

Five of the seven physiographic provinces within the Alturas 30’ x 60’ quadrangle are drained by the headwaters of the Pit River and the South Fork of the Pit River. The North Fork joins the system at the northern edge of the map just southwest of the city of Alturas (Plate 1). The eastern slope of the Warner Range, however, drains into the Surprise Valley, and the southern slopes of the central volcanoes drain into the Madeline Plains; both areas are part of the region of interior drainage of the Great Basin. Elsewhere in the map region all water flows westward as part of the Pit River, which joins the Sacramento River at Shasta Reservoir. The crest of the Warner Range is a first-order divide within the State of California between drainage to the east into the closed Great Basin and to the west into the Pacific Ocean.

The Warner Range collects heavy precipitation. As a result, the Pit River, which is sourced in the Warner Range, maintains a relatively even flow of water from the dry terrain of northeastern California. It is the only river entirely within California that maintains a course through the Sierra Nevada–Cascade topographic divide. In the vast system of natural and engineered water resources for which California is famous, the Warner Range and the Pit River are major contributors.

Formations

Nearly all of the bedrock exposed in the map region is volcanic in origin. Minor sedimentary rocks are interbedded with volcanic rocks, but they are primarily composed of reworked volcanic debris from nearby eruptions. Surficial formations include Quaternary alluvium in small patches along major streams. Very thick alluvium and lake sediments fill the Surprise Valley graben.

Most of the volcanic rocks in the Alturas 30' x 60' quadrangle occur in layered sequences, but these are generally discontinuous laterally and change significantly in thickness over relatively short distances because the deposits are proximal to their volcanic sources. Compositions range from basalt to andesite and rhyolite, including widespread, thin, highly-fluid tholeiitic basalt flows, thick to thin andesitic flows and tuff breccias, andesitic to rhyodacitic tuff breccias and lesser lahars, and fine to lapilli silicic tuffs with welded sections (Carmichael et al., 2006; Colgan et al., 2011; Egger and Miller, 2011).

Most of the sources for these volcanic rocks are located within the map area, identified on the map (Plate I) and in the description of map units (by number and letter), and tentatively correlated with their extrusive products. The types of sources include small shield volcanoes, small to medium-sized stratovolcanoes, dikes, explosion vents associated with massive tuff breccia, and silicic domal vent complexes. These sources are all deeply eroded, apparently at least several hundred to a few thousand feet.

The eastern side of the Warner Range reveals an excellent exposure of a well-bedded volcanic sequence about 13,200 feet thick (about 4,020 meters). From the bottom up, it consists of: 1) volcanic sandstones and conglomerates with rarely occurring granitic and metamorphic cobbles (Egger et al., 2009) and fossiliferous lake clays (Myers, 1998), 2) silicic to andesitic tuffs (Colgan et al., 2011; Duffield and McKee, 1986), and 3) andesitic and basaltic flow-on-flow sequences (Colgan et al., 2011; Duffield and McKee, 1986). The entire exposed section ranges in age from greater than 34 million years (latest Eocene) to less than 14 million years (mid-Miocene) (Egger and Miller, 2011). The volcaniclastic rocks are the oldest Cenozoic rocks exposed in the region. This gently west-dipping section dominates the eastern half of the Alturas 30' x 60' quadrangle. The upper part of the section may correlate in age with the thick east- and northeast-dipping lava flows and pyroclastic rocks in the Manzanita Range in the western half of the map. Details of regional volcanostratigraphic correlation across the Alturas Basin await further studies.

The rocks in the Hayden Hill, Big Valley, and Stone Coal Valley silicic complexes are layered and massive tuffs and tuff breccias that are variously deformed, in some places to local vertical dips (Stone Coal Valley), by faulting, intrusion, and perhaps vent collapse. Rhyolitic and andesitic domes and plugs are apparently cogenetic sources for the many varieties of silicic rocks in the area. The evidence is strong for very thick and local entrapment within volcanotectonic grabens and/or caldera collapse centers (Bowens and Grose, 2001). These three areas appear to occur stratigraphically beneath the Manzanita section of andesitic and basaltic lava flows. Other great silicic complexes in the Warner Range, especially the obsidian dome areas north of Alturas (Grose and Egger, 2016), and the vast tuff section of the Alturas Formation are probably partially correlative and coeval with the Hayden Hill, Big Valley, and Stone Coal Valley silicic centers. Understanding the relationships and correlations of the enormous volumes of pyroclastic rocks in the Alturas region offers one of the greatest challenges to geologists.

Within Surprise Valley, there are numerous sedimentary remnants of Pleistocene pluvial Lake Surprise, including coarse-grained fan deltas and fine-grained lake sediments (Egger, 2014).

Structure

Major tectonic structures in the Alturas 30' x 60' quadrangle include the Alturas syncline or regional basin, the Warner Range and Surprise Valley graben. Bedding is slightly to moderately tilted. Faults predominantly trend north-south to northwest-southeast and are especially numerous on the wide flanks of the Alturas syncline.

The largest fault is the Surprise Valley fault in the northeastern corner of the map, a NNW-trending normal fault that has accommodated approximately 8 km of dip-slip motion since the mid-Miocene (Egger and Miller, 2011). Numerous fault scarps line the front of the range, and additional

scarps lie as much as 5-7 km east of the range front within the valley (Bryant, 1990; Egger, 2014; Hedel, 1984). At its southern end, the Surprise Valley fault splays into faults of decreasing displacement and curvature trending southeasterly off the map into Nevada. Although no historic earthquakes have occurred along the Surprise Valley fault, paleoseismic trenching has revealed at least five earthquakes in the last 20 ka (Personius et al., 2009). The Surprise Valley fault is considered the westernmost boundary of the Basin and Range province at this latitude, accommodating roughly E-W extension over the last 12 Ma.

The nature of the Likely fault, which trends NW-SE across the central portion of the map, is less clear. A few observations of features such as sag ponds and apparent dextral offset of features have been noted (Jenkins, 1959), and it coincides with strong linear topographic features of mixed origin and age. There are contrasts in structure across the fault: The few faults northeast of the Likely Fault trend irregularly north-south or northeast-southwest, whereas on the southwest side of the Likely Fault, the many parallel faults trend northwest-southeast. In addition, the overall attitude of strata is also significantly different on opposite sides of the Likely Fault. Northeast of the fault, the strata dip westerly or are horizontal, while to the southwest, the strata dip generally to the northeast or in many directions locally in association with complex, silicic, eruptive centers. However, no specific bedrock geologic features are recognized as offset, and no definite drag or crush zone has been observed. Age of the fault activity is not known, although Quaternary movement seems to be absent.

Mapping in the Canby area (Grose and Bowens, 2003) revealed a newly defined fault zone, called the Blacks Canyon fault zone, at the northwest end (?) of the Likely fault zone. It splays north-northwesterly to north off the Likely Fault, and it consists of left-stepping fault segments that suggest a right lateral component of slip. This fault is clearly associated with deflections in the Pit River drainage, scarps interpreted to be the result of topographic displacement, and local thermal springs, suggesting Late Quaternary displacement. The intersection or merger of the Likely Fault with the Blacks Canyon Fault at the Canby thermal anomaly suggests the possibility of strike-slip strain on the Likely Fault transforming into dip-slip on the Blacks Canyon Fault. No other thermal anomalies or young fault scarps are known to be obviously connected with the Likely Fault.

Most of the faults on the east side of the Alturas Basin dip east and displace that side downward. Most of the faults on the west side dip west and displace that side downward. On the east flank and in the middle of the Alturas Basin, faults are few and trend north-south to northeast-southwest. On the west flank of the Alturas Basin, faults are numerous and parallel and trend northwest-southeast. All of the faults in the Alturas region are normal, but some display an en echelon left-stepping pattern, which indicates a minor component of right lateral-slip.

In summary, all of the tectonic structures within the Alturas 30’ x 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. Tensional strain dominates, but a minor component of right lateral shear is evident. The region is still tectonically active.

Description of Map Units

[Approximate stratigraphic relationships]

Surficial Deposits

Qa **Alluvium (Holocene)**—Unconsolidated sand, gravel, and silt associated with modern fluvial systems. Locally tuffaceous; usually less than 20 m thick. Big Valley and the valley of the South Fork of Pit River have a veneer of alluvium mixed with reworked tuff of underlying tuff formations. Surprise Valley has massive deposits of alluvium shed from the Warner Range that grade into lacustrine beds of Lake Surprise.

Qc **Colluvium (Holocene)**—Gravel, sand, and silt; local small accumulations that commonly grade into alluvium or talus. Includes sediments of the high stand of ancestral Lake Madeline, occurring north-northeast of Madeline where the lake may have once drained for a short period of time through the Cedar Creek drainage and ultimately into the Pit River.

Qe **Eolian sand (Holocene)**—Fine sand in local dunes that grade into sheet sand deposits. May grade into Ql.

Qf **Alluvial fan (Holocene and Pleistocene)**—Boulder, gravel, and sand deposits are present in several small fans, but are best developed in large coalescing fans composed of coarse debris washed out of the Warner Range eastward into the west side of Surprise Valley.

Qp **Playa deposits (Holocene)**—Evaporite and clay deposits from ephemeral lakes.

Ql **Lake deposits (Holocene and Pleistocene?)**—Lacustrine sand, silt and clay deposited by ephemeral lakes in many small basins which may have originated by faulting or irregular deposition of volcanic rocks. May grade into Qa and Qc.

Qls **Landslide debris (Holocene and Pleistocene)**—Undifferentiated landslides, including debris flows and slump blocks. Often composed of boulder-sized blocks of massive basalt and andesite lavas. Rapidly weathering underlying tuffs remove support on steep slopes of canyon walls and along active fault scarps. The best examples occur in the southern part of the Warner Range and several kilometers northwest and east of Likely.

Qt **Talus (Holocene and Pleistocene)**—Coarse blocky slope debris, consisting mainly of angular blocks of massive mafic lavas overlying soft and retreating slopes of tuff. May be associated with, and grade into, large landslides.

Qm **Moraine (Holocene and Pleistocene)**—Confined valley-floor moraine with kame-and-kettle topography and over 40 m of relief; occurring in glacial headwater basin of South Fork of Pine Creek in the Warner Range.

Qg **Gravels (Holocene and Pleistocene?)**—Mainly colluvial gravels locally preserved along the east front of the Warner Range and fluvial gravels of Pine Creek and Parker Creek.

Qoa **Older alluvium (Holocene and Pleistocene?)**—Older fluvial deposits, currently being dissected by modern streams.

Qof **Older fan deposits (Holocene and Pleistocene?)**—Includes fine, rounded grains and cobbles. Semi-consolidated; up to 3 m thick; distal extent of very large high-level, partially eroded alluvial fan occurring to the north of the map area, near Thoms Creek. Currently being dissected by modern streams.

Qpd **Delta deposits (Pleistocene)**—Gilbert-type fan delta deposits from Pleistocene Lake Surprise. Remnants of deltas on the floor of Surprise Valley are flat-topped with steep foreset beds of coarse gravel and horizontal topsets.

QThs **Sinter**—Hot spring deposit, localized within and on top of andesitic tuffs, associated with active faulting along the Willow Creek fault zone; probably Quaternary.

Volcanic Rocks

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

Volcanic Units Associated with a Source Volcano

(Numbers in brackets refer to source volcanoes shown on Figure 2 and listed in Table 1)

Washington Mountain [1]

Qbwb **Basalt of Badger Well (Quaternary)**—Olivine tholeiitic basalt. Dark gray to black, variably diktytaxitic to aphanitic and dense, sparsely microporphyritic with olivine < 2 mm. Widespread horizontal lava flows sourced from a small shield volcano, located 1.6 km west of the west-central margin of the map (Grose and Travis, 2006).

Twmb **Basalt of Washington Mountain**—Black to dark brown; holocrystalline to hypocrystalline; sparsely microporphyritic with olivine < 1mm. Thin, horizontal lava flows and associated pyroclastic deposits from two or possibly four vents. May be coeval with Tcrb.

Tcrb **Basalt of City Rock**—Black, gray and brown; finely crystalline, with abundant augite 22% and matrix analcite 8% altered to pseudo leucite. Several lava flows derived from four sources within two miles of City Rock. May be coeval with Twmb.

Stone Coal Volcanotectonic complex (caldera?) [2]

Tscb **Basalt of Stone Coal Valley**—Dark gray to black; aphanitic to sparsely microporphyritic and locally glomeroporphyritic with labradorite and olivine; locally interbedded with underlying tuffs; locally sourced. K-Ar age 7.8 ± 4.3 Ma Loc. 2

Tsct **Tuff and volcaniclastic rocks of Stone Coal Valley**—White, gray, and tan; mostly fine vitric lithic tuff and minor breccia interbedded with volcanic fluvial sandstones and siltstones and locally welded tuff; massive to variously bedded. Unit is locally interbedded with basaltic lava flows of Tsca and tuffs and sedimentary rocks of Trts. Locally strongly deformed with high dips; several hundred meters thick. Probably represents central infilling of volcanotectonic depression (caldera?).

Tscs **Sedimentary and tuffaceous rocks of Stone Coal Valley**—White, gray, tan and black; very fine to coarse grained, thinly bedded to massive. Sandstone, siltstone, shale, locally highly organic and coaly beds, and lacustrine fossiliferous clays with fine plant remains and petrified tree trunks, interbedded with fine massive siliceous tuff. 300 m. thick in tilted local facies within Tsct.

Tgbr **Volcanic breccias of Gerig Camp**—Gray, tan, red and black; variously vesiculated, angular to sub-rounded clasts less than one meter, in tuff matrix. Massive to crudely bedded. Lapilli cinder in upper part; intermediate to mafic; locally interbedded with thin basalt flows, unit thickness

greater than 800 meters, moderate discordance with underlying units, derived from sources within large eruptive depression. Widespread in western extent of map.

Tdu **Rhyodacitic to andesitic domal flow mass**—Dark gray; mostly aphanitic to moderately porphyritic, pilotaxitic, massive, dense. K-Ar age 12.9 ± 1.1 Ma (Grose and Bowens, 2002).

Trts **Tuffs and sedimentary rocks of Round Valley**—White and gray; very fine to fine grained lacustrine shales and siltstones and tuffs with local organic layers. Forms flat floor of Round Valley. Poorly exposed and limited well data. Probably correlative and continuous with Tsct.

Hermit Butte volcanoes [3]

Thbv **Basaltic andesite of Hermit Butte Volcano**—Medium to dark gray with local greenish splotches; sparsely microporphyritic with plagioclase, olivine, and pyroxene, intergranular and rarely glomeroporphyritic, locally platy lava flows; highest, youngest, and least eroded small shield volcano in the Manzanita Volcanic Range.

Tbrv **Basaltic andesite of Ballard Ridge Volcano**—Medium to dark gray, sparsely to moderately porphyritic with plagioclase, pyroxene, and olivine, platy flow structure, moderately lenticular lava flows derived from at least two vents.

Tfca **Basaltic andesite volcano**—Similar to Thbv and Tbrv. Smallest (< 2 km) of three volcanoes aligned northwest-southeast parallel to faults and strike of northeast-tilted layers comprising the Manzanita Volcanic Range.

Knox Mountain volcanoes [4]

Tkvc **Andesite of Knox Mountain volcanoes**—Gray to black; lavas interbedded with cogenetic pyroclastic rocks, radially dipping away from at least seven vents that are aligned about N30W sitting atop a foundation of thick Tmra lava flows.

Tsfv **Small andesite volcano**—Steep-sided, isolated, semi-symmetric and single-vented, less eroded volcano. Similar to Tkvc.

Tkft **Andesite lava flows and tuffs**—lava flows and tuff between volcanoes and primarily underlying Tmra flows. Poorly exposed.

Hayden Hill Silicic Center [5]

Twcr **Rhyolite of Willow Creek**—Gray to white; four lava flows and cogenetic (?) tuffs and slump and flow debris. Age date 8.9 Ma, Loc.11 (Obernyer, S., pers. comm., 2002)

Tdst **Tuff of Dago Spring**—White and tan; lithic , crystal, vitric block and ash flow; poorly lithified, slightly welded; similar to Tdsd petrographically and co-eruptive with it. Locally with interbeds of lake deposits. K-Ar age 9.2 Ma, Loc. 9 (Obernyer, S., pers. comm., 2002)

Tdsd **Dacite of Dago Spring**—Gray, black, red, glassy to vitrophyric with sanidine, orthopyroxene, and oligoclase-andesine phenocrysts; flow-banded and platy, extruded mostly from flow domes and dikes (especially the spectacular dikes along Highway 139 in SE1/4, Sec. 28, T37N, R10E); silica content 63.9% - a low-silica dacite (Hazlett, 1984).

Tart **Tuff of Anderson Ranch**—White and tan, heterolithic tuff breccias, pumice lapilli, crystal vitric ash-flow and ash-fall tuffs interbedded with volcaniclastic sandstones, siltstones, and mudstones. Locally intruded by dacite plugs. Altered at Hayden Hill.

Tlbb **Basalt of Letterbox Canyon**—Dark gray lava flows comprise a section over 60m thick preserved irregularly in paleocanyon of Willow Creek; northward flow indicators; sourced from Hayden Hill intrusive complex.

Twca **Basaltic andesite of Willow Creek**—Gray; finely sparsely porphyritic with augite, olivine, and labradorite phenocrysts: preserved about 100m of lava flows in one small (< 2 km) mass (Garmen, 1991).

Tbct **Tuff of Butte Creek**—Variously colored; andesitic to rhyolitic ash-fall and ash-flow lapilli tuff, bedded with fining-upward sequences, locally interbedded with andesite flows and lacustrine beds and locally moderately welded; over 200 m thick preserved irregularly in northeastern part of Hayden Hill complex. May be oldest unit in Hayden Hill complex; overlies Tmra.

Holbrook Canyon volcanoes [6]

Thca **Andesite and tuff of Holbrook Canyon volcanoes**—Basaltic andesite lavas and lesser pyroclastic interbeds dipping radially away from at least five eruptive centers of eroded and faulted volcano cluster covering about 36 km^2.

Tavv **Andesite**—Dark gray to black andesitic near-vent facies lava flows on steep-sided small volcanoes with relatively large vent on northeast side.

Tdva **Andesite and basalt**—Black to gray undifferentiated lava flows from linear local sources (dikes?) and generally related to huge McDonald – Three Peaks volcano complex to south of map (Grose and others, 2014).

Northwest Madeline volcanoes [7]

Tmma **Andesite and basalt of Northwest Madeline Volcano**—Gray to black; lava flows of aphanitic to microporphyritic basaltic andesites and basalts undifferentiated with minor pyroclastic interbeds and vent facies from plugs and dikes in at least six places on the large volcano.

Tsab **Andesite and basalt from local volcanoes**—Mafic lava flows derived from Northwest Madeline Volcano (Tmma) and Tule Mountain Volcano (Ttmb) as well as one small local source. Flows appear to be caught up within the Miocene (?) Likely fault zone.

Likely Mountain Volcano [8]

Tlma **Andesite and basalt of Likely Mountain Volcano**—Gray to black; mostly basaltic andesite lava flows with minor cogenetic pyroclastic rocks derived from several prominent crudely radial dikes and several small plugs occurring on the volcano flanks. Likely Mountain is the highest in the region and possibly slightly younger than the very similar volcanoes next door, i.e. Holbrook Canyon (Thca), Northwest Madeline (Tmma), and Tule Mountain (Ttmb).

Tule Mountain Volcano [9]

Ttmb **Basalt and andesite of Tule Mountain Volcano**—Gray to black; thin lava flows and pyroclastic and rubble interbeds sourced from six vents partially connected by dikes aligned north-south in a 5 km-long zone.

Southeast Madeline volcanoes [10]

Tmha **Andesite of Mitchell Hill Volcano**—Black to gray; andesite lava flows, platy, from nearly symmetrical small, steep-sided volcano with one central vent.

Tomb **Basalt and basaltic andesite of Olson Mountain Volcano**—Black to gray lava flows, thin to massive, platy, dipping radially from massive summit plug; nearly symmetrical steep-sided volcano, monolithologic somewhat similar to Mitchell Hill Volcano (Tmha).

Tchv **Andesite of Cochran Hill Volcano**—Black to gray; flow radially from central vent of small (2 km) symmetrical volcano.

Cold Spring Mountain Volcano [11]

Tcsma **Andesite with basalt of Cold Spring Mountain Volcano**—Gray to black; lava flows with pyroclastic interbeds sourced from at least three dike and vent centers aligned northwesterly within large composite volcano mass.

Cottonwood Mountain Volcano [12]

Tcoa **Andesite and basalt of Cottonwood Mountains Volcano**—Gray and black; numerous lava flows from several vents that collectively form a composite large shield volcano, most of which occurs to south of map (Grose and others 1992), basically similar to Cold Spring Mountain Volcano (Tcsma).

Anderson Mountain Volcano [13]

Taaf **Basaltic andesite of Anderson Mountain Volcano**—Gray; variously porphyritic with olivine, plagioglase, and pyroxene in intergranular to subophitic matrix; lava flows are locally platy, stony, and aphanitic; interbedded with cogenetic fragmental layers; derived from summit vent, plugs, and dikes occurring just to south of map (Grose and others, 2014).

McDonald Peak–Three Peaks volcanoes [14]

Tmrf **Basalt of Mendiboure Reservoir**—Medium gray to black lavas; moderately finely porphyritic with olivine and glomerocrysts of olivine, pyroxene and plagioclase; variously vesicular, aphanitic and dense; flow-on-flow sequence with some andesite and pyroclastic beds.

Tpsf **Basaltic andesite of Poulsen Spring**—Dark gray to black; sparsely finely porphyritic to microporphyritic with plagioclase and olivine phenocrysts; dense to vesicular and locally slightly diktytaxitic; derived from several vents on northwesterly alignment (Grose and others, 2014).

Probable Large Eruptive Centers

Tovc **Cedar Pass volcanic complex** [15]—Pyroclastic deposits and lesser lava flows exposed in the vicinity of Cedar Pass, up to 1200 m thick. Mostly massive and unsorted to crudely stratified debris flows and rock avalanches, though occasionally bedding is well developed. Lava blocks range in size from a few cm to >2 m, and range in texture from dark, phenocryst-poor lavas to lighter gray-green lavas with abundant phenocrysts of plagioclase and hornblende. In places, porphyritic lava flows with phenocrysts of plagioclase, hornblende, and lesser pyroxene are interbedded with the pyroclastic deposits.

Tvcu **Andesitic flows, tuffs, and intrusives of Emerson Creek Center** [16]—Huge, irregular masses of basaltic and andesitic lavas and intrusions associated with vent pyroclastic rocks that suggest a central plug and ponded lavas of a deeply eroded shield or strato-volcano (Duffield and Weldin, 1976). Overlain, at least in part by regional flows of Tabu and certainly contributes to some flows in the adjacent section.

Thvu **Rhyolitic and dacitic flows and tuffs of Red Rock Mountain** [17]—Massive, irregular lava flows and silicic tuffs including obsidian float from local buried dome, mostly covered. Extent and essential nature of inferred center are unknown.

Multiple Local and Regional Sources

Alturas Basin – Warm Springs Valley

Tdgb **Devils Garden Basalt**—Olivine tholeiite basalt. High Al, low K; dark gray to black; variously diktytaxitic to aphanitic and vesicular to dense, sparsely microporphyritic with olivine <2mm. Multiple horizontal lava flows, conformably overlying the Alturas Formation, occur along the northern margin of the map and on the present-day Alturas Plateau. The occurrences in the northern map margin mark the southern extent of the vast Devils Garden basalt plateau, which extends many kilometers into Oregon (McKee and others, 1983). The present-day Alturas Plateau was once continuous with the Devil’s Garden plateau, and both plateaus are capped by the Devil’s Garden basalt. Small plugs and shield volcanoes within a few kilometers of the map source the local flows. A K-Ar age of 2.9 ± 0.3 Ma was obtained at Loc. 4 (Potter, 1988), and is thought to be roughly representative of the Tdgb present within the map extent. However, olivine tholeiite lava flows mapped as Tdgb have yielded ages ranging from 0.63 to more than 8 Ma (Potter, 1988 and Donnelly-Nolan and Lanphere, 2005).

Tdrb **Basalt of Dorris Reservoir**—Dark gray to black lavas; moderately microporphyritic with plagioclase and lesser olivine and pyroxene, variously diktytaxitic to dense or aphanitic, subophitic; contains xenoliths up to few m in diameter of medium crystalline, black, dense olivine plagioclase-pyroxene peridotite; flows less than 20m thick extending for several km^2 as a “stray flow” entirely interbedded within the Ta 15 to 30m below Tdgb. K-Ar age of 7.8 ± 4.0 Ma at location 2 km north of map along Hwy 299 (McKee and others, 1983).

Tabpf **Pyroclastic flows of the Alturas Basin**—Tuff breccias, debris flows and lahars, and minor welded tuff. Rhyolitic to andesite pyroclasts fine to very coarse grained, angular, blocky, and rounded up to 3 m in chaotic arrangement, grading locally into thin welded layers and into finer tuff. Thickness up to 70m, but mostly less than 15 m. Resistant, topographically prominent layer which occurs irregularly in a 130 km^2 area southwest of Alturas. A local pyroclastic flow occurring within the much thicker Alturas Formation, 150 m below the overlying Devils Garden Basalt. Source inferred to be silicic calderas in the northern part of the Warner Range. $^{40}Ar/^{39}Ar$ age from a scoria fragment within Tabpf in 11.9 Ma (Carmichael and others, 2006).

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

Ta **Alturas Formation, tuff and volcaniclastic rocks**—White, light gray, tan; fine to coarse grained with minor pumice lapilli, thin to thick bedded. Increasing lake clays and fluvial volcanic sandstones in upper part (Collins, 1999). Includes pyroclastic flow (Tabpf) and local basalt (Tdrb) in exposed upper few hundred meters. One well near Canby encountered only pyroclastic rocks similar to the Alturas Formation to total depth of about 3600 feet (Dale Merrick, pers. comm.., 2008). The Alturas Formation is the most widespread unit in the region, and physical correlation with other pyroclastic sequences are problematic. The age is also enigmatic, possibly ranging from about 16 Ma to 5 Ma. Paleontologic studies indicate late Miocene and early Pliocene. The major sources of the vast volume of tuff in the Alturas area are most likely exposed in the northern and central parts of the Warner Range.

Tbmrb **Basalt of Big Meadows Reservoir**—Black to dark gray lavas; flow-on flow sequence of basalt and basaltic andesite up to 100 m thick, overlying upper tuff unit of the Alturas Formation, and occurring in several square kilometers southeast of Moon Lake.

Tccb **Basalt of Cedar Creek**—Black to gray lavas; thin to medium thickness lava flows of mostly basalt and basaltic andesite, horizontal to low west dips. Entire flow package ranges from over 400 m thick on the southeast to near zero on the northwest. Overlies Ta but interbeds with it in the south; occurs within uppermost 100 m of Ta where $^{40}Ar/^{39}Ar$ date is 12.1 Ma Loc. 37 (Carmichael and others, 2006).

Tbau **Basalt and andesite of Jess Valley**—Thin to thick bedded lava flows, microporphyritic with olivine and pyroxene to aphanitic and dense; thickness up to 400 m, dips < 5º west off tilted block of Warner Range; overlies Ta (partially) and Tabu; may intertongue with and mostly underlie Tccb; forms fine talus and landslides in canyon west of Jess Valley; several small vents indicate local origin.

Tcft **Andesite flows and tuffs undifferentiated**—Heterogeneous section, up to 60 m thick, lava flows and pyroclastic deposits, variously colored, that appear to lap up on flank of Tule Mountain Volcano; may be a facies of Ta as it underlies Tccb; contains at least one small source vent.

Tdrt **Dacite and rhyolite tuff**—Gray to white pumiceous tuff; in places it is a distinctive blue color, lightly welded pumiceous tuff that has been quarried for building stone. Most commonly is a light-gray, massive tuff breccia. Cross-bedding and interbedded gravel is common. Well rounded pebbles of obsidian are weathered out of the clay. The tuff is easily eroded so it is not well exposed and is often obscured by slope wash from overlying volcanic rocks. $^{40}Ar/^{39}Ar$ ages: Location No. 31 – 13.31±0.25 Ma; Location No. 32 – 13.73±0.42 Ma (this report). Exposed only in a small area near the southern edge of map, this tuff unit is widespread beyond and to the southeast of the map extent (Grose and others, 2014).

Tmaf **Basaltic andesite flows**—Gray to black lavas, mostly sparsely porphyritic with fine olivine, plagioclase, and pyroxene phenocrysts to aphanitic. Locally glomeroporphyritic, intergranular, dense, but locally vesicular and slightly diktytaxitic. Some interbeds of basalt, mafic flow breccias, and associated pyroclastic rocks. Primarily massive flows that are vesicular and platy near their margins. Often has distinctive green alteration blotches around vesicles. Exposed along southeastern margin of map and widespread to south (Grose and others, 2014).

Big Valley – Round Valley

Tabf **Basalt of Ambrose Valley**—Black and dark gray, aphanitic and vesicular tholeiitic basalt and basaltic andesite lavas; diktytaxitic; flows totaling < 40 m preserved in paleovalley; unfaulted; sourced from a single small plug vent on west side of Ash Valley. K-Ar date of 4.75 ± 0.36 Ma from unknown exact location (Hart, 1982). Apparently, the youngest unit in the general area.

Tbrb **Basalt of Barber Ridge**—Gray to black lavas; flows and co-genetic flow breccias and minor andesites, aphanitic to sparsely porphyritic, variously vesicular, locally > 200 m thick, mostly gradational contact with Tbrt.

Tbrt **Andesite tuffs of Barber Ridge**—Gray and brown, very fine tuff to coarse tuff breccias with volcaniclastic rocks in lower part and mainly cinder tuff breccias in upper part. Occurs in many square kilometers between Stone Coal Volcanic Complex and tuff field of Big Valley, and may represent a pyroclastic facies within an enormous caldera setting that is evident from all three volcanic areas.

Tbvt **Tuff of Big Valley**—White to gray, uniform, massive to variously bedded, fine to lapilli, mostly finely vitric; locally reworked and interstratified with volcanic sandstones, claystones, and fine conglomerates. Poorly exposed, occurs uniformly in floor of Big Valley covering about 275 square kilometers mostly to west of the map; Thickness unknown; may correlate with Tbrt, Trts and other units associated with the Stone Coal complex as well as the Hayden Hill Center.

Hayden Hill Volcanic Upland

Tsst **Tuff of Summit Spring**—Fine to coarse grained andesitic tuff, interbedded with overlying Tssb flows; < 50 m preserved in three half grabens.

Tjcd **Dacite of Juniper Creek**—Light-gray, moderately finely porphyritic with plagioclase, sanidine, hornblende, and quartz. Dense to highly vesicular. Occurs in southwest corner of map.

Tmsa **Andesite of McBride Springs**—Red, brown, purple, and gray lava flows, finely moderately porphyritic with augite, olivine and labradorite phenocrysts. Flows interbedded with tuff breccias and tuffs.

Tssb **Basalt of Summit Spring**—Dense, moderately diktytaxitic, < 100 m of lava flows subhorizontal “capping” the upland plateau.

Ttf **Andesite and basalt flows, and andesite tuffs**—Lava flows 70% and tuffs 30%. Mostly overlies Tft but may interbed with Tft as a facies. < 200 m thick.

Tft **Intermediate tuffs, andesite flows, and volcaniclastic rocks**—Tuffs 70%, lava flows 20%, and clastics 10%. Complex unit < 300 m thick, in facies relationship with Tft, TKrt, TKrf, and probably other units in Hayden Hill eruptive center.

Tkrf **Andesitic flows and lesser pyroclastic interbeds of Knudsen Ranch**—Probably in facies relationship with Tft.

Tkrt **Rhyolitic and andesitic tuffs of Knudsen Ranch**—May overly and/or interbed with Tbvt. Poorly exposed.

Tcfa **Basaltic andesite of Coyote Flat**—Gray, finely porphyritic with augite, olivine, and andesine phenocrysts. Occurs as lava flow remnants overlying several units in a northwesterly zone 2 km wide and 19 km long. Clinker and scoria at southern end suggest proximity to source, implying northward flow. Resembles occurrence of Tabf.

Tcsa **Basaltic andesite of Chicken Spring**—Gray, finely porphyritic with two-pyroxene and olivine phenocrysts, massive blocky vesicular lava apparently flowed from south to north in paleograben. K-Ar age of 7.4 ± 0.3 Ma from location 1.0 km south of margin of map (Garmen, 1991).

Tswt **Welded tuff of Stratton Spring**—Pinkish, and purplish gray; lithic, crystal, vitric lapilli ash-fall tuff with excellent pumice and obsidian fiamme. Scattered erosional remnants of a widespread welded tuff emplacement on north and east sides of Hayden Hill silicic center. K-Ar age of 9.9 ± 0.5 Ma Loc. 8 (Garman, 1991).

Tstf **Intermediate tuffs and flows of Stratton Spring**—White, gray, tan, brown, tuff breccia; composition is dominantly latite; massive to crudely bedded; minor well-bedded pumice lapilli tuff intertonguing with gray porphyritic latite lavas. Contains minor moderately welded discontinuous units. Appears to interstratify with Tskb and andesite flows locally.

Tlga **Andesite and tuff of Little Gold Hill**—Various tuffs and lava flows complexly interbedded and disorganized by slumping and faulting along Willow Creek fault zone. Probably in facies relationship with Tsut and possibly with Tft.

Tpct **Tuff of Preston Canyon**—White, gray, variously bedded, fine to coarse to lapilli, lithic, crystal, vitric tuff with local interbeds of volcaniclastic rocks. May partially interbed with Tftt and Tsut. K-Ar age of 6.4 ± 0.2 at Loc. 10 (pers. comm., McKee, E.H. and Obernyer, S., 1991).

Tas **Welded tuff and scoria vent facies**—Heterogeneous and complex assemblage of silicic and mafic tuffs, scoria, cinders, and small intrusions. Covers about 3 km^2. May be outlier of Hayden Hill center.

Tbba **Basaltic andesite of Bert Bath Spring**—Dark gray, finely sparsely porphyritic. Occurs in two small areas overlying Tdsd. Probably sourced from local dikes.

Manzanita Volcanic Range

Trpb **Basalt of Rocky Prairie**—Dark gray to black, diktytaxitic, horizontal lava flows, < 100 m thick, infilling a broad graben within the Manzanita Range. Source unknown.

Tfb **Basalt plug and flow**—Black; sparsely microporphyritic with calcic plagioclase, vesicular to dense, small local lava flow on young topography from a single plug.

Trtf **Andesite, basalt, tuff, and volcaniclastic rocks**—Complex assemblage of thinly interbedded to massive mafic lava flows, intermediate tuffs and variously welded tuffs, and volcanic sandstones. Overlies Tmra unit on moderate relief erosion surface. K-Ar age 8.2 ± 0.2 Ma Loc. 3 (McKee and others, 1983).

Tmra **Basaltic andesite and basalt of the Manzanita Range**—Gray to black; sparsely to moderately micro to finely porphyritic with plagioclase, pyroxene, and olivine, intergranular to pilotaxitic, locally with platy flow structure, medium to thick flow layering, lenticular to tabular. > 700 m thick. Sourced locally from several small-to medium-sized volcanoes. A major accumulation variously tilted to northeast and cut by northwest-trending normal faults. K-Ar age approximately 9 to 12 Ma (Grose, 2003 and Grose and Bowens, 2003).

Ttct **Tuffs of Turner Creek**—White to light gray; medium to coarse lapilli and less fine tuff with sandy tuff interbeds. Underlies Tmra flows. Relation to other tuff units in area is seriously enigmatic.

Twsa **Basaltic andesite of Walker Springs**—Gray, finely porphyritic with olivine andesine phenocrysts. Occurs as local erosional remnants.

Ash Valley

Tavb **Basalt of Ash Valley**—Black; thin basaltic lava flows, horizontal, at one locality on floor of Ash Valley, possibly a flow of Tavv volcano.

Tavt **Tuff of Ash Valley**—White, gray, black, cinder and lithic lapilli with thin, < 1 m, welded layers on lower part dipping < 5º to NE concordantly with general regional dip. Limited exposure.

Warner Range Volcanic Section

Tbc **Basaltic cinders**—Red cinders from three small eroded vents aligned northeasterly.

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

and phenocryst-poor. In the Warner Range north of map extent, these directly overlie the 27 Ma Lake City Basalts.

Tabu **Basalt and andesite of Warner Range**—Basaltic andesite and basalt flows undifferentiated. Basalt variously diktytaxitic to aphanitic, dense, locally platy. Flow sequence > 600 m thick with generally W dips up to 15º dominating highest elevations in the southern part of the Warner Range. Sourced in part from local eroded volcanoes and dikes. K-Ar ages range from 14 to 16 Ma (Duffield and McKee, 1986).

Tvt **Rhyolitic to andesitic pyroclastic rocks and minor basalt**—White to dark gray, mostly well-bedded ash, pumice, cinders, lithic fragments, with basalt more common in the south (Duffield and Weldin, 1976). Appears to be equivalent to Ttu and possibly Ttbf where thicknesses locally increase up to 300 m and source vents may occur. K-Ar ages range from 14 to 16 Ma (Duffield and McKee, 1986).

Tvb **Olivine Basalt Flows**—A series of olivine basalt lavas. Commonly porphyritic with plagioclase, olivine and pyroxene. Vesicular to dense, with zeolites common in vesicles (Duffield and Weldin, 1976). Unit is 300 to 400 m thick, comprised of up to 70 distinct flows average 6 m thickness. K-Ar ages range from 14 to 16 Ma (Duffield and McKee, 1986).

Trt **Rhyolitic tuffs and tuffaceous sediments**—A poorly exposed unit, up to 250 m. thick, consisting of biotite- and sanidine-bearing tuffaceous sandstone and siltstone and densely welded tuffs. The presence of biotite marks them as distinctly different from locally-derived pyroclastic flows. Included in Tvc mapped by Duffield and Weldin (1976), but ages of 17.3 Ma (Duffield and McKee, 1986) and 19.22 Ma (Colgan et al, 2011) suggest a significant hiatus in deposition after the underlying Oligocene layers.

Tvc **Andesite and welded rhyolite ash-flow tuff**—Composite 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 upper 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).

Ttfu **Rhyolitic tuffs**—Mostly unwelded rhyolitic tuffs, poorly exposed, that are probably a continuation of Tvcu and Thvu extrusive centers. Appears to directly underlie Tabu. Locally up to 450 m thick.

Trrt **Silicic tuffs of Red Rock Valley**—White, fine to lapilli, thin bedded to massive, relatively uniform, at least 250 m thick, probably a facies of Ta and Ttvt.

Tbcb **Basalt and lesser basaltic andesite**—Black to dark gray, finely porphyritic to aphanitic locally diktytaxitic, dense, flow-on-flow sequence of thin tabular lava flows. 400 m thick. 40Ar/39Ar age 15.4 Ma (Carmichael and others, 2006). Exposed in spectacular active fault scarp along Surprise Valley fault.

Tifau **Basaltic flows, dikes, and plugs**—Gray to black, aphanitic to porphyritic, irregularly bedded and locally intruded by many dikes and plugs, locally sourced basalt and andesite that forms an enigmatic mass about 5 km wide and 16 km long striking north-south and bounded by faults.

Tdob **Basalt of Dodge Reservoir**—Black diktytaxitic basalt; SiO_2 is 50%. Eruptive source is to south of map extent.

Tchf **Basalt, andesite, and lesser pyroclastic rocks**—Gray to black basaltic to andesitic lava flows, lenticular to tabular interbedded with cogenetic (?) intermediate pyroclastic rocks. Obscure deeply-eroded small volcanoes are local sources, < 600 m thick. May represent a facies of Tbcb.

Ttvt **Tuffs and volcaniclastic rocks of Tuledad Valley**—White, gray, tan, fine grained, mostly vitric, with some fluvial and lacustrine interbeds. Locally with petrified wood. At least 500 m of horizontal beds. May be correlative with Trrt.

Ttvtf **Mafic flow of Tuledad Valley**—Stray mafic lava flow within Ttvt.

Tbcat **Andesite to rhyolite tuffs**—White to tan; fine to coarse grained. Locally and poorly exposed underlying Tbcb and Tchf. May be a facies correlative with Ttfu and Ttvt. Less than 200 m thick.

Ttu **Rhyolitic flow, tuff, and intrusive complex**—Multi-colored complex of rhyolitic tuffs and minor andesitic lavas and tuffs; discontinuous; bedded to massive, locally welded, cut by massive domal intrusives and eroded cinder cones (Duffield and Weldin, 1976). Limited exposure and preservation east of Jess Valley suggest a large silicic center. May partially correlate with Ttfu. K-Ar ages of 14.5 ± 0.4 Ma and 16.0 ± 0.5 Ma (Duffield and McKee, 1986).

Ttbf **Andesite, basaltic, and tuffaceous beds**—Irregular and discontinuous lava flows and pyroclastic rocks obscured by slumping from overlying units. 15º M dip, may represent outflow of facies of Ttu. Poorly exposed.

Tppa **Basalt and andesite of Payne Peak**—Medium to dark gray andesitic and basaltic lavas, moderately finely porphyritic with plagioclase, clinopyroxene, and lesser olivine. Intergranular to subophitic, seriate pyroxene. 100 m thick, erosional remnant of flows. Flows cap Payne Peak and surrounding high points. May be derived from local intrusion. $^{40}Ar/^{39}Ar$ age 30.0 Ma (Carmichael and others, 2006).

Tlw **Lost Woods Formation**—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**—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.

Ts **Steamboat Formation, undifferentiated**—Undifferentiated sedimentary unit that includes both members of the Steamboat formation. (Egger)

Tscc **Steamboat Formation, Cougar Cliffs Member**—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**—Primarily fine-grained volcaniclastic sediments, including a lacustrine shale with abundant leaf fossils of late Eocene-early Oligocene age (Myers, 2006).

Surprise Valley

Tovh **Hays Volcano**—Volcanic edifice in the Hays Canyon Range composed of basaltic andesite lava flows, agglutinate, and scoriaceous tuffs. Two dates from flows within the volcanic sequence suggest rapid flow accumulation: a flow near the more eroded core was dated at 23.91 ± 0.13 Ma, and a flow on the top flank was dated at 24.55 ± 0.16 Ma (Carmichael et al, 2006).

References Cited

Bowens, T.E., 1998, Geology and mineral deposit reconnaissance in the Stone Coal Valley region, Modoc County, California: Colorado School of Mines, unpublished M.Sc. thesis, 131 p.

Bowens, T.E. and Grose, T.L.T., 2001, Probable Mid-Miocene caldera in the Modoc Plateau, northeast California: EOS Transactions, American Geophysical Union, v. 82, no. 47, Nov. 30, p. F 1406 (abstract)

Bryant, W.A., 1990, Surprise Valley and related faults, Lassen and Modoc counties, California: California Division of Mines and Geology, Fault Evaluation Report FER-217.

Bryant, W.A., 1991, Likely fault zone, Lassen and Modoc counties, California: California Division of Mines and Geology, Fault Evaluation Report FER-218.

California Department of Water Resources, 1963, Northeastern counties ground water investigation, Bulletin 98.

Carmichael, I.S.E., Lange, R.A., Hall, C.M., and Renne, P.R., 2006, Faulted and tilted Pliocene olivine-tholeiite lavas near Alturas, NE California, and their bearing on the uplift of the Warner Range: Geological Society of America Bulletin, v. 118, no. 9-10, p. 1196-1211.

Colgan, J.P., Dumitru, T.A., Reiners, P.W., Wooden, J.L., and Miller, E.L., 2006, Cenozoic tectonic evolution of the Basin and Range province in northwestern Nevada: American Journal of Science, v. 306, p. 616-654.

Colgan, J.P., Egger, A.E., John, D.A., Cousens, B., Fleck, R.J., and Henry, C.D., 2011, Oligocene and Miocene arc volcanism in northeastern California: Evidence for post-Eocene segmentation of the subducting Farallon plate: Geosphere, v. 7, no. 3, p. 733-755.

Collins, N.E., 1999, Stratigraphy and geochemistry of the Alturas Formation, Modoc Plateau, northeastern California: Humboldt State University, Arcata, M.S. Thesis.

Detra, E.H. and Burnett, J.L., 1994, Geology of Hayden Hill: California Geology, v. 47, no. 5, p. 134-138.

Donnelly-Nolan, J.M., and Lanphere, M.A., 2005, Argon dating at and near Medicine Lake volcano, California: Results and data: U.S. Geological Survey Open-File Report 2005-1416, p. 37.

Duffield, W.A. and McKee, E.H., 1986, Geochronology, structure, and basin-range tectonism of the Warner Range, northeastern California: Geological Society of America Bulletin, v. 97, no. 2, p. 142-146.

Duffield, W.A., Weldin, R.D., and Davis, W.E., 1976, Mineral Resources of the South Warner Wilderness, Modoc County, California: U.S. Geological Survey Bulletin 1385-D, p. 31.

Egger, A.E., 2010, Geological history and structural evolution of the Warner Range and Surprise Valley, northwestern margin of the Basin and Range Province [Ph.D. thesis]: Stanford University, 180 p.

Egger, A.E., 2014, Paleoearthquake magnitudes derived from lidar-based mapping of fault scarps in the northwestern Basin and Range: Geological Society of America Abstracts with Programs, v. 46, no. 6, p. 777.

Egger, A.E., Colgan, J.P., and York, C., 2009, Provenance and paleogeographic implications of Eocene-Oligocene sedimentary rocks in the northwestern Basin and Range: International Geology Review, v. 51, p. 900-911

Egger, A.E., Glen, J.M.G., and McPhee, D.K., 2014, Structural controls on geothermal circulation in Surprise Valley, California: A re-evaluation of the Lake City fault zone: Geological Society of America Bulletin, v. 126, no. 3-4, p. 523-531.

Egger, A.E. and Miller, E.L., 2011, Evolution of the northwestern margin of the Basin and Range: The geology and extensional history of the Warner Range and environs, northeastern California: Geosphere, v. 7, no. 3, p. 756-773.

Garman, C.E., 1991, Geology and tectonism of the northeast Hayden Hill area, Lassen County, California: Colorado School of Mines, unpublished M.S. thesis T 3987, 84 p.

Gay, T.E. and Aune, Q.A., 1958, Geologic map of California – Alturas sheet: California Division of Mines and Geology, scale 1:250,000.

Grose, T.L.T., 2003, Geologic map of the Likely 15' quadrangle, Lassen and Modoc counties, California: California Geological Survey, scale 1:62,500, unpublished map.

Grose, T.L.T., 2004, Geologic map of the Alturas 15' quadrangle, Modoc County, California: California Geological Survey, scale 1:62,500, unpublished map.

Grose, T.L.T., 2005a, Geologic map of the Dorris Reservoir 7.5’ Quadrangle, Modoc county, California: California Geological Survey, scale 1:24,000, unpublished map.

Grose, T.L.T., 2005c, Geologic map of the Jess Valley 7.5' quadrangle, California: California Geological Survey, scale 1:24,000, unpublished map.

Grose, T.L.T., 2006a, Geologic map of the Shields Creek 7.5' quadrangle, California: California Geological Survey, scale 1:24,000, unpublished map.

Grose, T.L.T., 2006b, Geologic map of the Soup Creek 7.5' quadrangle, California: California Geological Survey, scale 1:24,000, unpublished map.

Grose, T.L.T., 2008a, Geologic map of the Boot Lake 7.5' quadrangle, California: California Geological Survey, scale 1:24,000, unpublished map.

Grose, T.L.T., 2008b, Geologic map of the Cold Spring Mtn. 7.5' quadrangle, California: California Geological Survey, scale 1:24,000, unpublished map.

Grose, T.L.T., 2008c, Preliminary geologic map of the Eagleville 7.5' quadrangle, California: California Geological Survey, scale 1:24,000, unpublished map.

Grose, T.L.T., 2008d, Preliminary geologic map of the Hansen Island 7.5' quadrangle, California: California Geological Survey, scale 1:24,000, unpublished map.

Grose, T.L.T., 2008e, Preliminary geologic map of the Little Hat Mtn. 7.5' quadrangle, California: California Geological Survey, scale 1:24,000, unpublished map.

Grose, T.L.T., 2008f, Preliminary geologic map of the Snake Lake 7.5' quadrangle, California: California Geological Survey, scale 1:24,000, unpublished map.

Grose, T. L. T. and Bowens, T. E., 2003, Geologic map of the Canby 15' quadrangle, Modoc County, California: California Geological Survey, scale 1:62,500, unpublished map.

Grose, T. L. T. and Egger, A. E., in progress, Geologic map of the Cedarville 30’ x 60’ Quadrangle, Modoc County, California: California Geological Survey, scale 1: 100,000.

Grose, T.L.T., Garman, C., Obernyer, S., and Bowens, T.E., 2004, Geologic map of the Adin 15' quadrangle, Modoc and Lassen counties, California: California Geological Survey, scale 1:62,500, unpublished map.

Grose, T. L. T., Saucedo, G. J., and Wagner, D. L., 2014, Preliminary Geologic Map of the Eagle Lake 30' x 60' Quadrangle, Lassen County, California: California Geological Survey, scale 1:100,000

Grose, T.L.T. and Travis, C.A., 2006, Geologic Map of the Hackamore 15' Quadrangle, Modoc County, California: U.S. Forest Service, Modoc National Forest, Alturas, Scale 1:62,500, unpublished map.

Hart, W. K., 1982, Chemical, geochronologic, and isotope significance of low-K, high-alumina olivine tholeiite in the northwestern Great Basin, U.S.A.: Case Western Reserve University, Cleveland, unpublished PhD thesis, 410 p.

Hazlett, D. P., 1984, A volcanotectonic and paleomagnetic investigation in the Hayden Hill area, northeastern California: Colorado School of Mines MSc thesis, unpublished, 155 p.

Hedel, W. C., 1984, Maps showing geomorphic and geologic evidence for late Quaternary displacement along the Surprise Valley and associated faults, Modoc County, California: Miscellaneous Field Studies Map: U.S. Geological Survey Report 1429, 2 sheets, scale 1:62,500

Ibarra, D.E., Egger, A. E., Weaver, K.L., Harris, C.R., and Maher,K., 2014, Rise and fall of late Pleistocene pluvial lakes in response to reduced evaporation and precipitation: Evidence from Lake Surprise, California: Geological Society of America Bulletin, v. B31014.1, p. 30.

Jenkins, O.P., 1959, Geology of northeastern California: Mineral Information Service v. 12, p. 1-8.

Macdonald, G. A., 1966, Geology of the Cascade Range and Modoc Plateau in Bailey, E. H., editor, Geology of Northern California: California Division of Mines and Geology Bulletin 190, p. 65-96

Myers, J.A., 1998, Paleovegetational heterogeneity and the record of Eocene-Oligocene climate change in the interior Pacific Northwest [PhD thesis]: University of California at Santa Barbara, 503 p.

Myers, J.A., 2006, The latest Eocene Badger's Nose flora of the Warner Mountains northeast California; the "in between" flora: PaleoBios, v. 26, p. 11-29.

McKee, E. H., Duffield, W. A., and Stern, R. J., 1983, Late Miocene and early Pliocene basaltic rocks and their implications for crustal structure, northeastern California and south-central Oregon: Bull. Geol. Soc. Amer., v.94, p. 292-304

Obernyer, S., 2002, Geologic map of northern Hayden Hill, Lassen County, California: Colorado School of Mines, unpublished mapping.

Personius, S.F., Crone, A.J., Machette, M.N., Mahan, S.A., and Lidke,D. J., 2009, Moderate rates of late Quaternary slip along the northwestern margin of the Basin and Range Province, Surprise Valley fault, northeastern California: Journal of Geophysical Research, v. 114, no. B09405, p. 17.

Potter, S. L., 1988, Geology of the northern portion of the Likely fault lineament, Modoc County, northeastern California: Humboldt State University, Arcata, MS thesis, unpublished.

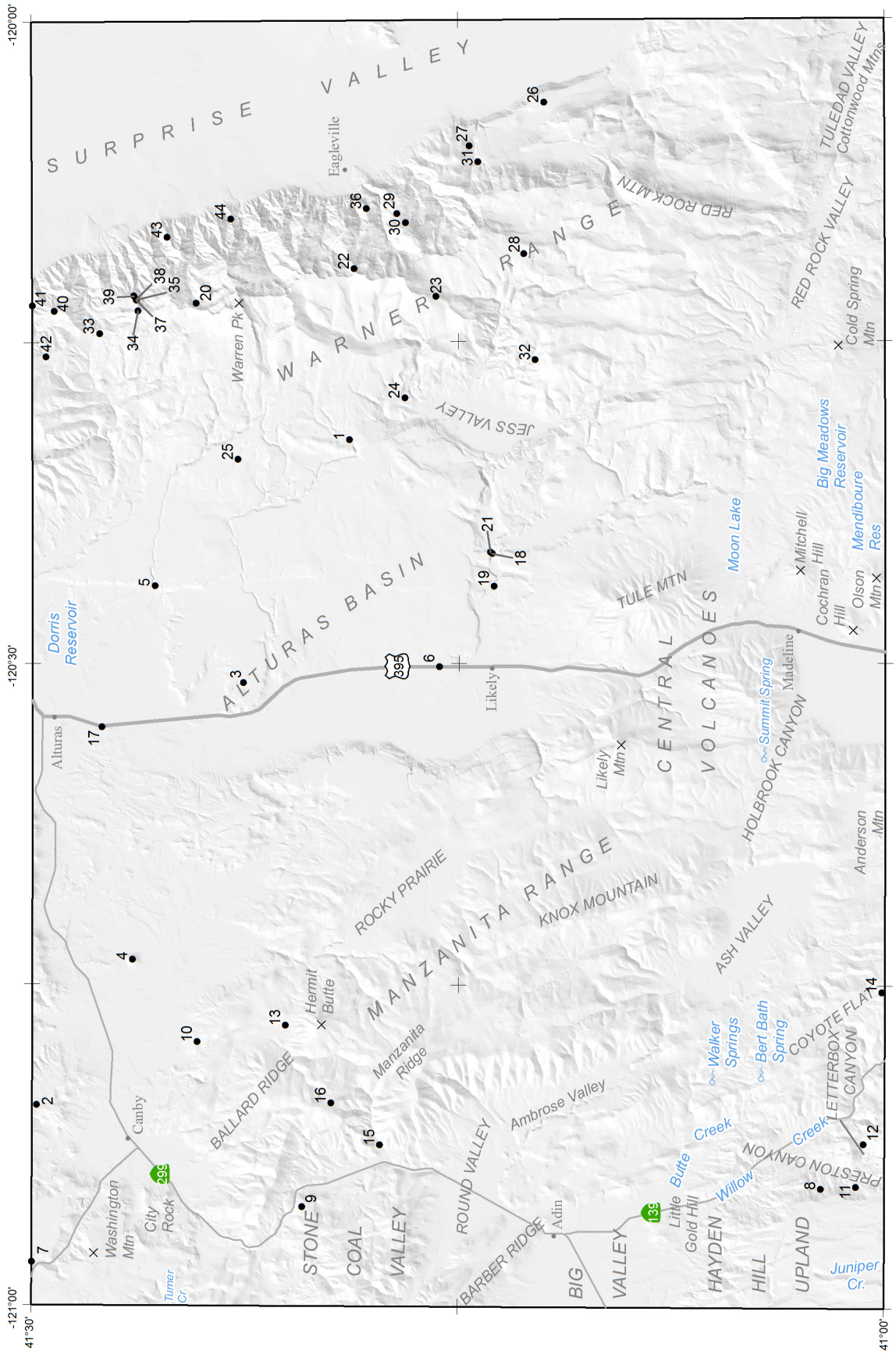


Figure 3. Map of the Alturas 30’x 60’quadrangle showing the locations of volcanic rocks dated by radiometric methods (numbers correspond to Location Numbers in Table 1).

Table 1. K-Ar ages of volcanic rocks within the Alturas 30'x60' quadrangle. Location Number refers to Figure 3 and geologic map.

Location Number	Sample	Rock Type	Map Unit	Latitude (North)	Longitude (West)	Age (Ma)	Reference
1	SV-139	LKOT	Tdgb	41.3142	120.3263	2.76 ± 0.20	Carmichael et al, 2006
2	–	Basalt	Tdgb	41.4972	120.8443	2.9 ± 0.3	Potter, 1988
3	SV-137	LKOT	Tdgb	41.3765	120.5152	2.94 ± 0.10	Carmichael et al., 2006
4	–	–	p (Tdgb?)	41.4412	120.7310	3.1	Collins, 1999
5	SV-27	LKOT	Tdgb	41.4283	120.4400	3.98 ± 0.06	Carmichael et al., 2006
6	SV-35	LKOT	Tdgb	41.2615	120.5028	4.61 ± 0.15	Carmichael et al., 2006
7	Alt 18	Basalt	Tdgb*	41.5000	120.9667	6.0 ± 4.2	McKee et al., 1983
8	–	–	Tpct	41.0375	120.9078	6.4 ± 0.2	McKee and Obernyer, 1991
9	Alt 1	Basalt	Tscb	41.3417	120.9233	7.8 ± 4.3	McKee et al., 1983
10	Alt 22	Andesite	Trtf	41.4033	120.7950	8.2 ± 0.2	McKee et al., 1983
11	–	–	Twcr	41.0168	120.9062	8.9	Obernyer, 2002
12	–	–	Tdst	41.0124	120.8731	9.2	Obernyer, 2002
13	–	Andesite	Tmra	41.3516	120.7819	9.3 ± 1.0	Potter, 1988
14	–	–	Tswt	41.0019	120.7555	9.9 ± 0.5	Garman, 1991
15	–	Andesite	Tmra	41.2961	120.8748	11.1 ± 0.9	Potter, 1988
16	–	Andesite	Tmra	41.3246	120.8424	11.5 ± 0.9	Potter, 1988
17	SV-52-2	Andesite glass	Tabpf	41.4593	120.5498	11.9 ± 0.08	Carmichael et al., 2006
18	SV-136	Basaltic andesite	Tccb	41.231	120.415	12.12 ± 0.05	Carmichael et al., 2006
19	SV-59	Pumice	Ta	41.2295	120.4403	13.52 ± 0.06	Carmichael et al., 2006
20	D173B	Basalt	Tvb	41.4039	120.2200	14.0 ± 0.4	Duffield and McKee, 1986
21	SV-31	Pumice	Ta	41.2315	120.4140	14.09 ± 0.13	Carmichael et al., 2006
22	D235B	Basalt	Tabu	41.3111	120.1933	14.1 ± 0.4	Duffield and McKee, 1986
23	D418B	Basalt	Tabu	41.2633	120.2150	14.1 ± 0.4	Duffield and McKee, 1986
24	D398B	Rhyolite	Ttu†	41.2817	120.2939	14.5 ± 0.4	Duffield and McKee, 1986
25	SV-142	Basalt	Tbau	41.3795	120.3415	14.57 ± 0.08	Carmichael et al., 2006
26	SV-126	Basalt	Tbcb	41.1997	120.0645	15.36 ± 0.08	Carmichael et al., 2006
27	R53B	Rhyolite	Tmr	41.2433	120.0983	15.5 ± 0.5	Duffield and McKee, 1986
28	D474B	Basalt	Tabu	41.2117	120.1822	15.7 ± 0.4	Duffield and McKee, 1986
29	D144B	Basalt	Tvb	41.2861	120.1506	15.7 ± 0.5	Duffield and McKee, 1986
30	D302B	Basalt	Tvb	41.2811	120.1578	15.8 ± 0.5	Duffield and McKee, 1986
31	R54B	Rhyolite	Tvt	41.2383	120.1106	15.9 ± 0.5	Duffield and McKee, 1986
32	BT-1	Rhyolite	Ttu	41.2053	120.2644	16.0 ± 0.5	Duffield and McKee, 1986
33	1011	Ashflow tuff	Trt	41.4606	120.2433	17.3 ± 0.6	Duffield and McKee, 1986
34	JC08-WR410	Reworked tuff	Trt	41.4380	120.2257	19.22 ± 0.27	Colgan et al., 2011
35	07-C-10	Andesite lava flow	Tvc	41.4392	120.2170	24.47 ± 0.34	Colgan et al., 2011
36	D79B	Ashflow tuff	Tvc	41.3039	120.1467	25.4 ± 1.0	Duffield and McKee, 1986
37	JC08-WR412	Ashflow tuff	Tvc	41.4388	120.2173	25.765 ± 0.061	Colgan et al., 2011
38	D27B	Ashflow tuff	Tvc	41.4389	120.2164	26.3 ± 1.0	Duffield and McKee, 1986
39	JC08-WR411	Ashflow tuff	Tvc	41.4405	120.2142	26.526 ± 0.058	Colgan et al., 2011
40	WR07-AE49	Basalt plug	Tvc	41.4870	120.2260	26.86 ± 0.08	Colgan et al., 2011
41	699-15A	Andesitic ash	Tdc	41.5000	120.2217	28.8 ± 1.1	Duffield and McKee, 1986
42	SV-70a	Basaltic andesite	Tppa	41.4920	120.2612	30.02 ± 0.52	Carmichael et al., 2006
43	D113B	Andesitic ash	Tscc	41.4208	120.1683	31.1 ± 1.3	Duffield and McKee, 1986
44	D63B	Andesitic ash	Tscc	41.3833	120.1544	33.9 ± 2.7	Duffield and McKee, 1986

Notes:

Rock Type: LKOT refers to low-potassium olivine tholeiite

***** Unresolved discrepancy between map unit and sample unit. This may result from several factors, including: 1) inability of map scale to fully represent local geology, 2) map error, 3) erroneous latitude/longitude values, 4) sampling errors (e.g. sample not in-place).

† Coordinates plot in landslide deposit.

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

Table 2. Terminology used in the description of volcanic rocks.

Porphyritic volcanic rock features		
Abundantly porphyritic	--	phenocrysts >20% (volume)
Moderately porphyritic	--	phenocrysts 5-20%
Sparsely porphyritic	--	phenocrysts <5%
Coarsely porphyritic	--	phenocrysts >5 mm (size)
Finely porphyritic	--	phenocrysts 1-5 mm
Microporphyritic	--	phenocrysts <1 mm
Volcanic rock names		
Basalt	--	<52% SiO_2 (weight %)
Basaltic andesite	--	52-57%
Andesite	--	57-63%
Dacite	--	63-68%
Rhyodacite	--	68-72%
Rhyolite	--	>72%
Example - *sparsely finely olivine porphyritic basaltic andesite; abundantly coarsely plagioclase, sanidine porphyritic dacite.*		