Text and references to accompany Nevada Bureau of Mines and Geology Map 117

GEOLOGY OF THE SOUTHERN PART OF THE TOE JAM MOUNTAIN QUADRANGLE

ELKO COUNTY, NEVADA

by Christopher D. Henry and David R. Boden

INTRODUCTION

The Toe Jam Mountain Quadrangle lies in the northern Tuscarora Mountains in western Elko County in northeastern Nevada (figs. 1, 2). The quadrangle covers the southwestern part of the Tuscarora volcanic field, which is the largest Eocene volcanic field in Nevada. Geologic mapping of the Toe Jam Mountain Quadrangle is part of a broader project, which includes mapping of the Mount Blitzen and Tuscarora Quadrangles to the east (Henry and Boden, 1998; Henry and others, 1999), to 1) understand Eocene magmatism and tectonism and their relation to major Carlin-type gold deposits in the region, 2) understand the setting of volcanic-hosted gold deposits in and around the Tuscarora volcanic field, and 3) ensure environmentally sound mineral production if major deposits were found in the area.

Eocene igneous rocks are widespread in northeastern Nevada, but until recently, only regional or reconnaissance studies had been done on these rocks (Berger and others, 1991; Boden and others, 1993; Brooks and others, 1995a, b). Other than our new mapping, published geologic maps of the Tuscarora volcanic field are either small scale (e.g., Elko County, 1:250,000, Coats, 1987) or cover only small areas (Tuscarora mining district, 1:6,000, Crawford, 1992).

Published reconnaissance and our new work indicate that the Tuscarora volcanic field includes several volcanic centers that were active during an intense period of magmatism between about 39.9 and 39.3 Ma (McKee and others, 1976; Berger and others, 1991; Crawford, 1992; Boden and others, 1993; Henry and Boden, 1998; Henry and others, 1998). Volcanic rocks of the Tuscarora volcanic field erupted through complexly deformed Paleozoic rocks, which are similar to those that crop out extensively to the south in the southern part of the Tuscarora Mountains and to the east in the Independence Mountains. Eocene volcanism was in part contemporaneous with extension in the region (Clark and others, 1985; Brooks and others, 1995a; Janecke and others, 1997). Middle Miocene volcanic rocks erupted from sources near Midas lap onto the western part of the volcanic field, and younger Miocene rocks of the Owyhee Plateau cover the field on the north and northwest. Independence Valley separates the Tuscarora volcanic field from the Independence Mountains to the east.

Rock units in the Toe Jam Mountain Quadrangle include 1) highly folded and probably thrust-faulted Paleozoic chert, siltstone, and quartzite; 2) a complex assemblage of Eocene volcanic and intrusive rocks erupted during several episodes from local and possibly more distant sources; 3) minor Miocene tuff erupted from sources to the west; and 4) Quaternary alluvial fan deposits shed westward from high areas in the eastern part of the quadrangle and from the Mount Blitzen Quadrangle (fig. 2). General characteristics of the rocks are described on the map. This discussion focuses on regional setting and significance, especially the volcanic-tectonic history.

PALEOZOIC ROCKS

Stratigraphy

Paleozoic rocks in the quadrangle are part of what is generally termed the western siliceous or allochthonous assemblage, which is interpreted to comprise the upper plate of the Roberts Mountains allochthon (Coats, 1987). Two similar but distinct packages of Paleozoic rocks crop out along the northeastern edge of the quadrangle and in two small areas in the southern part. The northern package contains pods or lenses of quartzite within siltstone, chert, argillite, and minor limestone. The southern package consists of chert, siltstone, and sandstone. Based on our work in the Mount Blitzen Quadrangle and on regional studies by others, rocks in the northern area are Ordovician (but possibly ranging to Devonian) and were thrust southeastward over rocks in the southern area, which are in part Devonian and Silurian.

The quartzite is equivalent to the middle Ordovician Valmy Formation (Merriam and Anderson, 1942; Roberts, 1964; Churkin and Kay, 1967; Ketner, 1966, 1975; Miller and Larue, 1983; Miller and others, 1984; Adams, 1996). Churkin and Kay (1967) and Miller and Larue (1983) concluded that the McAfee Quartzite, the equivalent of the Valmy Formation in the Independence Mountains, accumulated on the continental slope contemporaneously with deposition of Eureka Quartzite on the continental shelf to the east. However, Coats (1987) found Devonian fossils in limestone interbedded with siltstone, chert, and quartzite in the Tuscarora Quadrangle. Therefore, rocks of the northern package may range from Ordovician to Devonian.

Most quartzite appears to form boudins a few meters to about 300 m long and 1 to 100 m thick within siltstone. The pods have faulted, commonly striated surfaces and are surrounded by variably deformed siltstone. Mapping in the Mount Blitzen Quadrangle (Henry and Boden, 1998) indicates some quartzite bodies form lenses interbedded with chert and siltstone. The discontinuous nature of the quartzite probably reflects both primary stratigraphic relations and tectonic disruption. Churkin and Kay (1967) and Miller and Larue (1983) interpreted probably correlative quartzite in the northern Independence Mountains to be areally restricted channel deposits within a continental slope or rise. The more competent quartzite beds were probably deformed into boudins within a less competent, more ductile matrix of siltstone during Paleozoic deformation.

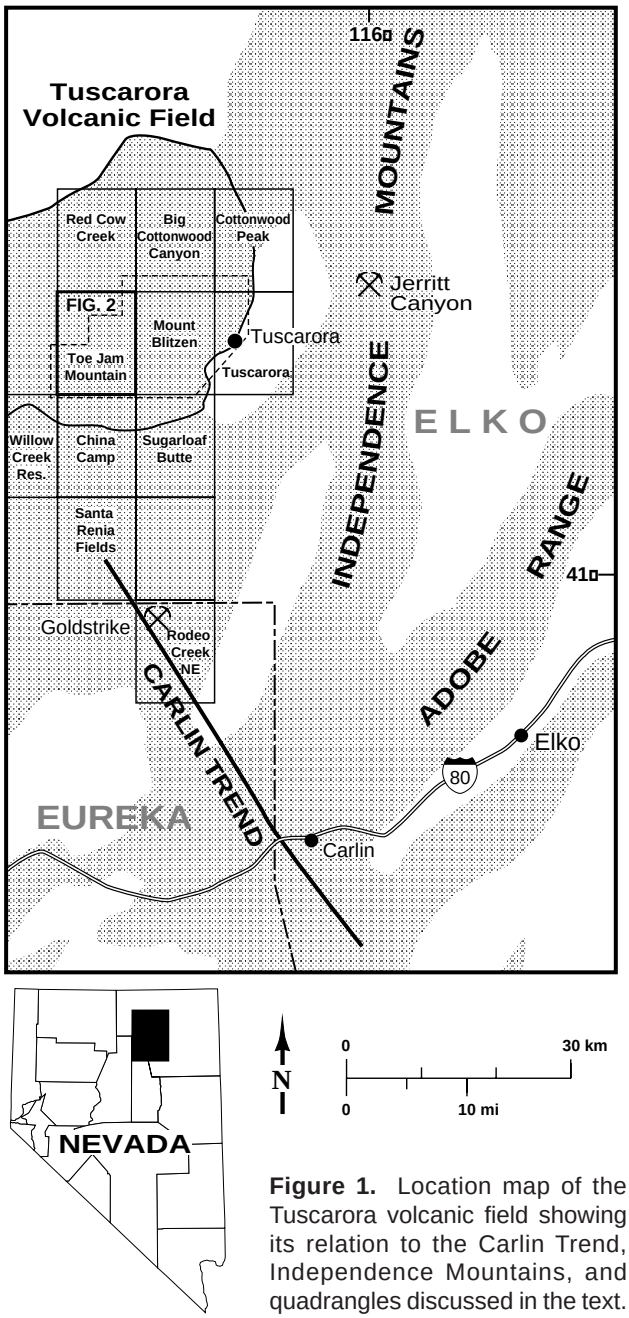

Figure 1. Location map of the Tuscarora volcanic field showing its relation to the Carlin Trend, Independence Mountains, and quadrangles discussed in the text.

Chert and siltstone in the southern package are similar to those in the north, but quartzite is absent. Also, conodonts from three limestone samples from the southern package in the Mount Blitzen Quadrangle are Devonian and Silurian (A. E. Saucier, written commun., 1997; Henry and Boden, 1998).

The rocks are highly folded and probably thrust faulted, similar to deformation in correlative rocks locally and regionally (Kerr, 1962; Churkin and Kay, 1967; Evans and Theodore, 1978; Saucier, 1997; Henry and Boden, 1998). Beds generally strike east to northeast and dip moderately to the northwest. Exceptions are immediately adjacent to the major north-striking fault in the eastern part of the quadrangle, where beds strike more northerly and dip to the west, and in the southern part of the quadrangle, where beds strike east and dip moderately to the south. These exceptions are probably due to drag along the major fault and to moderate (~30°) eastward tilting resulting from Cenozoic extension in the south. Correcting for these later events restores the beds to a east-northeast strike and northwest dip, similar to attitudes in the Mount Blitzen Quadrangle (Henry and Boden, 1998). Orientations of small-scale folds and thrust faults in the Mount Blitzen Quadrangle indicate contraction with transport toward the southeast. Henry and Boden (1998) interpreted a major east-northeast-striking, northwest-dipping thrust fault that places the Ordovician quartzite-bearing package over the Devonian-Silurian package. Polished surfaces and slickenlines on quartzite pods in the Toe Jam Mountain Quadrangle are consistent with these interpretations. The major thrust fault is not exposed in the Toe Jam Mountain Quadrangle, but extrapolation from its inferred position to the east places it between the northern and southern outcrops. Timing of deformation can only be constrained as post-Devonian and pre-Eocene in the Toe Jam Mountain Quadrangle. Regional considerations suggest that the deformation is part of the mid-Paleozoic Antler orogeny (Silberling and Roberts, 1962; Roberts, 1964; Evans and Theodore, 1978; Saucier, 1997).

TERTIARY IGNEOUS AND VOLCANICLASTIC ROCKS

At least seven major episodes of Eocene magmatism occurred in the southern part of the Tuscarora volcanic field (fig. 2). From oldest to youngest, these episodes are: 1) a regional, rhyolitic ash-flow tuff, the tuff of Nelson Creek (Tnt), derived from an unknown source (39.9 Ma); 2) andesitic to dacitic lavas and tuffaceous sedimentary rocks of the Pleasant Valley volcanic complex (39.8 to 39.7 Ma); 3) dacitic domes, small-volume pyroclastic-flow deposits, and epiclastic deposits of the Mount Blitzen volcanic center (between 39.8 and 39.7 Ma); 4) rhyolitic ash-flow tuff of the Big Cottonwood Canyon caldera (39.7 Ma); 5) dacitic intrusions, a granodiorite stock, and andesitic to rhyolitic dikes of the Mount Neva intrusive episode (39.5 to 39.3 Ma); 6) andesitic and dacitic lavas of Sixmile Canyon (39.3 Ma) and possibly correlative lavas of the Falcon Mine; and 7) lavas of the rhyolite of Walker Mountain (35.2 Ma).

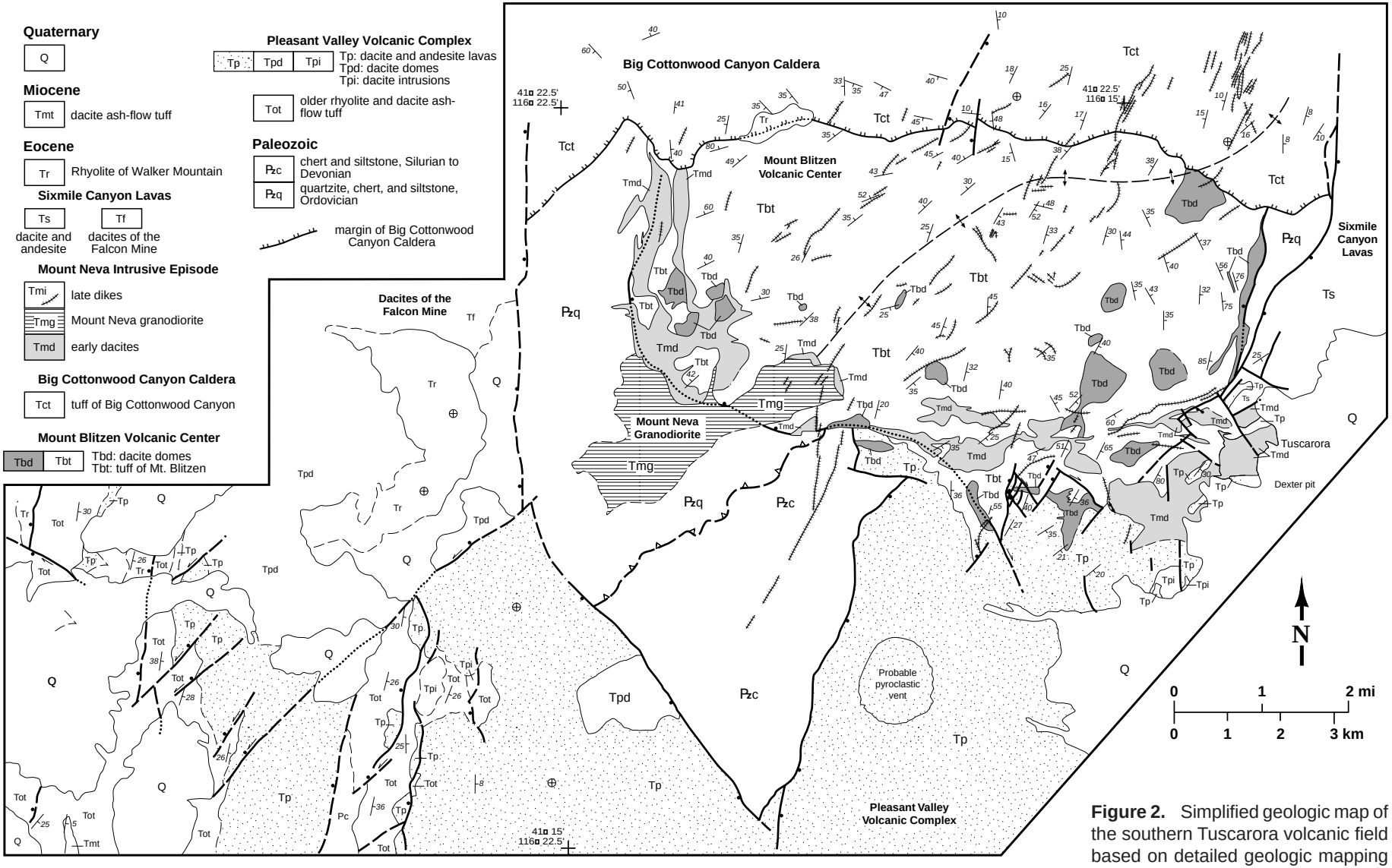

Figure 2. Simplified geologic map of the southern Tuscarora volcanic field based on detailed geologic mapping of the Toe Jam Mountain, Mount Blitzen, and Tuscarora Quadrangles (west to east).

Outcrop, petrographic, chemical, and $^{40}Ar/^{39}Ar$ age data (figs. 3, 4, and 5; tables 1 and 2) indicate that most of the rocks are genetically related and erupted or intruded from sources within the southern part of the volcanic field. Of these, all but rocks of the Mount Blitzen center, Mount Neva intrusive episode, and lavas of Sixmile Canyon crop out in the Toe Jam Mountain Quadrangle. Rocks of the Pleasant Valley volcanic complex and Big Cottonwood Canyon caldera definitely or likely erupted from sources within the quadrangle. Miocene (15.3 Ma) ash-flow and air-fall tuff crop out in the southwestern corner of the quadrangle.

Early Tuffs and Lavas

A sequence of tuffaceous rocks, including one major (tuff of Nelson Creek) and three minor ash-flow tuffs, and some andesite lavas crop out in the southern and western parts of the quadrangle. The lavas crop out only in the southwestern corner of the quadrangle and must be locally derived, although no vents are known. The lower southwestern andesite (Tea_1) is the stratigraphically lowest (i.e., oldest) Tertiary volcanic rock in the quadrangle, and its base is not exposed.

The tuff of Nelson Creek (Tnt) is interbedded with the andesite lavas in the southwest but rests directly upon Paleozoic rocks in the southern part of the quadrangle. The widespread tuff crops out over an east-west distance of 40 to 50 km from the Willow Creek Reservoir Quadrangle to the southwest, where it also rests directly upon Paleozoic rocks (Wallace, in preparation), to the southeastern corner of the Tuscarora Quadrangle, where it is interbedded with tuffaceous sedimentary rocks (Henry and others, 1999), and possibly into the eastern Independence Mountains. Chemical analyses show that the tuff is low-silica rhyolite (table 1). $^{40}Ar/^{39}Ar$ ages on sanidine from three samples (one in the Tuscarora Quadrangle and two in the Toe Jam Mountain Quadrangle) indicate the tuff is about 39.9 Ma (fig. 5; table 2). The source of the tuff is unknown, but the considerable thickness of densely welded tuff suggests a nearby caldera source. It may have been an early eruption from the Big Cottonwood Canyon caldera.

Another low-silica rhyolite, the tuff of Toe Jam Creek (Tjt), is widespread in the central and western parts of the quadrangle but dies out about 2 km north of the southern edge. Although undated, ages on over- and underlying units constrain it to be about 39.9 Ma also. Its distribution and possible thickening to the northwest suggest that it may be a distal ash-flow tuff derived from a source in that direction. The marker tuff (Tt_{2m}) is also low-silica rhyolite and crops out only in the south-central part of the quadrangle, where it forms a thin (≤2 m), distinctive marker bed. An $^{40}Ar/^{39}Ar$ age on plagioclase is 39.75±0.49 Ma (fig. 5; table 2), and ages on more precisely dated, over- and underlying rocks indicate it must be about 39.9 or 39.8 Ma. Its source is unknown but presumably nearby. The dacite ash-flow tuff (Ttd) crops out only in a small area just south of Louis Creek directly beneath lavas of the Pleasant Valley complex. However, a petrographically indistinguishable and probably correlative tuff directly underlies Pleasant Valley lavas in the Sugarloaf Butte Quadrangle to the southeast. An $^{40}Ar/^{39}Ar$ date on tuff in the Sugarloaf Butte Quadrangle is 39.84±0.10 Ma (table 2; sample H96-32). The stratigraphic position and similarity in composition, phenocryst assemblage, and age of the dacite tuff to the Pleasant Valley rocks suggest that the tuff may be an early pyroclastic eruption of the Pleasant Valley complex. However, its source is unknown and need not be nearby.

The early tuff sequence is as much as 400 m thick in the south-central and western parts of the Toe Jam Mountain Quadrangle but wedges out to the east beneath lavas of the Pleasant Valley complex (section B-B'). Pleasant Valley rocks rest directly upon Paleozoic rocks in the southern part of the Mount Blitzen Quadrangle (Henry and Boden, 1998). Although the tuff of Nelson Creek reappears still farther east, this relation suggests that the south-central Toe Jam Mountain Quadrangle was a broad basin and the southern Mount Blitzen Quadrangle was a topographic high at the time the units were emplaced. Continuity of the various tuffs across the apparent basin and lack of identifiable fault boundaries to it indicate that the basin was not a graben. All faults that cut and tilt the volcanic sequence are younger than the 35.2-Ma rhyolite of Walker Mountain.

Based upon a poorly constrained gravity low in the area (Erwin and others, 1985), Berger and others (1991) speculated that a large (~20-km diameter) caldera was centered on Toe Jam Mountain. Our mapping shows that a caldera is definitely not present there. The early tuffs are outflow deposits that are too thin to constitute intracaldera tuff, and no caldera boundary faults are present.

Pleasant Valley Volcanic Complex

The Pleasant Valley volcanic complex, the most voluminous volcanic center within the Toe Jam Mountain Quadrangle, consists of andesitic to dacitic lavas and lava domes, shallow intrusions, tuff, volcaniclastic sedimentary rocks, and coarse breccia. Sources and the thickest accumulations of these rocks are mostly in the Toe Jam Mountain and Mount Blitzen Quadrangles (fig. 2), and the rocks continue to the south into the China Camp and Sugarloaf Butte Quadrangles (fig. 1). The rocks are subdivided on the basis of phenocryst content, inferred chemical composition, and occurrence as lava, lava dome, or intrusion.

Sources for Pleasant Valley lavas almost certainly underlie the exposed rocks. This is most obvious for the two large Lewis Creek domes (Tld_1, Tld_2) and for the biotite dacite dome (Tpbd), which lies mostly in the Mount Blitzen Quadrangle. For example, prominent flow structures, visible both on the ground and on aerial photographs, in the younger Lewis Creek dome (Tld_2) suggest its vent is beneath Toe Jam Mountain. The andesite intrusions (Tldi) in Nelson Creek may have fed topographically higher lavas that crop out in the surrounding hills. Other lavas may have been fed by dikes or other intrusions that underlie the lavas.

$^{40}Ar/^{39}Ar$ ages of Pleasant Valley rocks and under- and overlying tuffs indicate emplacement between about 39.8 and 39.7 Ma (fig. 5). Ages on hornblende from two lavas in

the Mount Blitzen Quadrangle are 39.86±0.24 and 39.69±0.28 Ma (table 2; samples H96-73 and H96-86). Sanidine from the dacite ash-flow tuff (Ttd) that underlies Pleasant Valley lavas in the Sugarloaf Butte Quadrangle gives an age of 39.84±0.10 Ma (fig. 5; table 2; sample H96-32). Three samples of the overlying tuff of Big Cottonwood Canyon average 39.7 Ma.

Mount Blitzen Volcanic Center

The Mount Blitzen center is a fault-bounded basin filled with a variety of dacitic intrusive and extrusive rocks that lies entirely within the Mount Blitzen and Tuscarora Quadrangles (fig. 2). Mount Blitzen rocks appear in the Toe Jam Mountain Quadrangle only as a megabreccia block of sparsely porphyritic dacite of Mount Blitzen (Tbd), approximately 50 m in diameter, within intracaldera tuff of Big Cottonwood Canyon in the northeastern corner of the quadrangle. The Mount Blitzen center erupted between about 39.8 and 39.7 Ma (fig. 5; table 2).

Big Cottonwood Canyon Caldera

The Big Cottonwood Canyon caldera (Berger and others, 1991; Henry and Boden, 1998) is a large, rhyolitic ash-flow caldera that is mostly in the Mount Blitzen and Big Cottonwood Canyon Quadrangles (fig. 2). Only the southwestern corner of the caldera lies in the northeastern part of the Toe Jam Mountain Quadrangle. The margin is marked by the juxtaposition of thick intracaldera tuff of Big Cottonwood Canyon (Tct) against Paleozoic rocks in the caldera wall. The caldera is at least 15 km east-west, but its full extent in any direction is unknown. The southwestern part is cut off by the north-striking Falcon Mine fault that dropped lavas of the Falcon Mine down on the west. The caldera extends into unmapped areas to the north and northeast in the Red Cow Creek and Big Cottonwood Canyon Quadrangles, respectively.

The caldera formed during eruption, probably in two distinct episodes, of large volumes of rhyolitic ash-flow tuff (the tuff of Big Cottonwood Canyon; Tct). Geologic data cited below demonstrate that caldera collapse was contemporaneous with ash-flow eruption. $^{40}Ar/^{39}Ar$ ages on sanidine from samples in the Mount Blitzen, Big Cottonwood Canyon, and Willow Creek Reservoir Quadrangles reveal that the tuff erupted at about 39.7 Ma (fig. 5; table 2).

The tuff of Big Cottonwood Canyon is an abundantly lithic, densely to moderately welded, compound cooling unit. The phenocryst assemblage of quartz, sanidine, plagioclase, and biotite distinguishes it from tuffs related to the Mount Blitzen volcanic center, which lack sanidine and rarely contain quartz. All outcrops of this tuff in the Toe Jam Mountain Quadrangle are within the caldera. Unless repeated by unrecognized faults, intracaldera tuff may be several kilometers thick, based on its somewhat irregular 15° to 25° westward dip across the caldera. Outflow tuff has been recognized only to the south and southwest, in the China Camp (our unpublished mapping) and Willow Creek Reservoir Quadrangles (Wallace, in preparation), but is likely more widely distributed.

Tuff near the caldera margin contains abundant blocks of older rocks. Two types of deposits were mapped. (1) Individual large blocks (megabreccia) about 10 to 50 m in diameter were mapped as their original rock type. Clast types are dacite of Mount Blitzen (Tbd) and early andesite (Ta), which may be part of the Pleasant Valley volcanic complex. (2) Lenses and irregular bodies of massive breccia and poorly bedded debris-flow deposits (Tcx) consist of amalgamations of clasts up to several meters in diameter. Clast types are the same as in megabreccia, but many debris deposits are composed entirely of small to large pieces of Paleozoic rocks. Matrix of most of these breccia and debris deposits consists of finer pieces of the same rocks, although some deposits may be extremely lithic ash-flow tuff. Both types of deposits are interpreted as landslide debris that slumped from the caldera wall during eruption of the tuff and caldera collapse.

Characteristics of ash-flow tuff in the southern part of the Big Cottonwood Canyon Quadrangle, which is included with the map of the Mount Blitzen Quadrangle (Henry and Boden, 1998), suggest the tuff erupted in two distinct episodes. In this area, a lower tuff contains abundant megabreccia blocks up to several hundred meters in diameter. This lower tuff is overlain by a thin (~1 m thick) lens of sandstone and conglomeratic sandstone composed mostly of fragments of tuff of Mount Blitzen and Paleozoic rocks. Tuff above this lens contains abundant lithic fragments up to 30 cm in diameter but no megabreccia. Our interpretation is that the caldera underwent a major episode of collapse during catastrophic eruption of the lower tuff. Failure of the caldera wall during this event generated numerous blocks that were incorporated in tuff. The sedimentary rocks were then reworked from material within or along the walls of the caldera during a brief (possibly as little as a few days) hiatus that was followed by a second eruption that generated the overlying, lithic tuff.

Lavas of the Falcon Mine

A series of andesite and dacite lavas, interbedded with minor tuff and tuffaceous sedimentary rock, and intruded by dacite, crop out in the northeastern part of the quadrangle. They have been dropped down against the tuff of Big Cottonwood Canyon and Paleozoic rocks along the Falcon Mine fault. The lavas host veins at the Falcon Mine, source of the informal name, along north-striking faults that parallel the major fault. Lavas of the Falcon Mine are subdivided on the basis of stratigraphic position and relative abundance of mafic phenocrysts. They are petrographically similar to lavas of the Pleasant Valley complex but are demonstrably younger because they overlie the tuff of Big Cottonwood Canyon (Tct). They are older than the rhyolite of Walker Mountain (Twr).

Lavas of the Falcon Mine may be correlative with petrographically similar andesite-dacite lavas (Sixmile Canyon lavas) in the northern part of the Tuscarora Quadrangle (fig. 2; Henry and others, 1999). The Sixmile

Canyon lavas are also younger than and downfaulted against the tuff of Big Cottonwood Canyon. An $^{40}Ar/^{39}Ar$ age of 39.25±0.32 Ma on hornblende from a Sixmile Canyon lava (fig. 5; table 2) may indicate the age of the lavas of the Falcon Mine. However, the two areas are separated by a distance of 15 km that is occupied by the Big Cottonwood Canyon caldera in which similar lavas do not crop out. If this correlation is correct, the combined lava sequences would represent a major volcanic complex comparable in area to that of the Pleasant Valley lavas.

Rhyolite of Walker Mountain

An extensive rhyolite lava or series of similar lavas crop out in the central part of the Toe Jam Mountain Quadrangle. These rocks are part of an episode of rhyolitic volcanism that extends into the Mount Blitzen Quadrangle and is substantially younger than the 39.9 to 39.3 Ma main pulse of magmatism in the Tuscarora volcanic field. Approximately flat-lying rhyolite caps Walker and Toe Jam Mountains, and similar lava crops out in two east-tilted fault blocks near the western edge of the quadrangle. The different areas could all be parts of a single flow that flowed south and west from a vent beneath Walker Mountain. $^{40}Ar/^{39}Ar$ dates on sanidine from samples from Walker Mountain and from one of the tilted fault blocks are 35.29±0.10 and 35.15±0.10 Ma, respectively (table 2; DB-19 and H97-85). A distinctly separate rhyolite lava dome and associated tuff that erupted along the southern margin of the Big Cottonwood Canyon caldera in the Mount Blitzen Quadrangle (Henry and Boden, 1998) has an $^{40}Ar/^{39}Ar$ date of 35.05±0.10 Ma. A rhyolite dike in the Mount Blitzen Quadrangle has an age of 33.77±0.10 Ma, distinctly younger than the lavas. These data indicate a major pulse of rhyolite magmatism at about 35.2 Ma with minor, later activity.

Miocene-Oligocene(?) Sandstone and Conglomerate

Poorly indurated sandstone and conglomerate (Tom) composed entirely of clasts of Tertiary volcanic rocks are extensive in the southwestern part of the quadrangle. Clasts are mostly of Pleasant Valley rocks but include some rhyolite of Walker Mountain, so the deposits are younger than 35 Ma. The sedimentary rocks rarely crop out, but, where they are exposed, dips range between 10° and 16° to the east, distinctly less than the 20° to 40° eastward dip of the Eocene rocks. We interpret the sedimentary rocks to have been

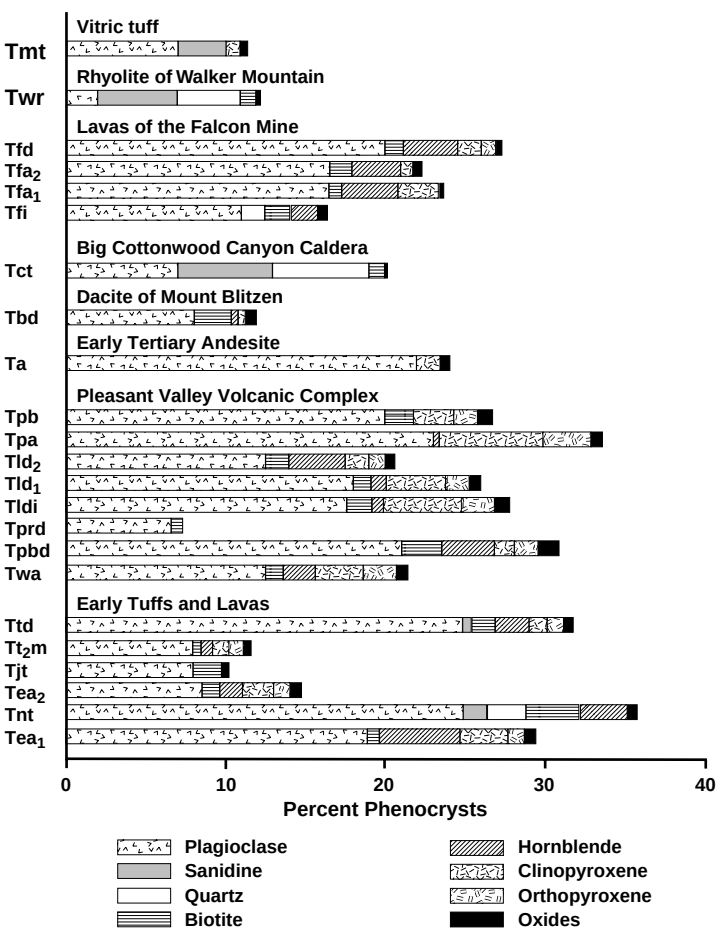

Figure 3. Phenocryst abundances in Tertiary igneous rocks of the Toe Jam Mountain Quadrangle.

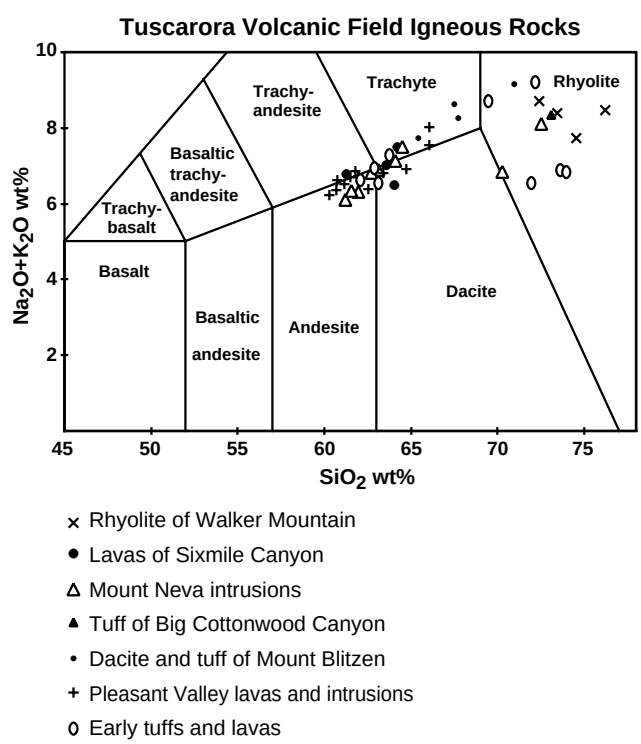

Figure 4. Total alkalies - silica plot of Tertiary igneous rocks of the Tuscarora volcanic field, Nevada. Classification follows Le Bas and others (1986). Major elements normalized to 100% volatile free. Data from table 1 and Henry and Boden (1998).

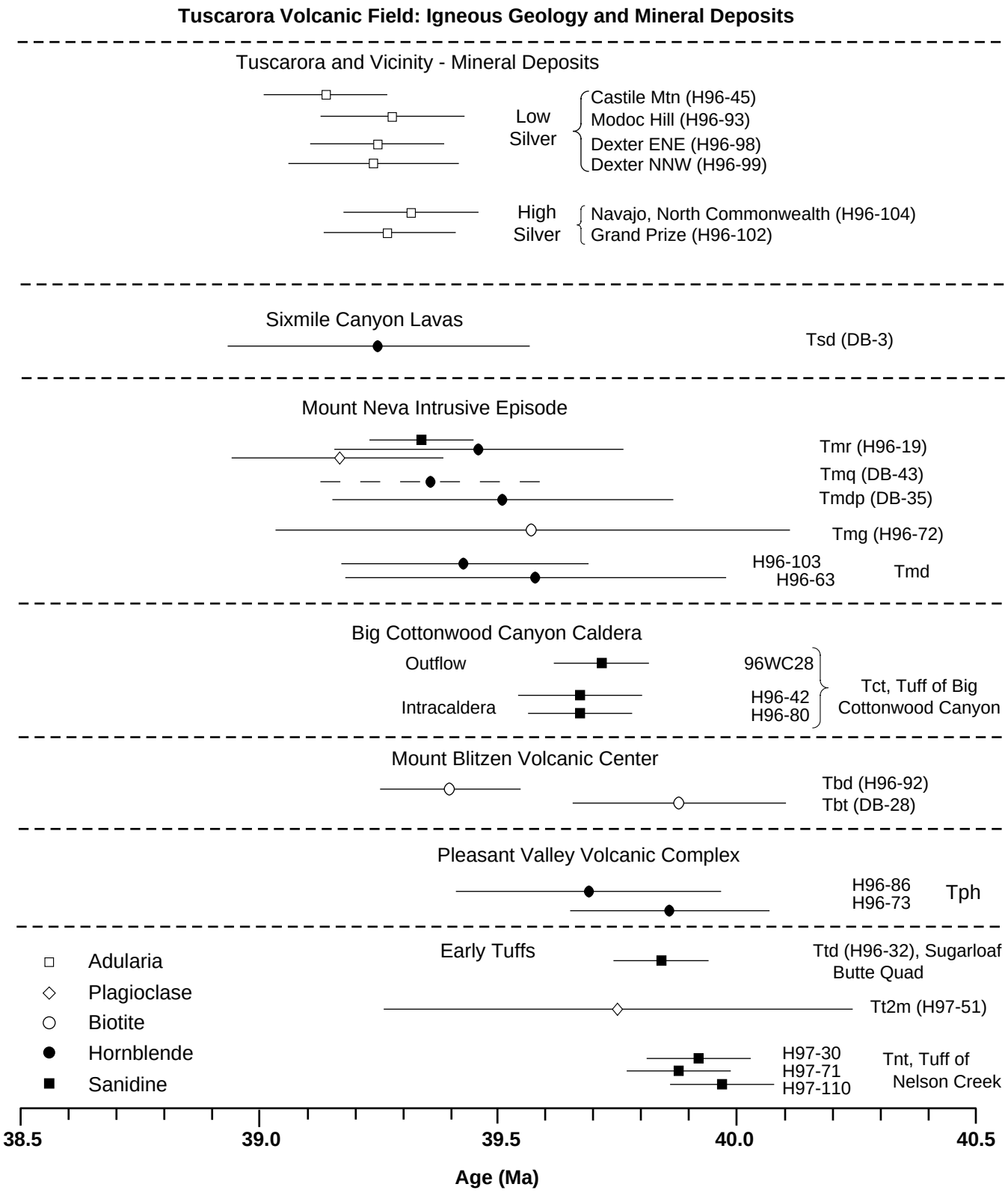

Figure 5. $^{40}Ar/^{39}Ar$ ages (±2σ) of igneous rocks and mineralization in the Tuscarora volcanic field. Rocks are in stratigraphic order determined from field relations. Sanidine and adularia give the most precise and reliable ages, hornblende is next, and biotite is the least precise.

Table 1. Chemical analyses of Tertiary igneous rocks, Tuscarora volcanic field

Sample	H97-30	H97-71	H97-110	H97-82	H97-83	H97-53	H97-51	H97-32	H97-37	H97-54	H97-112	H97-101	H97-88	H97-86	H97-64	H97-87	H96-55A	H96-55B	H97-27	H97-85	H97-84
Map unit	Tnt	Tnt	Tnt	Ted1	Ted2	Tjt	Tvt	Tdi	Tal	Twd	Twd	Tldi	Tld1	Tld1	Tld2	Tld2	Tma	Tmr	Tsb	Twr	Tmt
Long 116° W	08.0'	25.2'	30.1'	29.8'	29.4'	29.2'	27.6'	07.8'	07.6'	28.9'	28.9'	24.4'	25.9'	25.9'	24.9'	26.9'	17.3'	17.3'	13.5'	28.3'	29.2'
Lat 41° N	16.4'	15.1'	15.8'	15.7'	15.4'	18.1'	16.8'	16.3'	15.8'	18.0'	19.3'	16.4'	19.3'	18.8'	17.6'	18.3'	20.9'	20.9'	19.5'	17.6'	15.3'
Quadrangle	T	TJM	TJM	TJM	TJM	TJM	TJM	T	T	TJM	TJM	TJM	TJM	TJM	TJM	TJM	MB	MB	T	TJM	TJM
Major Oxides (percent)																					
SiO_2	73.64	71.94	73.98	62.09	63.12	72.19	69.46	65.23	62.34	61.48	60.68	61.80	61.17	63.40	64.75	61.96	62.70	72.52	64.03	72.38	71.46
TiO_2	0.51	0.57	0.40	0.95	0.84	0.42	0.41	0.76	0.81	0.89	0.88	0.84	0.90	0.84	0.75	0.87	0.72	0.31	0.73	0.28	0.44
Al_2O_3	14.69	14.28	13.38	17.13	16.71	14.23	16.08	17.01	16.64	17.04	17.25	16.81	17.13	17.16	16.37	17.11	15.69	14.58	16.45	14.50	13.56
FeO*	1.21	2.66	2.28	4.95	4.93	2.10	2.46	3.48	5.31	5.42	5.84	5.18	5.19	4.12	4.76	5.40	4.87	2.07	4.58	1.83	3.18
MnO	0.01	0.02	0.02	0.09	0.08	0.02	0.07	0.07	0.13	0.14	0.12	0.11	0.11	0.08	0.07	0.09	0.10	0.06	0.0:	0.04	0.05
MgO	0.38	0.69	0.50	2.48	2.36	0.32	0.48	1.89	2.42	2.48	2.87	2.74	2.91	2.22	1.90	2.14	3.47	0.87	1.87	0.46	0.53
CaO	2.54	3.11	2.45	5.32	5.11	1.36	2.20	4.56	5.06	5.53	5.68	5.37	5.75	5.07	4.25	5.37	5.30	1.39	5.50	1.69	1.29
Na_2O	3.08	2.99	2.93	3.48	3.30	3.53	3.36	3.13	3.59	3.60	3.36	3.33	3.34	3.44	3.61	3.54	2.91	3.57	3.26	3.27	2.88
K_2O	3.81	3.55	3.91	3.14	3.25	5.68	5.36	3.62	3.34	3.09	3.01	3.53	3.17	3.38	3.30	3.20	3.90	4.52	3.22	5.45	6.46
P_2O_5	0.13	0.19	0.15	0.37	0.30	0.13	0.11	0.25	0.35	0.32	0.31	0.30	0.33	0.29	0.25	0.31	0.34	0.11	0.26	0.10	0.13
Total	99.13	98.69	98.72	98.76	98.30	99.33	97.92	97.57	98.18	98.66	98.22	98.56	98.71	98.72	98.92	98.61	97.39	99.31	97.99	98.56	98.13
Trace Elements (ppm)																					
Sc	8	9	3	13	14	6	9	12	15	16	16	12	17	15	13	12	15	5	15	7	7
V	75	73	34	128	127	22	20	97	120	129	136	133	138	120	97	117	126	41	113	20	15
Cr	13	14	6	25	21	2	0	19	29	17	19	37	21	18	31	19	81	8	19	2	5
Ni	13	10	8	14	14	8	8	13	12	11	8	9	12	9	11	9	34	13	10	10	12
Cu	2	3	5	2	7	2	3	1	13	9	5	378	3	3	7	3	13	3	1	4	9
Zn	21	50	31	87	76	52	74	61	81	79	86	87	88	138	69	80	65	43	70	49	96
Ga	16	19	18	22	22	19	20	19	20	20	22	22	20	21	20	19	20	18	19	19	23
Rb	111	98	120	76	93	150	136	108	119	79	88	90	84	92	98	87	102	161	89	203	168
Sr	508	541	416	788	711	296	478	448	700	708	733	680	706	710	522	708	563	302	674	264	94
Y	40	18	13	20	18	23	23	27	22	21	22	22	24	25	21	22	22	17	21	20	71
Zr	191	201	168	183	171	244	284	182	205	187	191	191	191	196	188	190	178	141	201	170	593
Nb	13	12	11	15	14	16	18	15	15	12	13	13	13	14	14	13	12	15	14	17	42
Ba	1890	1940	1380	1400	1420	1830	1830	1220	1250	1220	1360	1360	1390	1442	1280	1310	1330	1110	1600	1060	1730
La	42	50	41	38	47	41	52	52	43	47	32	36	42	25	52	39	29	35	50	42	68
Ce	82	61	52	74	67	81	82	78	86	81	57	78	93	76	74	90	66	71	75	68	145
Pb	15	13	15	12	20	19	24	28	19	15	18	19	12	17	16	14	17	27	23	29	26
Th	16	12	12	7	11	12	10	14	12	9	9	11	11	11	12	9	14	18	11	24	18

All analyses by X-ray fluorescence at the Geoanalytical Laboratory, Washington State University.

Major elements are normalized to 100% on a volatile-free basis; total is before normalization. FeO*= total Fe expressed as FeO.

Quadrangles: T-Tuscarora, MB-Mount Blitzen, TJM-Toe Jam Mountain

Table 2. $^{40}Ar/^{39}Ar$ ages of Tertiary igneous rocks and mineral deposits, Tuscarora volcanic field

Sample No	Rock type	Quadrangle	Mineral	Age Method	n* or %^{39}Ar	Age (Ma)	±2σ
Mineralized rock of the Tuscarora District							
H96-45	Castile Mountain alteration	Mount Blitzen	adularia	plateau	88.7	39.14	0.13
H96-93	Modoc vein	Mount Blitzen	adularia	plateau	96.4	39.28	0.15
H96-98	Dexter zone	Tuscarora	adularia	plateau	90.5	39.25	0.14
H96-99	North-northwest vein at Dexter pit	Tuscarora	adularia	plateau	82.5	39.24	0.18
H96-102	Grand Prize vein	Tuscarora	adularia	plateau	99.7	39.27	0.14
H96-104	Navajo vein, North Commonwealth Mine	Tuscarora	adularia	plateau	91.6	39.32	0.14
Miocene tuff							
H97-84	Miocene ash-flow tuff (Tmt)	Toe Jam Mountain	sanidine	single crystal	13	15.26	0.05
96WC24	Miocene ash-flow tuff (Tmt)	Willow Creek Reservoir	sanidine	single crystal	15	15.29	0.06
Lavas of Sixmile Canyon							
DB-3	Dacite lava (Tsd)	Tuscarora	hornblende	plateau	59.6	39.25	0.32
Rhyolite of Walker Mountain							
H96-65	Porphyritic rhyolite dike (Twir)	Mount Blitzen	sanidine	single crystal	12	33.77	0.10
H96-59	Porphyritic rhyolite lava dome (Twr)	Mount Blitzen	sanidine	single crystal	15	35.05	0.10
H97-85	Porphyritic rhyolite lava (Twr)	Toe Jam Mountain	sanidine	single crystal	15	35.15	0.10
DB-19	Porphyritic rhyolite lava (Twr)	Toe Jam Mountain	sanidine	single crystal	15	35.29	0.10
Mount Neva Intrusive Episode							
Late dikes							
H96-19	Porphyritic rhyolite (Tmr)	Tuscarora	sanidine	single crystal	15	39.34	0.08
··			hornblende	plateau	93.1	39.46	0.30
··			biotite	integrated age	100	39.2	0.4
··			plagioclase	plateau	65.8	39.17	0.22
DB-35	Porphyritic dacite (Tmdp)	Mount Blitzen	hornblende	plateau	63.2	39.51	0.36
DB-43	Quartz-phyric porphyritic dacite (Tmq)	Mount Blitzen	hornblende	single step	84.9	39.37	0.24
Mount Neva pluton							
H96-72A	Granodiorite (Tmg)	Mount Blitzen	biotite	plateau	58.7	39.37	0.28
··			··	integrated age	100	39.6	0.6
Early porphyritic dacite (Tmd)							
H96-63		Mount Blitzen	hornblende	plateau	92.6	39.58	0.40
H96-103		Tuscarora	hornblende	plateau	77.2	39.43	0.26
Big Cottonwood Canyon Caldera							
Tuff of Big Cottonwood Canyon (Tct)							
H96-42	Intracaldera tuff	Mount Blitzen	sanidine	single crystal	15	39.67	0.10
H96-80	Intracaldera tuff, single pumice	Big Cottonwood Canyon	sanidine	single crystal	13	39.67	0.10
96WC28	Outflow tuff	Willow Creek Reservoir	sanidine	single crystal	15	39.72	0.08
Mount Blitzen Volcanic Center							
DB-28	Tuff of Mount Blitzen (Tbt)	Mount Blitzen	biotite	plateau	96	39.88	0.22
··			··	integrated age	100	39.5	0.6
H96-92	Dacite of Mount Blitzen (Tbd)	Mount Blitzen	biotite	plateau	83.8	39.40	0.14
··			··	integrated age	100	39.03	0.36
Pleasant Valley Volcanic Complex							
H96-86	Hornblende-phyric andesite lava (Tph)	Mount Blitzen	hornblende	plateau	93.4	39.69	0.28
H96-73	Hornblende-phyric andesite lava (Tph)	Mount Blitzen	hornblende	plateau	97.8	39.86	0.24
Early Tuffs							
H96-32	Dacite ash-flow tuff (Ttd)	Sugarloaf Butte	sanidine	single crystal	15	39.84	0.10
H97-51	Marker tuff (Tt2m)	Toe Jam Mountain	plagioclase	single crystal	39	39.75	0.49
H97-30	Tuff of Nelson Creek (Tnt)	Tuscarora	sanidine	single crystal	16	39.92	0.11
H97-71	Tuff of Nelson Creek (Tnt)	Toe Jam Mountain	sanidine	single crystal	12	39.88	0.11
H97-110	Tuff of Nelson Creek (Tnt)	Toe Jam Mountain	sanidine	single crystal	9	39.97	0.11

* n = number of single crystals analyzed; %^{39}Ar = percentage of ^{39}Ar that defines plateau.
Decay constants after Steiger and Jager (1977).
All ages relative to an age of 27.84 Ma on Fish Canyon sanidine (520.4 Ma on MMhb-1 hornblende).

derived by erosion of fault scarps and deposition in half graben during an episode of faulting that tilted all rocks to the east. The lesser dip indicates the sedimentary rocks were deposited after some faulting and tilting. The sedimentary rocks are not in contact with, but are more steeply tilted than, 15.3-Ma Miocene tuff in the southwest, so they are probably older than the tuff.

Miocene Ash-Flow and Air-Fall Tuff

Well-bedded air-fall tuff (Tma) overlain by a prominent ash-flow tuff (Tmt) crop out in the southwestern corner of the quadrangle. The same low-silica rhyolite ash-flow tuff is widespread to the west and southwest, especially in the Willow Creek Reservoir Quadrangle, where Miocene volcanic rocks are abundant (Wallace, in preparation). The source of the tuff is unknown but may be in an area west or south of Willow Creek Reservoir, which has numerous, Miocene silicic domes. $^{40}Ar/^{39}Ar$ ages of 15.26±0.05 and 15.29±0.06 Ma were obtained from sanidine from samples in the Toe Jam Mountain and Willow Creek Reservoir Quadrangles (table 2). The air-fall and ash-flow tuff dips gently (≤5°) to the east and unconformably overlies the tuff of Nelson Creek (Tnt) and lower southwestern andesite (Tea_1).

QUATERNARY DEPOSITS

A variety of Quaternary gravel, alluvial fan, landslide, and other deposits are exposed throughout the quadrangle. An extensive Quaternary-late Tertiary (?) gravel covers much of the older Tertiary rocks, especially in the western part of the quadrangle and continues at least another 12 km farther to the west. The gravel probably covered all of the low country in the southwestern part of the quadrangle before more recent erosion. The gravel is composed almost entirely of Paleozoic quartzite and chert, with minor amounts of Pleasant Valley rocks. Coarsest clasts are in the east, adjacent to the major Falcon Mine fault, where quartzite boulders are as much as 3 m in diameter. The gravel is finer grained to the west but contains meter-sized clasts even to the western edge of the quadrangle.

CENOZOIC STRUCTURE

Rocks of the Toe Jam Mountain Quadrangle were affected by two and possibly three episodes of Cenozoic faulting. An early episode between about 35 and 15 Ma generated the north-striking, west-dipping normal faults and resulted in most of the eastward tilting of volcanic rocks. A post-15-Ma episode appears to have generated most of the northeast-striking, left-oblique-slip faults. Finally, much of the motion along the major Falcon Mine fault along the eastern margin of the quadrangle may have occurred in latest Cenozoic time.

Oligocene-Miocene East-Directed Extension

The most important faulting was part of an episode of regional, approximately east-directed extension that affected much of northern Nevada. The Toe Jam Mountain Quadrangle lies astride a transition between relatively unextended rocks to the east and moderately extended rocks to the west. Sections A-A' and B-B' best illustrate this transition. Rocks of the Pleasant Valley complex and rhyolite of Walker Mountain in the east are approximately flat lying. To the west, these and other Eocene volcanic rocks turn up to dip moderately to the east and are cut by north- to slightly east of north-striking, down to the west, normal faults. Dips increase progressively into the central and western parts of the quadrangle, where they average about 30°. Similarly, displacements on individual faults increase westward from a few tens of meters on easternmost faults to approximately 1 km on faults to the west. Small displacement faults are present throughout the area, however. More faults are probably present than were mapped but are buried by younger deposits or were not identified in the monotonous soft tuffs of the early tuff sequence or the andesitic lavas of the Pleasant Valley complex.

Timing of this episode of extension is only broadly constrained between 35.2 Ma, the age of the rhyolite of Walker Mountain (Twr), the youngest dated tilted rock, and 15.3 Ma, the age of the Miocene ash-flow tuff (Tmt), which unconformably overlies tilted rocks. Deposition of the Miocene-Oligocene? sandstone and conglomerate (Tom) was apparently in part contemporaneous with faulting. The lack of Paleozoic clasts in conglomerate demonstrate that Paleozoic rocks were not exposed by the faulting. Isotopic or paleontologic dating of these sedimentary rocks could further constrain the timing of faulting, but neither dateable rocks nor fossils have been observed.

East-tilted rocks and west-dipping normal faults continue to the west. In the Willow Creek Reservoir Quadrangle, Eocene volcanic rocks including the tuff of Big Cottonwood Canyon are tilted as much as 50° (Wallace, in preparation). Eocene rocks throughout much of north-central Nevada are similarly east-tilted and overlain by less tilted ~15 Ma rocks (Wallace and John, 1998).

Late Miocene(?) Northeast-Striking Oblique-Slip Faults

Numerous northeast-striking faults cut Eocene and Miocene volcanic rocks and the earlier north-striking faults. The faults were therefore active after 15 Ma and are probably not related to the older faults. Although fault surfaces are not exposed, the sense of motion was probably left-lateral and down to the northwest because both east-dipping rocks and west-dipping faults show apparent left slip. Amount of slip on most faults appears to be no more than a few hundred meters. The large fault that bounds the southeast side of the younger Lewis Creek dome (Tld_2) may have greater displacement.

These faults may be the easternmost manifestation of the Midas trough, a large east-northeast-striking basin southwest of the Toe Jam Mountain Quadrangle (Zoback and Thompson, 1978; Coats, 1987; Wallace, 1990, 1993).

Faults that bound the trough cut 15-Ma volcanic rocks and have left-oblique motion (Zoback and Thompson, 1978; Wallace, 1990, 1993). Faults in the Toe Jam Mountain Quadrangle lie approximately on strike with the trough, but with a somewhat more northeasterly orientation, and have the same sense of motion. The topographic expression of the Midas trough dies out about 15 km southwest of the Toe Jam Mountain Quadrangle, but northeast-striking faults are also present in the intervening area in the Willow Creek Reservoir Quadrangle (Wallace, in preparation). The left-oblique sense of motion on northeast-striking faults is consistent with extension oriented between east-northeast and east-southeast.

Latest Cenozoic Extension

Slickenlines along small faults that parallel the Falcon Mine fault along the eastern side of the quadrangle indicate dominantly dip-slip motion. Timing of displacement on the fault is unknown, but compositions of different mid-Tertiary to Quaternary gravels suggest that most displacement may be late Tertiary. Clasts in Miocene-Oligocene(?) sandstone and conglomerate are exclusively Tertiary igneous rocks, mostly from the Pleasant Valley complex. Paleozoic rocks were apparently not exposed during the extensional episode between 35 and 15 Ma. In contrast, clasts in Quaternary-late Tertiary gravel (QTg) are almost exclusively Paleozoic. Clasts are as much as 3 m in diameter near the Falcon Mine fault, and clast size decreases to the west. These data indicate the gravel was derived from the Paleozoic rocks on the eastern, upthrown side of the fault, and the fault had a considerable topographic scarp at the time of gravel deposition. The fault may not have been active during the 35- to 15-Ma episode of extension, although it has a similar strike and down-to-the-west sense of motion as faults of that episode.

ECONOMIC GEOLOGY

The Falcon Mine in the Rock Creek district (LaPointe and others, 1991) is the only significant mine or prospect in the mapped part of the Toe Jam Mountain Quadrangle. The Falcon Mine produced silver ore between 1879 and 1881, and ore there has associated Hg, Au, As, and Sb (LaPointe and others, 1991). Host rocks are andesite and dacite lavas of the Falcon Mine. Thick (up to 2 m wide) veins follow a north-striking, steeply dipping fault through the altered lavas. The veins consist of quartz and quartz-cemented breccia containing ruby silver minerals, pyrite, stibnite, and hematite. Vein quartz typically is chalcedonic, having banded, colliform, or mammillary texture. Fine-grained drusy quartz is common in areas of open space. Fluted drape textures are locally present on vein surfaces and indicate precipitation from silica gel. These textures, along with the abrupt decrease in alteration away from veins, suggest formation at a very high level of an epithermal system, probably ≤100 m from the paleosurface.

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REFERENCES

Adams, O.F., 1996, Stratigraphy, structure, and exploration potential of the Big Springs gold deposits, northern Independence Range, Nevada, *in* Coyner, A.R., and Fahey, P.L., eds., Geology and Ore Deposits of the American Cordillera: Geological Society of Nevada Symposium Proceedings, Reno/Sparks, Nevada, April 1995, p. 1–13.

Berger, B.R., Ridley, W.I., and Tingley, J.V., 1991, Interrelationship of mineralization, volcanism, and tectonism, northern Tuscarora Mountains, Elko County, Nevada, *in* Thorman, C.H., ed., Some current research in eastern Nevada and western Utah: U.S. Geological Survey Open-File Report 91-386, p. 13–19.

Boden, D.R., Struhsacker, E.M., and Wright, B.A., 1993, Structurally controlled volcanism and contrasting types of mineralization, Tuscarora mining district and vicinity, Nevada: Geological Society of America Abstracts with Programs, v. 25, no. 6, p. 11.

Brooks, W.E., Thorman, W.E., and Snee, L.W., 1995a, The $^{40}Ar/^{39}Ar$ ages and tectonic setting of the middle Eocene northeast Nevada volcanic field: Journal of Geophysical Research, v. 100, p. 10,403–10,416.

Brooks, W.E., Thorman, W.E., Snee, L.W., Nutt, C.W., Potter, C.J., and Dubiel, R.F., 1995b, Summary of chemical analyses and $^{40}Ar/^{39}Ar$-spectra data for Eocene volcanic rocks from the central part of the northeast Nevada volcanic field: U.S. Geological Survey Bulletin 1988-K, p. K1–K33.

Churkin, M., Jr., and Kay, M., 1967, Graptolite-bearing Ordovician siliceous and volcanic rocks, northern Independence Range, Nevada: Geological Society of America Bulletin, v. 78, p. 651–668.

Clark, T.M., Ehman, K.D., and Axelrod, D.I., 1985, Late Eocene extensional faulting in the northern Basin and Range province, Nevada: Geological Society of America Abstracts with Programs, v. 17, no. 6, p. 348.

Coats, R.R., 1987, Geology of Elko County, Nevada: Nevada Bureau of Mines and Geology Bulletin 101, 112 p.

Crawford, K.S., 1992, The geology of the Tuscarora mining district, Elko County, Nevada [M. S. thesis]: University of Nevada, Reno, 85 p.

Erwin, J.W., Ponce, D.A., and Wagini, A., 1985, Bouguer gravity map of Nevada - McDermitt sheet: Nevada Bureau of Mines and Geology Map 86, 1:250,000.

Evans, J.G., and Theodore, T.G., 1978, Deformation of the Roberts Mountains allochthon in north-central Nevada: U.S. Geological Survey Professional Paper 1060, 18 p.

Henry, C.D., and Boden, D.R., 1998, Geologic map of the Mount Blitzen Quadrangle, Elko County, northeastern Nevada: Nevada Bureau of Mines and Geology Map 110.

Henry, C.D., Boden, D.R., and Castor, S.B., 1998, Geology and mineralization of the Eocene Tuscarora volcanic field, Elko County, Nevada, *in* Tosdal, R.M., ed., Contributions to the Au metallogeny of northern Nevada: U.S. Geological Survey Open-File Report 98-338, p. 278–290.

Henry, C.D., Boden, D.R., and Castor, S.B., 1999, Geologic map of the Tuscarora Quadrangle, Elko County, northeastern Nevada: Nevada Bureau of Mines and Geology Map 116, 1:24,000.

Janecke, S.U., Hammond, B.F., Snee, L.W., and Geissman, J.W., 1997, Rapid extension in an Eocene volcanic arc: Structure and paleogeography of an intra-arc half graben in central Idaho: Geological Society of America Bulletin, v. 109, p. 253–267.

Kerr, W., 1962, Paleozoic sequences and thrust slices of the Seetoya Mountains, Independence Range, Elko County, Nevada: Geological Society of America Bulletin, v. 73, p. 439–460.

Ketner, K.B., 1966, Comparison of Ordovician eugeosynclinal and miogeosynclinal quartzites of the Cordilleran geosyncline: U.S. Geological Survey Professional Paper 550-C, p. C54–C60.

Ketner, K.B., 1975, Stratigraphic sequence of Paleozoic and Mesozoic rocks exposed in central Elko County, Nevada: U.S. Geological Survey Open-File Report 75-213, 122 p.

LaPointe, D.D., Tingley, J.V., and Jones, R.B., 1991, Mineral resources of Elko County, Nevada: Nevada Bureau of Mines and Geology Bulletin 106, 236 p.

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

McKee, E.H., Tarshis, A.L., and Marvin, R.F., 1976, Summary of radiometric ages of Tertiary volcanic and selected plutonic rocks in Nevada, part V — Northeastern Nevada: Isochron/West, no. 16, p. 15–27.

Merriam, C.W., and Anderson, C.A., 1942, Reconnaissance survey of the Roberts Mountains, Nevada: Geological Society of America Bulletin, v. 53, p. 1675–1728.

Miller, E.M., Holdsworth, B.K., Whiteford, W.B., and Rodgers, D., 1984, Stratigraphy and structure of the Schoonover sequence, northeastern Nevada: Implications for Paleozoic plate-margin tectonics: Geological Society of America Bulletin, v. 95, p. 1063–1076.

Miller, E.M., and Larue, D.K., 1983, Ordovician quartzite in the Roberts Mountains allochthon, Nevada: Deep sea fan deposits derived from cratonal North America: *in* Stevens, C.H., ed., Pre-Jurassic rocks in western North American suspect terranes: Society of Economic Paleontologists and Mineralogists, Pacific Section, Special Publication, p. 91–102.

Roberts, R.J., 1964, Stratigraphy and structure of the Antler Peak quadrangle, Humboldt and Lander Counties, Nevada: U.S. Geological Survey Professional Paper 459-A, 93 p.

Saucier, A.E., 1997, The Antler thrust sytem in northern Nevada, *in* Perry, A.J., and Abbott, E.W., eds., The Roberts Mountains thrust, Elko and Eureka Counties, Nevada: Nevada Petroleum Society Field Trip Guidebook, p. 1–16.

Silberling, N.J., and Roberts, R.J., 1962, Pre-Tertiary stratigraphy and structure of northwestern Nevada: Geological Society of America Special Paper 163, 28 p.

Steiger, R.H., and Jager, E., 1977, Subcommission on geochronology: convention on the use of decay constants in geo- and cosmochronology: Earth and Planetary Science Letters, v. 36, p. 359–362.

Wallace, A.R., 1990, Geologic map of the Jake Creek Mountain Quadrangle, Elko County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-1672.

Wallace, A.R., 1993, Geologic map of the Snowstorm Mountains and vicinity, Elko and Humboldt Counties, Nevada: U.S. Geological Survey Miscellaneous Investigations I-2394.

Wallace, A.R., in press, Geologic map of the Willow Creek Reservoir Quadrangle, Nevada: Nevada Bureau of Mines and Geology Geologic Map.

Wallace, A.R., and John, D.A., 1998, New studies of Tertiary volcanic rocks and mineral deposits, northern Nevada rift: *in* Tosdal, R.M., ed., Contributions to the Au metallogeny of northern Nevada: U.S. Geological Open-File Report 98-338, p. 264–278.

Zoback, M.L., and Thompson, G.A., 1978, Basin and Range rifting in northern Nevada: clues from a mid-Miocene rift and its subsequent offsets: Geology, v. 6, p. 111–116.