Text and references to accompany Nevada Bureau of Mines and Geology Map 116

GEOLOGY OF THE TUSCARORA QUADRANGLE

ELKO COUNTY, NEVADA

by

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INTRODUCTION

The Tuscarora Quadrangle lies in the northern Tuscarora Mountains in western Elko County in northeastern Nevada (figs. 1, 2). The quadrangle covers the southeastern part of the Tuscarora volcanic field, which is the largest Eocene volcanic field in Nevada, and the southern part of Independence Valley, a broad alluviated basin drained by the South Fork of the Owyhee River. Mapping of the Tuscarora Quadrangle is part of a broader project, which began with mapping of the Mount Blitzen Quadrangle to the west (Henry and Boden, 1998), 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 deposits in and around the Tuscarora volcanic field, and 3) ensure environmentally sound mineral production if major deposits were found in the area.

The origin of Carlin-type deposits, especially in the Carlin Trend and Independence Mountains (fig. 1), is controversial, but recent work shows that many formed in the Eocene, contemporaneously with extensive Eocene igneous activity (Brooks and others, 1995a, b; Thorman and others, 1995; Phinisey and others, 1996; Groff and others, 1997; Henry and Boden, 1998; Henry and others, 1998). Despite the possible importance of Eocene magmatism, only regional studies or reconnaissance of Eocene volcanic centers have been made previously (Berger and others, 1991; Boden and others, 1993; Brooks and others, 1995a). The Tuscarora volcanic field has significant mineral potential, and epithermal gold-silver deposits at Tuscarora are clearly associated with igneous activity and structure. Because of concern about possible impacts of mining, information is needed about the distribution and structure of bedrock and valley fill as they influence the movement of ground and surface water. Other than the map of the Mount Blitzen Quadrangle (Henry and Boden, 1998), previous 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 (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, 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 of the Owyhee Plateau cover the Tuscarora volcanic field on the north and northwest. Independence Valley separates the Tuscarora volcanic field from the Independence Mountains to the east.

Rock units in the Tuscarora Quadrangle include highly folded and probably thrust faulted Paleozoic chert, siltstone, and quartzite; a complex assemblage of Eocene volcanic and intrusive rocks erupted during several episodes of activity; and Quaternary alluvial fan and fluvial deposits in Independence Valley (fig. 2). General characteristics of the rocks are described on the map. This discussion focuses on regional geologic setting and significance, especially the volcanic-tectonic history, and on characteristics of mineral deposits in the Tuscarora mining district.

PALEOZOIC ROCKS

Stratigraphy

Paleozoic rocks crop out in the triangular, fault-bound wedge in the northwestern part of the quadrangle and consist of quartzite pods within a matrix of siltstone or argillite, chert, and lesser sandstone and limestone. Because the rocks are intensely folded and probably thrust faulted, their true thicknesses are unknown. Most quartzite appears to form boudins a few meters to about 0.5 km 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) indicated that 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.

From regional correlation, the quartzite is undoubtedly 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. Additionally, Coats (1987) found Devonian fossils in limestone in Sixmile Canyon. Therefore, the Paleozoic rocks may range from Ordovician through Devonian.

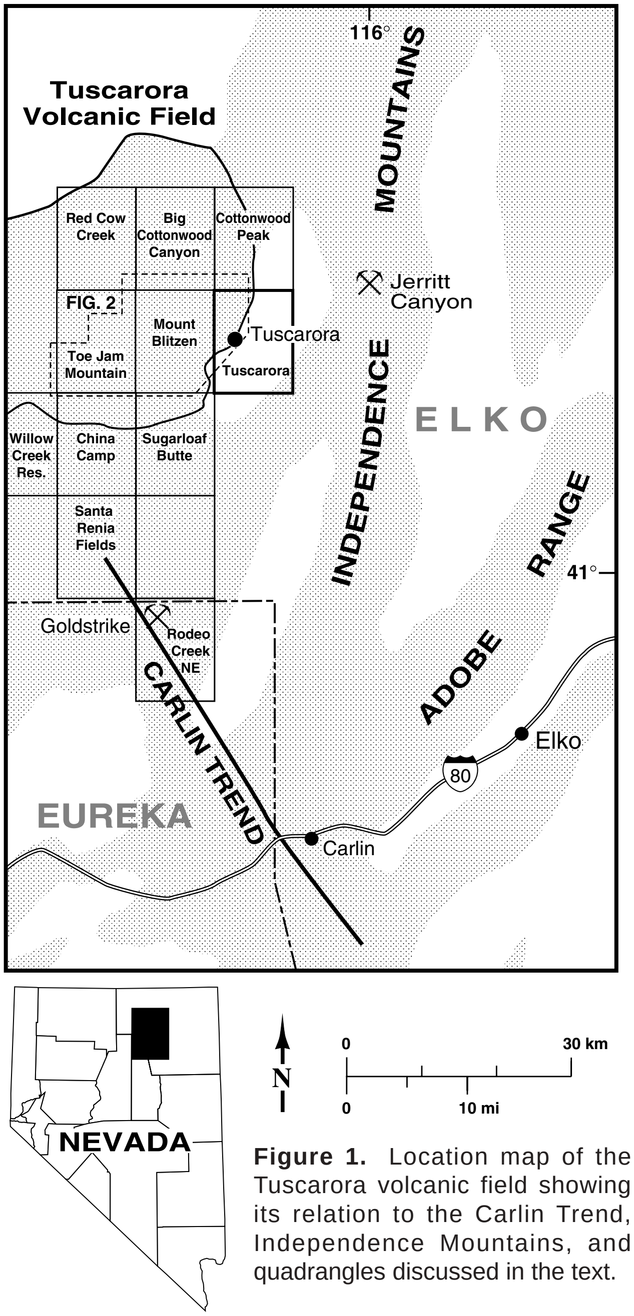

Figure 1. Location map of the Tuscarora volcanic field showing its relation to the Carlin Trend, Independence Mountains, and quadrangles discussed in the text.

Structure

The Paleozoic rocks are highly deformed, 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). However, the dominant west to northwest strike and north to northeast dip of beds are oblique to northeast to east-northeast strikes and northwest dips seen in the Mount Blitzen Quadrangle and Independence Mountains. We interpret the unusual attitude in the Tuscarora Quadrangle to be a result of substantial (~50°) eastward tilting along the eastern margin of the Mount Blitzen volcanic center during formation of the Mount Blitzen anticline in the Eocene. Removing this tilt restores the beds to a northeast strike and northwest dip. This attitude is consistent with major northwest-southeast shortening with transport toward the southeast. The timing of deformation can only be constrained as post-Devonian and pre-Eocene in the Tuscarora 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).

The Paleozoic rocks 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). Additionally, we interpret Paleozoic rocks of the Tuscarora Quadrangle to be part of the northern, quartzite-bearing package of the Mount Blitzen Quadrangle (Henry and Boden, 1998). This northern package appears to have been displaced southeastward along a regional, east- to northeast-striking thrust fault over a southern, quartzite-free package of Silurian and Devonian siltstone and chert (fig. 2), all within the upper plate of the Roberts Mountains allochthon.

TERTIARY IGNEOUS ROCKS

Several major episodes of Eocene magmatism occurred in and around the Tuscarora Quadrangle (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 at about 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 and andesitic to rhyolitic dikes of the Mount Neva intrusive episode (39.5 to 39.3 Ma); and 6) andesitic and dacitic lavas of Sixmile Canyon (39.3 Ma). Outcrop, petrographic, chemical, and $^{40}Ar/^{39}Ar$ age data (figs. 3, 4, and 5; tables 1 and 2) indicate that all but the tuff of Nelson Creek are genetically related rocks erupted or intruded from sources within or near the quadrangle.

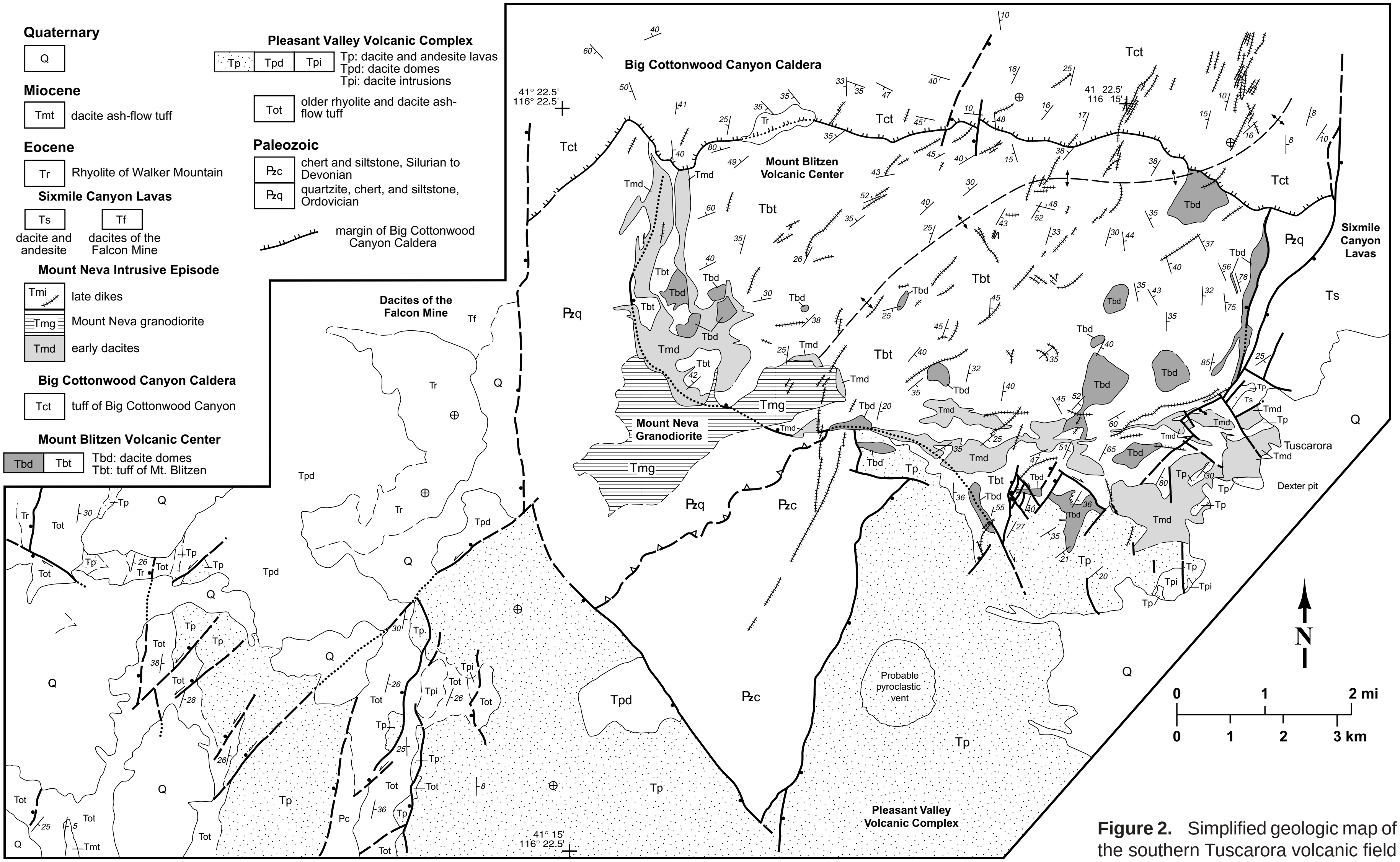

Figure 2. Simplified geologic map of the southern Tuscarora volcanic field based on detailed geologic mapping of the Toe Jam Mountain, Mount Blitzen, and Tuscarora Quadrangles (west to east).

Rocks in the Southeastern Part of the Quadrangle

A sequence of tuffaceous sedimentary rocks, an extensive ash-flow tuff (tuff of Nelson Creek), and minor dacite and andesite lava or shallow intrusions crop out in the southeastern part of the quadrangle. The tuff of Nelson Creek is named for exposures in the Toe Jam Mountain Quadrangle (Henry and Boden, 1999) and also crops out in the Willow Creek Reservoir Quadrangle (Wallace, in preparation). In these areas, it generally rests directly upon Paleozoic rocks, and tuffaceous sedimentary rocks that underlie it in the southeastern part of the Tuscarora Quadrangle rest upon basal Tertiary conglomerate (Tc of Mount Blitzen Quadrangle; Henry and Boden, 1998) and Paleozoic rocks just outside the quadrangle. ^{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 indicates a nearby caldera source. Possibly, it was an early eruption from the Big Cottonwood Canyon caldera.

The small bodies of andesite and dacite in the southeastern corner could be either lavas or shallow intrusions. If lavas, they are probably similar in age to the tuff of Nelson Creek and are some of the oldest igneous rocks in the quadrangle. If intrusions, they could be significantly younger. Both are petrographically and chemically similar to, and possibly distal parts of, rocks of the Pleasant Valley complex. The abundance of porphyritic silicic to intermediate igneous rocks as cobbles in conglomerate in the sedimentary rocks indicates still older igneous activity nearby.

Pleasant Valley Volcanic Complex

The Pleasant Valley volcanic complex consists of andesitic to dacitic lavas and lava domes, shallow intrusions, tuff and volcaniclastic sedimentary rocks, and coarse breccia. Sources and the thickest accumulations of these rocks are mostly in the Mount Blitzen and Toe Jam Mountain Quadrangles (fig. 2), and the rocks continue to the south into the Sugarloaf Butte and China Camp Quadrangles (fig. 1). Pleasant Valley rocks in the Tuscarora Quadrangle are mostly volcaniclastic sedimentary rocks and tuff (Tps), which crop out in a band along the southeastern margin of the Mount Blitzen volcanic center. These rocks host many of the veins of the Tuscarora district. A thick (as much as 300 m?) poorly to moderately welded ash-flow tuff underlies the sedimentary rocks in drill hole CT-3 in the Dexter pit but does not crop out. Biotite-bearing lava (Tpb) crops out near the western edge of the quadrangle and may have erupted from a source farther west. A dacite dome (Tpd) that cuts the lava could be a source within the quadrangle. Alternatively, this altered body may be part of the dacite of Mount Blitzen (Tbd) and unrelated to Pleasant Valley rocks.

The Pleasant Valley complex is the oldest of known, locally derived volcanic sequences in the quadrangle. Lavas in this complex rest directly upon basal Tertiary conglomerate in two locations and upon Paleozoic rocks at two other locations in the Mount Blitzen Quadrangle (Henry and Boden, 1998). ^{40}Ar/^{39}Ar ages on Pleasant Valley rocks and underlying 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 a dacitic ash-flow tuff 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), and the tuff of Nelson Creek is about 39.9 Ma.

Early andesite (Ta), which occurs only as blocks within the tuff of Mount Blitzen (Tbt), is petrographically and chemically similar to andesite lava of the Pleasant Valley complex. These blocks presumably were derived from lava that formerly cropped out along the margins of the Mount Blitzen center. However, this correlation is uncertain, and the blocks extend well beyond the present known distribution of Pleasant Valley rocks.

Mount Blitzen Volcanic Center

The Mount Blitzen center is a fault-bounded basin filled with a variety of dacitic intrusive and extrusive rocks. It lies mostly in the Mount Blitzen Quadrangle, but the eastern margin is in the western part of the Tuscarora Quadrangle (fig. 2). The basin is approximately 11 km east-west by about 6 km north-south; however, it is truncated on the north by the younger Big Cottonwood Canyon caldera, and the original extent in that direction is unknown. Most boundaries appear to be high-angle faults. Paleozoic rocks make up most of the eastern, western, and southern margins of the center. Extensive intrusion by dacite of Mount Blitzen (Tbd), early dacite (Tmd), and, in the Mount Blitzen Quadrangle, the Mount Neva granodiorite (Tmg) of the Mount Neva intrusive episode obscure much of the original character of these margins.

The Mount Blitzen center is filled with a thick sequence of dacitic domes (Tbd) and the dacitic tuff of Mount Blitzen (Tbt), which consists of small-volume pyroclastic-flow and epiclastic deposits. These rocks were tilted into a northeast- to east-northeast-trending anticline through the middle of the center (fig. 2; section A-A'). Therefore, the oldest rocks are exposed in the middle of the center and are progressively younger outward. The composite tuff of Mount Blitzen is at least 1 km thick and could be several kilometers thick. However, the base is not exposed and complex stratigraphy, lack of marker beds, and uncertainty in repetition by faults preclude determining an accurate thickness.

The age of the Mount Blitzen volcanic center is constrained between about 39.8 and 39.7 Ma by ^{40}Ar/^{39}Ar ages on the older Pleasant Valley volcanic complex and on the younger Big Cottonwood Canyon caldera (fig. 5; table 2). Biotite, which gives relatively imprecise ages by the ^{40}Ar/^{39}Ar method, from one tuff in the Mount Blitzen Quadrangle (sample DB-28; plateau age = 39.88±0.22; integrated age = 39.5 ± 0.6) gives reasonable ages, but biotite from a dacite dome (sample H96-92; plateau age = 39.40±0.14 Ma; integrated age = 39.03±0.36 Ma) appears too young.

The dacitic domes occur throughout the center but are most abundant near the eastern margin (fig. 2). All bodies are petrographically similar and have about 10 to 15% phenocrysts mostly of plagioclase and minor biotite. Several of the domes are in-situ lava domes or intrusions that cut the tuff, particularly many of the larger (≥500 m diameter) bodies. Some of these distinctly cut surrounding rocks, have flow-laminated and/or spherulitic margins, or appear to have shed debris into surrounding epiclastic deposits. Other dacites, including most of the smaller bodies, are rootless blocks (megabreccia) floating within pyroclastic and epiclastic deposits. Both pyroclastic and epiclastic rocks contain clasts of dacite from a few millimeters up to several meters in diameter. The setting of many dacites, whether in situ or megabreccia, cannot be determined.

The tuff of Mount Blitzen is a subequal mix of small-volume pyroclastic-flow and epiclastic deposits. The pyroclastic deposits are densely to poorly welded, pumiceous and commonly lithic tuff. Lithic fragments consist mostly of the dacite of Mount Blitzen, which can comprise as much as 50% of individual deposits, but include Paleozoic rocks and other igneous rocks. The phenocryst assemblage is similar to that of the dacite domes, but tuffs are notably more porphyritic. A variant that contains 1-2% quartz phenocrysts crops out in the northwestern part of the quadrangle. The pyroclastic deposits are interpreted as small-volume tuff eruptions from or related to the domes, similar to dome-collapse tuffs seen around many modern intermediate to silicic lava domes (Cas and Wright, 1987).

The tuffs are complexly interbedded with epiclastic rocks that range from massive breccias to well-bedded sedimentary rocks. Breccias generally are thick, contain abundant, angular to subrounded clasts of dacite as much as 2 m in diameter, and appear to be landslides or debris flows shed from the domes. Other rock types include coarse, massive to poorly bedded, plagioclase-rich, lithic sandstone and conglomerate with variable amounts of green pumice and well-bedded, graded sandstone and siltstone. The epiclastic layers are discontinuous along strike. Abrupt, local changes in strike of both pyroclastic and epiclastic deposits probably reflect a combination of steep primary dips as tuff and debris accumulated around domes and slumping of semi-consolidated deposits on steep primary slopes.

The tuff contains scattered megabreccia blocks up to about 150 m in diameter. Most blocks consist of dacite of Mount Blitzen (Tbd) or early andesite (Ta). One block of Paleozoic quartzite, approximately 50 m across, is present just northwest of Tuscarora. Megabreccia within the Mount Blitzen center is similar to that within typical rhyolitic ash-flow calderas, for example, the Big Cottonwood Canyon caldera (see below). Blocks of early andesite and quartzite must have slumped from former outcrop in the walls. Blocks of dacite may also have slumped from the walls, but many may have formed through collapse of domes within the center.

The Mount Blitzen center was previously interpreted as a stratovolcano (Berger and others, 1991), a caldera (Crawford, 1992), or a volcano-tectonic graben (Boden and others, 1993). Caldera-like features are that it is a deep, roughly circular, fault-bounded basin filled with a thick sequence of volcanic rocks that commonly contain megabreccia. It is dissimilar to most calderas in that the fill consists of complexly interbedded, small-volume pyroclastic flows and epiclastic rocks. These deposits contrast with the typical, more homogeneous intracaldera tuff of most calderas, as illustrated by the tuff of Big Cottonwood Canyon within its caldera to the north. It is possible that such a typical intracaldera tuff underlies tuff of Mount Blitzen, but we have no evidence for such a deposit, and equivalent outflow tuff has not been identified in the region.

Big Cottonwood Canyon Caldera

The Big Cottonwood Canyon caldera, first recognized by Berger and others (1991) during reconnaissance study, is a classic, large rhyolitic ash-flow caldera that lies north of and truncates the Mount Blitzen volcanic center (fig. 2). Only the southeastern corner of the caldera is in the northwestern part of the Tuscarora Quadrangle. The margin is marked by the juxtaposition of thick intracaldera tuff of Big Cottonwood Canyon (Tct) against older rocks in the caldera wall. The caldera is at least 15 km east-west, but its full extent is unknown. The southeastern part is cut off by a north-striking normal fault in the Tuscarora and Cottonwood Peak Quadrangles. The caldera extends into unmapped areas to the north and northwest in the Big Cottonwood Canyon and Red Cow Creek 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 ~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 outcrop of this tuff in the Tuscarora Quadrangle is 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 in the Willow Creek Reservoir Quadrangle, about 35 km to the southwest (Wallace, in preparation), but is likely more widely distributed.

Tuff near the caldera margin contains abundant blocks of older rock. Two types of deposits were mapped. (1) Individual large blocks (megabreccia) more than about 10 m up to about 50 m in diameter were mapped as their original rock type. Clast types are tuff of Mount Blitzen (Tbt) and and Paleozoic chert (Pzu) and quartzite (Pzq). Larger blocks, up to several hundred meters in diameter and including dacite of Mount Blitzen (Tbd) and early andesite (Ta) are present farther west. (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, and many debris deposits consist 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 renewed eruption that generated the overlying, lithic-rich tuff.

Mount Neva Intrusive Episode

The Mount Neva intrusive episode consists of numerous small to moderately large intrusions emplaced into and around the Mount Blitzen volcanic center (fig. 2). The intrusions developed in three distinct pulses, as determined from field relations, but only two are present in the Tuscarora Quadrangle. In the first pulse, porphyritic dacite (Tmd) formed numerous irregularly shaped bodies along the margin of the Mount Blitzen center and a few dikes within the center. In the third, a series of andesite to low-silica rhyolite dikes (Tmr, Tmdp, Tmq, Tma) intruded as a dominantly northeast-striking swarm through the center and slightly beyond. The ~5 by 1.5 km Mount Neva granodiorite of the Mount Blitzen Quadrangle makes up the second pulse. Field relations and ^{40}Ar/^{39}Ar ages demonstrate that most of the dikes and probably the other intrusions postdate activity in the Big Cottonwood Canyon caldera. ^{40}Ar/^{39}Ar ages on two samples of early dacite (including H96-103 in the Tuscarora Quadrangle), one sample of granodiorite, and three samples of late dikes (including H96-19 in the Tuscarora Quadrangle) indicate that these intrusions were emplaced between about 39.5 and 39.3 Ma (fig. 5; table 2).

Early dacites intruded extensively along the eastern margin of the Mount Blitzen volcanic center in the Tuscarora district and are the most common host rocks for veins. This distribution indicates that the intrusions rose along the faults that bound the center. The dacite is petrographically and compositionally fairly uniform, with only minor variations in composition or relative abundances of hornblende and biotite (figs. 3 and 4; table 1).

Numerous late dikes, ranging in composition from andesite to low-silica rhyolite (figs. 3 and 4; table 1), were the last manifestations of the Mount Neva episode. Although divided into four map units on the basis of phenocryst assemblage and inferred composition, field data and ^{40}Ar/^{39}Ar ages indicate that they were emplaced contemporaneously and are probably genetically related. Petrographic characteristics are broadly gradational (fig. 3). Moreover, many dikes are composite and grade inward from andesite (Tma) or dacite (Tmdp) at the margins to rhyolite (Tmr). Samples H96-55A and H96-55B from the margin and core of a dike in the Mount Blitzen Quadrangle illustrate this compositional gradation (table 1). In several composite dikes, the more mafic margin contains scattered quartz phenocrysts that are not generally present in isolated andesite or dacite dikes. These features suggest contemporaneity and partial mixing between the different magmas or tapping of a zoned chamber.

The dikes are most abundant in a broad, north-northeast-striking band through the middle of the Mount Blitzen center (fig. 2), where they intrude tuff of Mount Blitzen (Tbt). This band also parallels and generally coincides with the anticline. Dikes of porphyritic rhyolite (Tmr) and porphyritic dacite (Tmdp) continue northeast at least 3 km into the Big Cottonwood Canyon caldera, where they cut the tuff of Big Cottonwood Canyon (Tct). A few dikes cross the southwestern margin of the center in the Mount Blitzen Quadrangle, where they cut the Mount Neva pluton (Tmg) and early porphyritic dacite (Tmd), and continue about 4 km into Paleozoic rocks. Individual dikes strike dominantly north-northeast to east-northeast and, in the Tuscarora Quadrangle, dip to the northwest as shallowly as 48° (i.e., they are nearly perpendicular to the dip of the tuff of Mount Blitzen). The distribution of dikes suggests they may be apophyses from a larger intrusion that underlies the Mount Blitzen center.

Lavas of Sixmile Canyon

A series of dacite and andesite lavas that crop out northeast of Tuscarora are the youngest igneous rocks in the Tuscarora Quadrangle. They continue an unknown distance farther north in the Cottonwood Peak Quadrangle. In and around Sixmile Canyon, at least two petrographically similar dacite lavas (Tsd) containing both hornblende and pyroxene phenocrysts are locally separated by thin lenses of volcaniclastic sedimentary rocks. These lavas are overlain by an andesite lava (Tsa) that contains clino- and orthopyroxene as the only mafic phenocryst phases. Several small intrusions are probably related to the Sixmile Canyon lavas. The largest, a coarsely porphyritic biotite dacite (Tsb), intrudes volcaniclastic sedimentary rocks and tuff that are probably part of the Pleasant Valley complex (Tps).

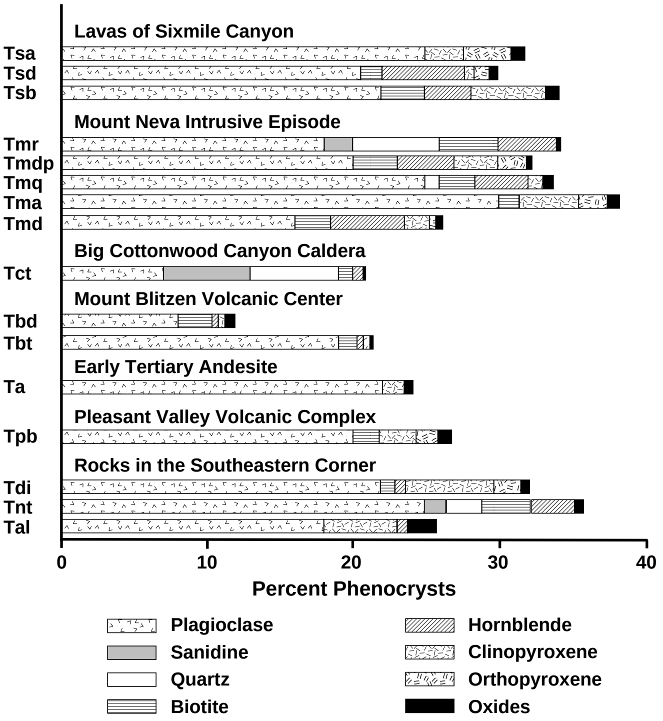

Figure 3. Phenocryst abundances in Tertiary igneous rocks of the Tuscarora Quadrangle.

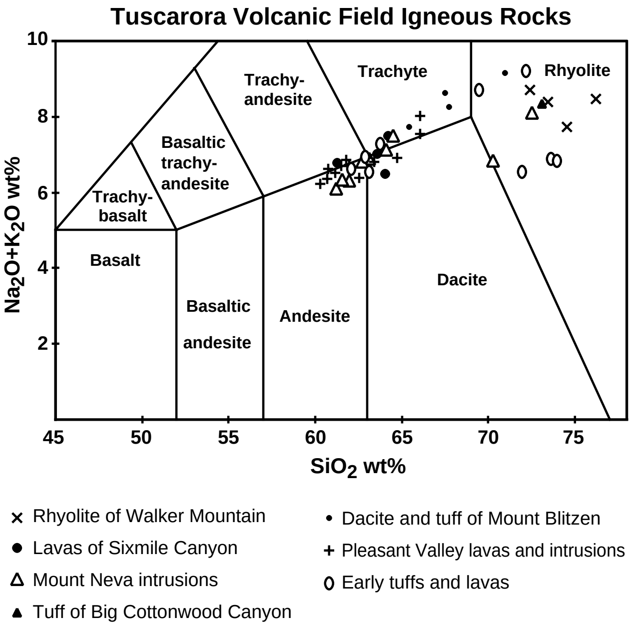

Figure 4. Total alkalies - silica plot of Tertiary igneous rocks of the Tuscarora volcanic field, Nevada. Classification follows Le Bas and others (1986). Major elements normalized to 100% volatile free. Data from table 1 and Henry and Boden (1998).

Table 1. Chemical analyses of the 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	Ted_1	Ted_2	Tjt	Tvt	Tdi	Tal	Twd	Twd	Tldi	Tld_1	Tld_1	Tld_2	Tld_2	Tma	Tmr	Tsb	Twr	Tmt
Long 116° W	8.0'	25.2'	30.1'	29.8'	29.4'	29.2'	27.6'	7.8'	7.6'	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	0.10	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	5.06	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	98.73	98.76	98.30	99.34	97.92	97.57	98.18	98.66	98.22	98.57	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

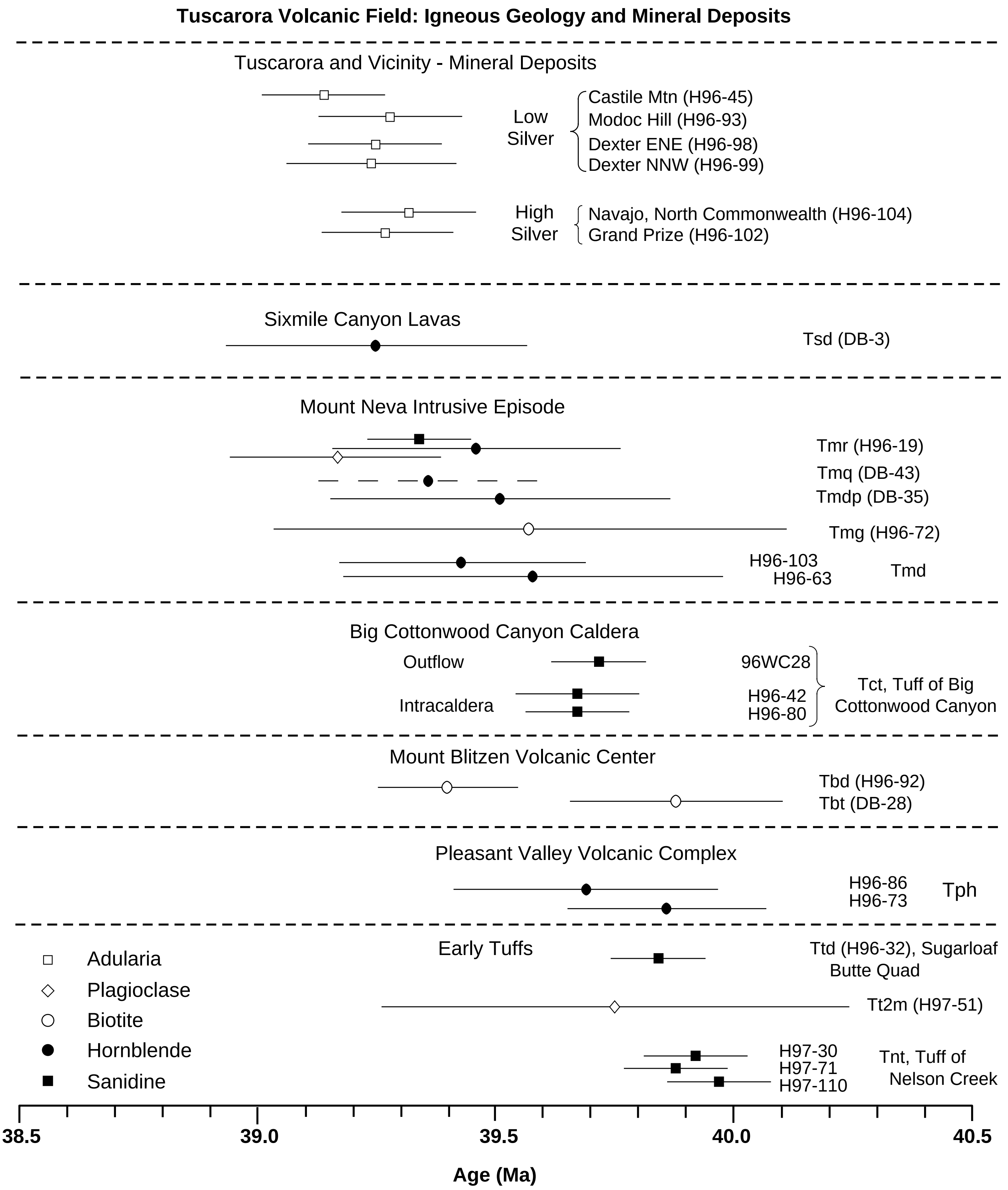

Figure 5. ^{40}Ar/^{39}Ar ages (±2σ) of igneous rocks and mineralization in the Tuscarora volcanic field. Rocks are in stratigraphic order determined from field relations. Sanidine and adularia give the most precise and reliable ages, hornblende is next, and biotite is the least precise.

Table 2. ^{40}Ar/^{39}Ar ages of Tertiary igneous rocks and mineralization, 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).

TABLE 3. Chemical analyses of altered or mineralized rocks, Tuscarora mining district

Low-Silver Zone

Lab	USML	Acme	USML	USML	USML	Acme	Acme	USML	Acme	USML	Acme	Acme	USML	Acme	USML	USML	Acme	Acme	Acme	Acme	Acme
Element	Ag	Al	As	Au	Ag/Au	Ba	Be	Bi	Ca	Cd	Ce	Co	Cu	Fe	Ga	Hg	K	La	Li	Mg	Mn
Samples	ppm	%	ppm	ppm		ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	%	ppm	ppm	%	ppm	ppm	%	ppm
B97-1	68.3	2.18	8900	17.7	4	115	< 1	0.40	0.04	0.00	8	2	15	6.26	0.4	1.81	2.03	5	82	0.01	7
B97-2	18.8	2.55	982	14.8	1	515	< 1	0.59	0.05	0.03	12	5	6	1.51	0.4	2.28	2.14	8	108	0.02	19
B97-3	1.0	5.08	107	0.081	12	1220	< 1	0.54	0.02	0.05	66	2	3	0.69	1.1	0.19	5.64	40	25	0.01	13
B97-3A	1.5	5.49	58	0.122	12	1400	< 1	0.46	0.07	0.05	56	5	6	0.72	1.3	0.40	4.36	34	23	0.18	34
B97-4	11.5	0.63	22	7.42	2	211	< 1	0.48	0.02	0.05	7	< 2	7	0.44	0.2	1.19	0.33	3	29	0.02	10
C97-11	0.3	6.62	35	0.016	17	1240	< 1	0.45	0.06	0.02	56	2	3	0.68	1.7	0.40	5.92	33	34	0.04	23
C97-11A	0.4	0.33	5	0.268	2	89	< 1	0.67	0.06	0.02	2	< 2	2	0.29	0.6	0.10	0.05	2	56	< 0.01	26
C97-30	0.0	6.13	48	0.042	0	1550	< 1	0.51	0.16	0.15	76	4	8	1.55	7.0	0.03	6.75	47	26	0.23	441
C97-31	2.8	6.33	28	0.157	18	1460	< 1	0.40	0.07	0.03	63	< 2	4	0.53	1.0	0.02	5.20	40	87	0.07	13
C97-33	15.4	2.65	17	1.37	11	628	< 1	0.43	0.06	0.39	17	11	20	1.66	2.0	0.19	2.36	13	48	0.09	929
C97-34	1.4	6.41	31	0.208	7	1500	< 1	0.44	0.13	0.83	63	4	19	2.44	7.7	0.44	6.27	37	29	0.54	1071
C97-46	8.7	4.60	146	0.112	78	700	< 1	0.53	0.07	0.06	18	4	3	1.46	0.5	0.58	4.94	12	40	0.07	23
C97-47	777	3.62	142	5.27	147	562	< 1	1.04	0.01	1.61	5	2	5	1.35	0.2	1.29	4.21	5	56	0.02	18
C97-90	3680	3.21	46	0.652	5644	1020	1	0.43	0.02	0.02	13	< 2	15	0.99	0.4	3.40	3.60	7	35	0.02	27
C97-93	0.0	5.47	28	0.331	0	1270	1	0.21	0.05	0.07	60	< 2	13	2.02	0.3	0.15	4.44	38	21	0.10	71
C97-95	38.2	2.08	268	0.508	75	150	1	0.37	0.08	0.28	40	3	35	12.96	2.0	0.59	1.47	26	29	0.08	142
C97-99	0.8	5.57	37	0.099	8	1840	1	0.29	0.02	0.01	26	< 2	2	0.79	1.1	0.21	6.01	17	19	0.02	40
C97-110	8.1	7.33	38	0.471	17	66	1	0.28	0.03	0.02	24	< 2	4	2.99	0.4	0.28	7.72	18	9	0.06	22
C97-111	7.0	8.70	22	0.090	78	438	1	0.21	0.19	0.02	77	< 2	3	1.57	1.7	0.14	8.97	53	10	0.04	35
C97-112	12.1	3.75	76	0.111	109	497	1	0.29	0.07	0.03	61	< 2	15	1.70	0.5	1.84	2.81	40	26	0.19	63
C97-113	3.8	6.65	96	0.274	14	1920	1	0.37	0.10	0.05	60	< 2	17	1.52	1.5	0.13	6.36	37	12	0.08	36
C97-114A	2.8	3.03	124	3.44	1	759	1	0.33	0.09	0.09	20	< 2	8	2.21	0.6	1.18	3.44	14	38	0.04	235
C97-117	25.3	1.63	37	16.9	1	284	< 1	0.30	0.08	0.08	10	< 2	276	1.13	1.4	0.76	1.35	6	52	0.17	294
C97-119	15.1	2.36	1200	3.31	5	236	1	0.26	0.05	0.03	19	< 2	11	2.96	0.7	2.39	2.65	11	77	0.05	32
C97-120	1.8	7.08	111	0.127	14	1880	1	0.33	0.13	0.05	64	< 2	3	1.42	1.2	0.00	6.86	44	19	0.12	46
C97-121A	1.2	6.37	110	0.036	33	2060	2	0.15	0.09	0.07	62	< 2	4	1.96	0.6	0.65	5.63	41	18	0.13	39
C97-123	1.6	6.71	1310	0.232	7	115	1	0.25	0.15	0.03	49	2	3	2.02	0.2	0.09	5.99	31	15	0.19	34
C97-124	8.9	2.61	103	4.65	2	866	1	0.26	0.05	0.03	27	< 2	5	0.80	0.3	0.25	2.04	18	40	0.09	27
CT2-211	60.7	5.27	65	2.28	27	1520	2	0.45	0.04	0.30	52	< 2	24	1.42	0.6	3.95	4.73	30	25	0.10	48
CT3-39	15.7	8.24	70	0.030	523	1860	4	0.32	0.10	0.11	58	6	7	9.20	2.8	0.09	5.01	33	21	0.14	1912
CT3-64.5	379	6.59	28	0.064	5922	15,900	3	0.57	0.10	1.04	95	80	40	1.32	2.0	1.29	5.03	37	13	0.07	24,800
CT3-352	2.7	6.45	33	0.044	60	1840	1	0.33	0.13	0.01	66	< 2	2	1.36	1.5	0.07	4.13	41	38	0.05	74
CT3-419	7.1	6.67	251	0.061	116	117	2	0.50	0.18	0.18	83	2	7	1.72	1.0	0.43	3.57	50	391	0.10	78
Mean	157	4.80	442	2.46	393	1390	1	0.41	0.08	0.18	43	5	18	2.17	1.3	0.81	4.30	26	47	0.10	930
Median	7.1	5.47	65	0.232	14	866	1	0.40	0.07	0.05	52	< 2	7	1.51	1.0	0.40	4.44	31	29	0.07	36
High	3680	8.24	8900	17.7	5922	15,900	4	1.04	0.18	1.61	95	80	276	12.96	7.7	3.95	8.97	53	391	0.54	24,800
Low	0.0	1.63	5	0.030	0	66	< 1	0.15	0.02	0.00	2	< 2	2	0.29	0.2	0.00	0.05	2	9	< 0.01	7

Lab	USML	Acme	Acme	Acme	Acme	USML	Acme	USML	Acme	USML	Acme	Acme	USML	Acme	Acme	USML	Acme	Acme	Acme	Acme	USML	Acme
Element	Mo	Na	Nb	Ni	P	Pb	Rb	Sb	Sc	Se	Sn	Sr	Te	Th	Ti	Tl	U	V	W	Y	Zn	Zr
Samples	ppm	%	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm
B97-1	8.01	0.10	4	5	0.01	24.1	118	656	1	0.9	< 2	78	0.00	5	0.10	2.24	18	20	6	< 2	3	31
B97-2	8.87	0.13	4	13	0.01	10.1	129	62.8	2	0.5	< 2	83	0.09	2	0.10	1.96	< 10	22	10	3	9	33
B97-3	2.25	0.06	13	5	0.01	18.4	343	6.3	2	0.0	2	74	0.14	11	0.10	1.21	25	13	< 4	10	2	118
B97-3A	1.16	0.06	11	3	0.01	7.6	259	8.8	4	0.1	4	57	0.09	11	0.18	1.54	16	22	5	23	3	117
B97-4	1.72	0.01	3	9	0.00	1.8	12	4.8	< 1	0.0	< 2	24	0.20	< 2	0.03	1.16	< 10	11	< 4	2	3	9
C97-11	1.83	0.20	15	6	0.01	5.0	429	4.6	2	0.1	5	112	0.07	13	0.16	0.70	< 10	16	9	10	5	153
C97-11A	26.6	0.01	3	9	0.02	4.7	4	9.3	< 1	0.0	< 2	47	0.13	2	< 0.01	1.03	< 10	18	< 4	< 2	3	< 2
C97-30	3.37	0.10	11	2	0.03	22.0	440	3.1	2	0.3	2	197	0.13	11	0.12	0.85	< 10	17	< 4	12	55	132
C97-31	2.13	0.08	10	< 2	0.01	5.1	299	2.2	2	0.2	2	127	0.00	9	0.11	1.17	10	12	< 4	9	6	98
C97-33	6.01	0.05	5	11	0.06	37.3	120	2.1	2	0.7	2	65	0.13	4	0.08	1.46	< 10	24	6	4	49	35
C97-34	2.53	0.12	10	7	0.06	21.1	344	1.6	4	0.3	< 2	177	0.00	7	0.19	1.01	< 10	45	< 4	11	94	72
C97-46	3.38	0.08	6	9	0.04	36.3	272	3.1	2	0.3	< 2	100	0.12	6	0.12	1.64	< 10	18	5	4	12	39
C97-47	1.38	0.07	3	7	0.01	463	225	36.6	< 1	23.8	< 2	90	1.80	3	0.03	1.94	< 10	6	< 4	< 2	398	9
C97-90	5.60	0.05	5	7	0.02	71.5	159	41.6	2	4.6	2	55	0.10	5	0.05	1.32	< 10	4	< 4	7	12	52
C97-93	3.00	0.07	7	3	0.03	9.3	249	4.6	3	0.4	3	81	0.15	8	0.12	0.39	< 10	22	< 4	10	30	62
C97-95	11.6	0.03	3	9	0.10	20.7	68	15.2	2	0.7	< 2	128	0.14	5	0.06	0.48	< 10	44	< 4	8	77	49
C97-99	8.52	0.13	6	4	0.01	9.7	299	1.0	2	0.2	2	157	0.16	6	0.19	0.69	< 10	16	< 4	5	2	51
C97-110	4.95	0.21	7	4	0.02	21.2	508	1.5	4	0.8	3	243	0.13	8	0.20	0.52	< 10	38	< 4	7	4	107
C97-111	2.95	0.24	7	3	0.07	13.7	572	1.1	6	0.0	4	206	0.11	7	0.22	0.44	< 10	44	< 4	7	6	69
C97-112	4.64	0.06	6	4	0.04	24.9	144	5.0	4	0.9	3	130	0.18	7	0.15	0.50	< 10	55	< 4	6	8	56
C97-113	5.30	0.21	7	5	0.06	19.0	327	3.4	4	0.0	2	212	0.09	8	0.21	0.40	< 10	26	< 4	7	13	59
C97-114A	7.66	0.08	2	8	0.03	19.6	154	34.7	1	0.0	< 2	70	0.16	2	0.07	0.62	< 10	44	< 4	3	30	16
C97-117	6.04	0.04	< 2	9	0.03	45.5	47	10.5	2	0.2	< 2	40	0.33	< 2	0.06	0.59	< 10	27	< 4	3	17	15
C97-119	9.08	0.13	2	6	0.02	20.8	113	15.4	2	3.3	< 2	84	0.17	2	0.10	1.51	< 10	29	< 4	2	12	26
C97-120	4.94	0.26	11	4	0.04	10.0	436	2.4	4	0.2	3	184	0.15	11	0.25	0.44	< 10	33	< 4	9	21	116
C97-121A	3.65	0.15	9	4	0.03	8.6	295	16.9	4	0.7	6	132	0.17	10	0.22	0.44	< 10	57	< 4	10	11	117
C97-123	8.73	0.09	8	2	0.05	15.5	370	26.9	5	0.6	3	122	0.11	6	0.29	0.44	< 10	77	< 4	7	7	71
C97-124	7.57	0.12	3	7	0.02	15.0	90	2.5	2	0.7	< 2	60	0.13	2	0.11	0.49	< 10	33	< 4	3	8	29
CT2-211	12.5	0.07	9	4	0.02	27.0	241	9.5	3	0.1	3	76	0.17	8	0.13	0.37	< 10	17	< 4	11	39	89
CT3-39	5.15	0.07	6	2	0.10	59.8	289	4.6	5	0.1	2	129	0.15	9	0.21	2.36	< 10	74	< 4	11	165	44
CT3-64.5	25.4	0.09	5	< 2	0.07	3.7	266	5.4	4	0.0	2	167	0.14	4	0.11	29.6	< 10	9	< 4	15	218	41
CT3-352	4.28	0.11	7	4	0.05	15.7	174	2.7	3	0.1	3	94	0.15	9	0.13	0.39	< 10	21	< 4	10	63	66
CT3-419	8.45	0.07	11	< 2	0.03	40.5	148	8.8	3	0.3	4	67	0.15	9	0.14	0.60	< 10	10	< 4	10	113	100
Mean	6.64	0.10	7	5	0.03	34.2	241	30.8	3	1.3	2	111	0.18	6	0.13	1.83	6	28	3	7	45	63
Median	5.15	0.08	6	5	0.03	19.0	249	5.0	2	0.3	2	94	0.14	7	0.12	0.70	< 10	22	< 4	7	12	56
High	26.6	0.26	15	13	0.10	463	572	656	6	23.8	6	243	1.80	13	0.29	29.6	25	77	10	23	398	153
Low	1.16	0.01	< 2	< 2	0.00	1.8	4	1.0	< 1	0.0	< 2	24	0.00	< 2	< 0.05	0.37	< 10	4	< 4	< 2	2	< 2

All analyses by inductively coupled plasma atomic-emission spectrometry, except Au by graphite furnace atomic absorption; USML analyses used organic extraction.
USML Laboratories, North Highlands, California
Acme Laboratories, Vancouver, British Columbia

High-Silver Zone

Laboratory	USML	Acme	USML	USML	USML	Acme	Acme	USML	Acme	USML	Acme	Acme	USML	Acme	USML	USML	Acme	Acme	Acme	Acme	Acme
Element	Ag	Al	As	Au	Ag/Au	Ba	Be	Bi	Ca	Cd	Ce	Co	Cu	Fe	Ga	Hg	K	La	Li	Mg	Mn
Samples	ppm	%	ppm	ppm		ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	%	ppm	ppm	%	ppm	ppm	%	ppm
C97-15	0.2	7.74	30	0.003	66	1600	< 1	0.69	2.38	0.21	74	11	9	3.98	7.7	0.04	3.64	43	38	1.08	692
C97-17	30.7	5.38	95	0.461	67	1060	< 1	0.74	4.36	0.63	44	2	3	1.68	0.4	0.29	5.15	33	11	0.12	1004
C97-19	1449	0.94	58	6.79	213	262	< 1	0.60	24.71	7.95	29	2	27	2.48	0.3	0.70	1.03	17	6	0.06	7790
C97-19A	0.0	7.44	41	0.017	0	1500	< 1	0.50	1.60	0.22	79	3	6	2.10	5.6	0.03	5.08	50	17	0.44	1111
C97-19B	108	7.47	46	0.769	140	488	< 1	0.59	2.42	1.47	66	7	23	2.70	5.5	0.29	5.70	39	23	0.56	1364
C97-19C	31.4	5.66	52	0.267	118	451	< 1	0.74	0.11	2.30	56	< 2	11	2.16	2.4	0.13	4.41	32	28	0.14	271
C97-20	303	7.15	112	2.05	148	312	< 1	0.71	1.34	0.30	69	5	7	2.65	4.0	0.32	5.31	40	21	0.42	780
C97-21A	14.6	5.35	65	0.129	113	1010	< 1	0.54	0.45	0.35	40	3	22	1.87	2.9	0.16	5.00	24	26	0.16	590
C97-21B	3.5	2.00	90	0.120	29	378	< 1	0.79	17.73	3.28	42	2	37	2.07	1.2	0.15	1.72	34	11	0.16	2630
C97-23	3.9	5.44	112	0.107	36	802	< 1	0.65	0.08	0.06	62	< 2	1	1.32	0.7	0.26	5.03	37	18	0.12	76
C97-24	69.2	5.41	335	0.627	110	811	30	0.99	0.13	1.29	9	< 2	35	3.55	1.1	0.50	6.80	10	23	0.05	28,900
C97-24A	4854	6.84	218	0.541	8972	2020	< 1	0.77	0.10	1.59	50	5	26	3.58	2.1	0.79	7.17	31	12	0.10	163
C97-24B	78.1	5.16	62	0.151	517	1290	< 1	0.68	0.05	0.05	50	< 2	2	0.67	1.2	0.18	4.52	30	10	0.16	76
C97-25	0.0	7.76	14	0.004	0	1420	< 1	0.67	2.86	0.19	73	10	6	3.21	8.3	0.14	3.32	44	31	0.93	666
C97-25A	0.0	6.90	51	0.035	0	494	< 1	0.59	0.72	0.18	79	2	2	2.09	3.1	0.18	4.42	46	20	0.32	641
C97-27	10.7	6.28	94	0.119	90	1180	< 1	0.46	0.08	0.10	67	2	4	1.93	1.0	0.17	5.14	39	14	0.18	193
C97-27A	9.4	3.82	59	0.112	84	833	< 1	0.35	12.94	0.20	43	5	4	3.31	2.1	0.03	3.06	26	20	0.35	6331
C97-28	127	6.61	77	0.124	1024	1940	< 1	0.55	0.32	5.69	85	63	23	13.87	4.7	0.12	3.98	34	38	0.39	19,200
C97-29	684	4.56	241	2.38	287	109	< 1	0.89	8.01	18.10	23	4	26	7.02	0.2	2.09	4.65	16	17	0.11	2950
C97-29A	2.7	3.65	149	0.086	32	454	< 1	0.75	0.04	0.03	49	2	3	2.73	1.0	0.03	2.23	30	25	0.16	114
C97-29C	1671	3.36	1515	1.97	848	111	< 1	0.61	0.06	0.60	18	3	32	6.13	1.8	0.10	2.65	11	26	0.11	103
C97-29D	324	2.74	771	0.816	397	104	< 1	0.43	0.05	0.36	11	4	11	11.03	0.3	5.03	2.41	5	26	0.09	135
C97-29E	4808	2.61	303	24.7	195	49	< 1	0.34	0.06	0.87	13	6	39	13.18	0.7	1.10	2.80	7	18	0.08	263
C97-35	73.7	0.93	519	1.34	55	321	< 1	0.68	0.28	0.21	21	< 2	42	15.48	10.6	2.34	0.28	17	43	0.13	301
C97-35A	132	0.71	452	1.04	127	346	< 1	1.23	0.15	0.08	27	< 2	14	7.18	2.9	0.26	0.53	22	64	0.08	196
C97-35B	32.1	0.57	397	2.06	16	99	< 1	0.98	0.06	0.03	23	< 2	22	19.15	10.8	0.34	0.15	15	54	0.02	202
C97-35C	321	2.79	1064	0.341	941	89	< 1	0.64	0.08	0.08	23	9	8	13.63	0.7	0.17	2.01	12	25	0.10	173
C97-38	22.0	4.79	108	0.178	124	504	< 1	0.59	0.11	0.08	32	3	8	1.91	0.4	0.14	4.13	19	37	0.15	46
C97-38A	9.2	3.49	237	0.242	38	310	< 1	0.38	2.99	0.14	22	4	24	2.07	2.3	0.02	3.40	18	45	0.30	3270
C97-38B	4.4	6.01	497	0.347	13	222	< 1	0.47	0.15	0.15	32	3	7	2.39	0.5	0.40	6.19	20	20	0.05	32
C97-39	861	1.50	27	0.417	2065	753	23	0.39	1.12	1.10	6	4	92	3.07	0.7	0.61	1.54	10	68	0.04	56,500
C97-39B	3.1	7.42	104	0.078	40	569	< 1	0.48	0.08	0.02	44	3	1	1.52	0.2	0.43	9.21	27	7	0.02	42
H97-26	9.8	5.18	142	0.410	24	1050	< 1	0.55	0.09	0.20	32	7	54	2.94	0.6	1.61	3.15	20	38	0.15	186
Mean	486.4	4.66	247	1.48	513	695	2	0.64	2.60	1.46	42	5	19	4.99	2.7	0.58	3.81	26	27	0.22	4150
Median	31.4	5.18	108	0.341	110	494	< 1	0.61	0.15	0.21	42	3	11	2.73	1.2	0.26	3.98	26	23	0.14	301
High	4854	7.76	1515	24.7	8972	2020	30	1.23	24.71	18.10	85	63	92	19.15	10.8	5.03	9.21	50	68	1.08	56,500
Low	0.0	0.57	14	0.003	0	49	< 1	0.34	0.04	0.02	6	< 2	1	0.67	0.2	0.02	0.15	5	6	0.02	32

Laboratory	USML	Acme	Acme	Acme	Acme	USML	Acme	USML	Acme	USML	Acme	Acme	USML	Acme	Acme	USML	Acme	Acme	Acme	Acme	USML	Acme
Element	Mo	Na	Nb	Ni	P	Pb	Rb	Sb	Sc	Se	Sn	Sr	Te	Th	Ti	Tl	U	V	W	Y	Zn	Zr
Samples	ppm	%	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm
C97-15	1.75	1.35	9	5	0.10	16.0	197	0.8	6	0.0	3	475	0.21	11	0.32	2.06	13	96	< 4	16	90	115
C97-17	3.61	0.08	10	< 2	0.02	160	320	8.3	2	0.7	< 2	166	0.14	12	0.10	1.47	10	12	4	9	180	87
C97-19	1.33	0.04	< 2	< 2	0.01	2654	51	253	2	28.9	< 2	774	0.37	< 2	0.01	1.55	10	4	< 4	19	2183	8
C97-19A	1.09	1.22	13	< 2	0.04	16.4	292	5.5	3	0.3	3	321	0.18	11	0.18	0.97	31	15	< 4	14	78	122
C97-19B	3.54	1.23	8	6	0.09	316	302	10.0	5	2.5	2	396	0.28	10	0.26	1.63	< 10	66	< 4	14	440	103
C97-19C	2.81	0.26	12	< 2	0.03	1189	222	3.9	2	6.1	2	116	0.37	7	0.13	1.43	< 10	5	< 4	8	637	72
C97-20	3.32	0.83	9	4	0.07	349	297	45.6	5	2.7	2	222	0.27	10	0.26	1.45	< 10	55	< 4	13	99	103
C97-21A	3.83	0.11	8	6	0.05	54.6	277	3.9	3	0.5	2	173	0.21	6	0.17	1.66	< 10	21	6	7	108	67
C97-21B	2.23	0.08	3	< 2	0.02	457	89	2.2	2	1.7	< 2	640	0.34	< 2	0.04	1.71	< 10	19	< 4	8	897	13
C97-23	3.75	0.07	11	3	0.01	27.4	289	3.0	2	0.3	3	109	0.25	8	0.12	1.61	< 10	11	6	8	14	93
C97-24	20.0	0.12	5	13	0.02	478	383	6.2	< 1	8.7	< 2	491	0.66	< 2	0.01	2.26	< 10	35	< 4	4	1248	17
C97-24A	6.12	0.18	8	4	0.07	458	410	27.9	5	12.6	2	239	0.35	10	0.24	3.76	19	69	5	15	152	86
C97-24B	3.24	0.05	11	< 2	0.01	40.3	259	3.4	2	0.3	3	116	0.22	11	0.13	1.95	25	16	< 4	11	6	123
C97-25	2.01	1.66	10	6	0.10	21.0	172	0.7	7	0.0	2	395	0.19	12	0.32	1.47	16	88	< 4	17	80	126
C97-25A	1.74	0.10	14	< 2	0.04	21.2	271	0.8	3	0.2	3	134	0.18	11	0.17	1.29	< 10	17	< 4	12	63	89
C97-27	5.45	0.07	11	< 2	0.03	33.1	309	5.3	3	0.4	4	133	0.08	8	0.14	0.95	10	16	< 4	9	52	86
C97-27A	2.13	0.24	3	3	0.04	21.8	173	2.7	4	0.0	< 2	862	0.00	5	0.12	0.87	< 10	33	< 4	16	72	52
C97-28	20.2	0.48	6	23	0.11	77.5	296	21.4	6	0.2	3	231	0.21	6	0.20	5.69	< 10	87	< 4	21	1413	62
C97-29	1.36	0.19	4	3	0.03	1765	271	68.0	3	10.5	2	248	0.00	2	0.08	0.97	< 10	25	< 4	10	5699	28
C97-29A	26.6	0.03	8	3	0.01	69.2	148	6.5	2	0.6	2	47	0.03	8	0.08	0.99	< 10	31	< 4	13	11	98
C97-29C	23.7	0.05	4	8	0.05	911	136	32.3	2	7.7	2	88	0.14	3	0.08	1.73	< 10	54	6	4	209	23
C97-29D	7.64	0.05	3	7	0.04	596	120	64.9	2	7.3	2	59	0.14	4	0.08	1.77	13	36	< 4	2	243	19
C97-29E	8.43	0.05	4	10	0.02	3745	136	355	2	77.9	< 2	83	0.28	4	0.09	2.68	< 10	13	4	3	279	27
C97-35	28.6	0.02	3	8	0.08	49.8	10	63.3	2	1.6	< 2	63	0.15	5	0.12	2.18	12	141	< 4	7	50	36
C97-35A	56.6	0.02	6	7	0.03	123	16	21.0	1	2.2	< 2	71	0.17	7	0.06	1.16	< 10	73	< 4	9	8	62
C97-35B	37.5	0.02	3	8	0.04	170	6	17.9	1	1.1	< 2	45	0.15	5	0.05	1.26	< 10	64	4	5	69	33
C97-35C	4.91	0.08	4	10	0.02	87.6	96	18.4	3	4.3	< 2	47	0.20	5	0.09	1.13	12	39	< 4	6	15	40
C97-38	3.19	0.06	7	7	0.06	43.8	240	6.2	4	3.2	< 2	91	0.16	7	0.18	1.02	< 10	41	5	6	24	66
C97-38A	1.59	0.08	6	6	0.05	31.1	172	6.6	2	0.9	< 2	149	0.22	4	0.12	1.02	< 10	28	< 4	6	53	41
C97-38B	4.45	0.07	7	9	0.07	28.3	342	7.4	4	3.1	< 2	128	0.16	8	0.20	1.35	< 10	38	6	6	16	67
C97-39	1.08	0.01	< 2	4	0.04	183	72	95.9	< 1	10.5	< 2	78	0.10	< 2	0.02	1.65	< 10	8	< 4	8	329	36
C97-39B	1.26	0.12	8	3	0.05	16.3	576	1.7	4	0.6	< 2	331	0.01	10	0.23	1.40	< 10	29	< 4	10	4	85
H97-26	2.56	0.08	6	7	0.03	130	180	12.3	5	0.1	< 2	102	0.17	6	0.17	1.55	< 10	67	4	8	93	70
Mean	9.02	0.28	7	5	0.04	435	216	35.8	3	6.0	2	231	0.20	7	0.14	1.69	5	41	2	10	452	65
Median	3.54	0.08	7	5	0.04	87.6	222	7.4	3	1.6	2	134	0.18	7	0.12	1.47	0	33	0	9	90	67
High	56.6	1.66	14	23	0.11	3745	576	355	1	77.9	4	862	0.66	12	0.32	5.69	31	141	6	21	5699	126
Low	1.08	0.01	< 2	< 2	0.01	16.3	6	0.7	< 1	0.0	< 2	45	0.00	< 2	0.01	0.87	< 10	4	< 4	2	4	8

Miscellaneous Prospects

Laboratory	USML	Acme	USML	USML	USML	Acme	Acme	USML	Acme	USML	Acme	Acme	USML	Acme	USML	USML	Acme	Acme	Acme	Acme	Acme
Element	Ag	Al	As	Au	Ag/Au	Ba	Be	Bi	Ca	Cd	Ce	Co	Cu	Fe	Ga	Hg	K	La	Li	Mg	Mn
Samples	ppm	%	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	%	ppm	ppm	%	ppm	ppm	%	ppm	ppm
C97-32	264	4.85	5.06	0.04	7543	333	< 1	1.84	1.6	265	40	20	5697	3.95	1.67	1.98	2.89	25	25	0.74	2280
C97-37	0.0	8.46	8.64	0.0	NA	1470	2	0.43	2.14	0.09	68	13	16	3.22	2.15	20.9	2.73	38	12	0.29	224

Laboratory	USML	Acme	Acme	Acme	Acme	USML	Acme	USML	Acme	USML	Acme	Acme	USML	Acme	Acme	USML	Acme	Acme	Acme	Acme	USML	Acme
Element	Mo	Na	Nb	Ni	P	Pb	Rb	Sb	Sc	Se	Sn	Sr	Te	Th	Ti	Tl	U	V	W	Y	Zn	Zr
Samples	ppm	%	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm
C97-32	4.14	0.1	5	6	0.04	9730	135	66.3	3	24.6	4	122	4.34	< 2	0.12	0.0	< 10	64	< 4	8	21,012	49
C97-37	1.68	2.3	11	11	0.11	5.41	130	4.95	7	0.0	< 2	553	0.1	11	0.39	0.96	11	96	< 4	19	127	145

Table 3
Centerfold

Sample descriptions for Table 3

Low-Silver Zone

B97-1	Vein quartz with sulfide and electrum, Eureka vein
B97-2	Vein quartz with sulfide, Eureka vein
B97-3	Silicified Tbd
B97-3A	Altered non-welded ash-flow tuff
B97-4	Intricately banded quartz vein
C97-11	Brecciated and silicified Tbd
C97-11A	Quartz vein, banded, lattice texture
C97-30	Dike(?) rock with hydrothermal breccia and silica veinlets
C97-31	Clay-altered non-welded ash-flow tuff with limonite
C97-33	Quartz vein, East Modoc adit
C97-34	Pyritized wall rock adjacent to C97-33
C97-46	Silicified rock with quartz veins and sulfide, Modoc Mine dump
C97-47	Quartz vein with sulfide, Modoc Mine dump
C97-90	Silicified Tps with partly oxidized quartz + sulfide vein, Dexter Mine
C97-93	Altered Tps with limonitic comb quartz vein, Dexter Mine
C97-95	Pyrite-rich breccia, partially oxidized, Dexter Mine
C97-99	Stockwork quartz + sulfide veins, Modoc Mine
C97-110	Stockwork sulfide veins in altered volcanic, Battle Mountain area
C97-111	Stockwork sulfide veins in altered volcanic, Battle Mountain area
C97-112	Silicified rock with drusy quartz, pyrite, and limonite
C97-113	Silicified porphyry with disseminated pyrite
C97-114A	Oxidized quartz vein, North Modoc vein
C97-117	Quartz vein with pyrite, chalcopyrite, and malachite, N. Modoc vein
C97-119	Quartz vein with sulfide
C97-120	Silicified flow-banded rhyolite
C97-121A	Altered porphyry with qtz. + limonite veins, s. extension Eureka vein
C97-123	Altered Tmd with limonite + drusy quartz veins, Bessie Mine
C97-124	Altered Tmd and quartz + pyrite veins, W and D shaft
CT2-211	Altered Tps with limonite on fractures, Dexter Mine drill core
CT-3-39	Limonite vein, ca. 2 cm thick, in Tps, Dexter Mine drill core
CT-3-64.5	Mn oxide vein, ca. 5 cm thick, in Tps, Dexter Mine drill core
CT-3-352	Limonitized lapilli tuff (Tps), Dexter Mine drill core
CT-3-419	Bedded tuff (Tps) with disseminated pyrite, Dexter Mine core

High-Silver Zone

C97-15	Propylitized Tmd with sulfide
C97-17	Carbonate vein with limonite and sulfide, Nevada Queen Mine
C97-19	Carbonate-sulfide vein, North Commonwealth Mine
C97-19A	Propylitized wall rock, North Commonwealth Mine
C97-19B	Wall rock with sulfide vein, North Commonwealth Mine
C97-19C	Bleached rock with pyrite, North Commonwealth Mine
C97-20	Sulfide-bearing rock, Commonwealth Mine
C97-21A	Silic. breccia and ct. vein with sulfide, North Belle Isle Mine
C97-21B	Carbonate vein with sulfide, North Belle Isle Mine
C97-23	Altered Tps with disseminated pyrite, Belle Isle Mine
C97-24	Altered Tps with sulfide, limonite, and Mn oxide, De Frees Mine
C97-24A	Silicified Tmd with acanthite, De Frees Mine
C97-24B	Quartz + sulfide veinlet in altered Tps, De Frees Mine
C97-25	Propylitized Tmd
C97-25A	Altered Tmd with pyrite
C97-27	Altered Tmd with pyrite, Independence Mine
C97-27A	Carbonate vein with sulfide and Fe oxide, Independence Mine
C97-28	Limonitic rock from shear zone, North Navajo vein
C97-29	Carbonate vein with sulfide, Navajo Mine
C97-29A	Silicified Tps with sulfide, Navajo Mine
C97-29C	Silicified breccia with sulfide, Navajo Mine
C97-29D	breccia vein with limonite and sulfide, Navajo Mine
C97-29E	Replacement silica vein with abundant sulfide, Navajo Mine
C97-35	Breccia with hematite and limonite, South Navajo vein
C97-35A	Breccia with hematite and limonite, South Navajo vein
C97-35B	Comb quartz vein in silicified rock, South Navajo vein
C97-35C	Silicified rock with sulfide, South Navajo vein
C97-38	Quartz vein with sulfide, Grand Prize Mine
C97-38A	Quartz + carbonate vein with sulfide, Grand Prize Mine
C97-38B	Silicified rock with sulfide, Grand Prize Mine
C97-39	Breccia with Mn oxide, Argenta Mine
C97-39B	Silicified Tmd with pyrite, Argenta Mine
H97-26	Tmd with quartz, pyrite, adularia vein

Miscellaneous Prospects

C97-32	Breccia containing galena, sphalerite, and chalcopyrite
C97-37	Red Bird Mine, altered dacite

Sixmile Canyon lavas depositionally overlie probable Pleasant Valley sedimentary rocks around Sixmile Canyon. Most other contacts are faults. However, dacite lava overlies the tuff of Big Cottonwood Canyon in the Cottonwood Peak Quadrangle. These relations and a ^{40}Ar/^{39}Ar date on hornblende of 39.25±0.32 Ma (fig. 5; table 2) from the upper of the two dacite lavas demonstrate their young age. The lavas are petrographically similar to many of the Mount Neva dikes and could be eruptive counterparts.

QUATERNARY DEPOSITS OF INDEPENDENCE VALLEY

Independence Valley is covered by a complex series of active and older alluvial fans that slope gently to the active alluvium and terraces of the South Fork of the Owyhee River. The alluvial fans are subdivided on the basis of source area and clast composition, which are related, and relative age. Three broad groups are fans draining the northern Tuscarora Mountains (or Mount Blitzen area), the Independence Mountains, and the southeastern part of the quadrangle, which is a spur of the Independence Mountains. Clasts in fans from the Tuscarora Mountains are almost exclusively Eocene igneous rocks derived from outcrops to the west. Clasts of Paleozoic quartzite and less abundant chert become dominant in a wedge-shaped area just south of Sixmile Creek, obviously derived from Paleozoic rocks that crop out there. Clasts in fans from the Independence Mountains are mostly Paleozoic chert, with other Paleozoic rocks in lesser abundance. Because the chert is highly resistant to weathering, many fans are noticeably gravel rich. Fans in the southeastern corner of the quadrangle contain variable mixes of Eocene volcanic rocks, which crop out there, and of Paleozoic rocks, which crop out just southeast of the quadrangle.

Within each group, fans are further subdivided on the basis of relative age, which is inferred from height above modern drainages and degree of erosion. Active fans have numerous anastomosing channels, which contain water mostly in the spring during snowmelt, through smooth floodplains that stay wet into the summer. Older fans are progressively higher and separated by distinct topographic breaks from adjacent younger fans. Absolute ages of the fans are unknown. Coats (1968) designated all as late Quaternary. The oldest, most highly dissected fans of the Tuscarora Mountains and Crooked Creek (Qt_1 and Qco) probably span a much greater age range than do the younger fans.

Coats (1968) thought the fans were mostly a thin veneer over bedrock, which sloped only slightly more steeply than the fans. This is the case only near the irregular northeast-striking contact between bedrock and the oldest alluvial fans (Qt_1). Sparse mineral exploration and water wells indicate that fan deposits are less than about 70 m thick between there and the northwesternmost line of Quaternary fault scarps. Bedrock drops across the fault zone to more than 100 m deep. A well midway along the north-trending part of the Midas road encountered bedrock at 180 m, and deeper water wells (up to 260 m) farther southeast never reached bedrock. Gravity data suggest that late Cenozoic fill may be as much as 2 km thick in the deepest part of the valley (Jachens and others, 1996). The fill would include deposits probably as old as late Miocene.

CENOZOIC STRUCTURE

Both igneous processes and regional extension have affected the structure of the rocks of the Tuscarora Quadrangle. The relative contribution of each to the origin of the Mount Blitzen volcanic center and anticline is uncertain.

Structure of the Mount Blitzen Volcanic Center

The geometry of the Mount Blitzen volcanic center and its included rocks is reasonably well understood (fig. 2). The center was described in detail by Henry and Boden (1998), who concluded that it resulted mostly from volcanic eruption and subsidence, with some influence of regional, northwest-oriented extension. Here we emphasize the characteristics of its eastern margin, which is entirely within the Tuscarora Quadrangle. The preserved basin is approximately 11 km east-west by about 6 km north-south; it is truncated on the north by the younger Big Cottonwood Canyon caldera, and the original extent in that direction is unknown. The nearly linear western and southern boundaries strike north and slightly south of east, respectively (fig. 2). The southeastern boundary is more complex with several north-northwest and northeast-striking segments.

The eastern margin is mostly linear and north-northeast trending. However, as with the southeastern margin, it appears to be segmented by a few north-northwest-striking faults with apparent lateral displacement. These faults in part coincide with a few of the major fault-veins of the Tuscarora district. Dacite of Mount Blitzen (Tbd) intruded extensively along the eastern margin north of Tuscarora, which suggests that the dacite rose in part along a boundary fault. Early dacite (Tmd) of the Mount Neva intrusive episode partly overprinted the margin northwest and southwest of Tuscarora.

Most boundaries, including the eastern margin, appear to be normal faults with substantial displacement, down into the Mount Blitzen center. For example, Paleozoic rocks along the eastern margin are substantially downdropped into it. Total displacement there is unknown but probably at least 1.5 km. If the tuff of Mount Blitzen is a homoclinal sequence not repeated by normal faults, displacement may be about 4 km. A drill hole in Threemile Canyon started in dacite of Mount Blitzen but passed into Paleozoic rocks at depth. Therefore, the fault dips to the west.

The Mount Blitzen Anticline

The tuff of Mount Blitzen forms a northeast- to east-northeast-trending anticline through the middle of the Mount Blitzen center (fig. 2). The anticline is roughly symmetrical with dips mostly between 25° and 50° in both limbs. This symmetry is slightly complicated by the local, probably depositional variations in attitude described above. More important, strike bends to north or slightly west of north in an approximately 8-km^2 area in the northeastern part of the Mount Blitzen center. All along the eastern and southeastern margin of the center, the tuff of Mount Blitzen parallels the margin and steepens toward it. Rocks more than about 1 km away from the margin dip about 40°, but they steepen to vertical and locally are slightly overturned near the margin.

The eastern margin of the Mount Blitzen center and pre-Mount Blitzen rocks in the wall of the center also appear to be tilted (sections A–A´, B–B´). As noted above, the unusual strike of Paleozoic rocks along the eastern margin is consistent with about 50° eastward tilt. Volcaniclastic sedimentary rocks and tuff (Tps) of the Pleasant Valley complex dip southeastward in and around the Tuscarora district. Dips are as steep as 63° near the margin but decrease to 25° to 30° in less than a kilometer to the southeast. The drill hole in Threemile Canyon is consistent with, but does not prove, that the eastern margin dips westward at a moderate dip. In contrast, lavas of Sixmile Canyon are approximately flat lying throughout their distribution.

Continuation of the anticline north of the Mount Blitzen center is uncertain. The tuff of Big Cottonwood Canyon (Tct) in most of the eastern half of its caldera dips northwest, similar to the attitude of the tuff of Mount Blitzen immediately to the south in the Mount Blitzen Quadrangle (fig. 2 and Henry and Boden, 1998). In the northwestern corner of the Tuscarora Quadrangle, the tuff of Big Cottonwood Canyon appears to flatten and roll over to a gentle east-southeast dip, which, however, is represented by only three measurements. Combined with the change in attitude of the tuff of Mount Blitzen immediately to the south, this gives the impression that the anticline plunges northeast. Thus, the anticline could continue into the caldera, but dips in the tuff of Big Cottonwood Canyon are distinctly less than in the tuff of Mount Blitzen.

These data are consistent with the Mount Blitzen anticline involving an area that extends slightly outside the Mount Blitzen center, certainly to the east and possibly to the north. The anticline also appears to have formed before deposition of the lavas of Sixmile Canyon and possibly after deposition of the tuff of Big Cottonwood Canyon. Henry and Boden (1998) concluded that the anticline is most likely an elongate dome resulting from emplacement of a large intrusion that parallels and underlies the anticline. Late dikes of the Mount Neva intrusive episode may be apophyses from this major intrusion. The distinct northeast orientation of both the anticline and the dike swarm probably reflect regional, northwest-oriented extension.

Structures Related to Late Cenozoic-Quaternary Extension

Independence Valley is a north-northeast-striking, east-tilted half graben typical of basins developed during late Cenozoic, west-northwest-oriented Basin and Range extension. A large, abrupt scarp separates the valley from bedrock along the eastern side along the Independence Mountains. This main scarp is mostly east of the Tuscarora Quadrangle, but the faults, including Quaternary scarps, that cut alluvial fan deposits or separate them from Eocene volcanic rocks in the southeastern corner of the quadrangle are a less abrupt, southern continuation of this eastern boundary. The northwestern side of the valley may be a hinge where bedrock bends down to the east. Quaternary scarps there are in part developed along this possible hinge and probably represent young movement on faults that developed in the late Miocene.

The north-northeast-striking fault that separates Paleozoic rocks or tuff of Big Cottonwood Canyon (Tct) on the west from lavas of Sixmile Canyon on the east may also have been active in the late Cenozoic. It is a normal fault with similar orientation to the eastern boundary fault of Independence Valley and to the Quaternary scarps. However, field relations demonstrate only that it is post ~39 Ma. This fault is prominent in the northern part of the quadrangle and the southern part of the Cottonwood Peak Quadrangle (fig. 2), where down-to-the-east displacement is at least 500 m (section A-A'). Continuation of the fault south of where it intersects the eastern margin of the Mount Blitzen volcanic center is obscure. The north-northeast-striking fault clearly cuts off dacite of Mount Blitzen (Tbd), so it is younger than the volcanic center and its marginal faults. However, net displacement along the combined volcanic margin and the north-northeast fault is down to the west. We suspect that the north-northeast fault continues but is obscured by the much greater displacement, possibly several kilometers, on the boundary fault of the volcanic center.

Quaternary faults, which were first recognized by Coats (1968), are abundant in both the northwest and southeast sides of Independence Valley (Dohrenwend and Moring, 1991). The faults strike north-northeast, parallel to the overall orientation of the valley. Faults in the northwestern side make a complex, 15-km-long, 2- to 3-km-wide graben (Ramelli and dePolo, 1993). At the southern end, faults define three, mostly narrow (≤300 m) subgraben within the larger graben. These subgraben tend to coalesce to the north, where numerous faults make a 1-km-wide central graben with only a few outer faults. The geometry of individual fault swarms are illustrated by three topographic profiles across faults in the northwestern side of the valley (fig. 6). The southeasternmost fault of each swarm has the largest displacement and is down to the west, i.e., parallel to and with similar sense of displacement as the eastern boundary fault of Independence Valley. Topographic scarps are as large as 10 m (profile 1) but may have been enhanced slightly by erosion along gullies that drain parallel to the scarp into larger, southeast-striking drainages. One to as many as six, smaller down to the east (antithetic) scarps lie northwest of the main scarp; topographic breaks on these are typically no more than 2 m. Net displacement across these fault zones is difficult to determine but is probably down to the west. Faults in the southeastern side of Independence Valley are mostly down to the northwest, but a narrow graben similar to those in the northwest side is developed at the southern edge of the quadrangle.

Quaternary scarps are most abundant and largest in oldest fan deposits (Qt_1 and Qco). However, scarps are prominent in younger deposits (Qt_2 and Qcm) on both the northwest and southeast sides of the valley. Poorly defined scarps appear to be present in still younger fans (Qt_3) near the southwest end of the valley. The youngest and active fans (Qt_4, Qta, and Qca) are not cut by faults. The scarps may be latest Pleistocene in age (Ramelli and dePolo, 1993; A.R. Ramelli, personal commun., 1998).

TUSCARORA MINING DISTRICT

The Tuscarora mining district lies along and just outside the southeastern margin of the Mount Blitzen volcanic center, and ore formation was closely connected to the igneous geology and structures of that center. Host rocks include volcaniclastic sedimentary rocks and tuff (Tps) of the Pleasant Valley complex and early porphyritic dacite

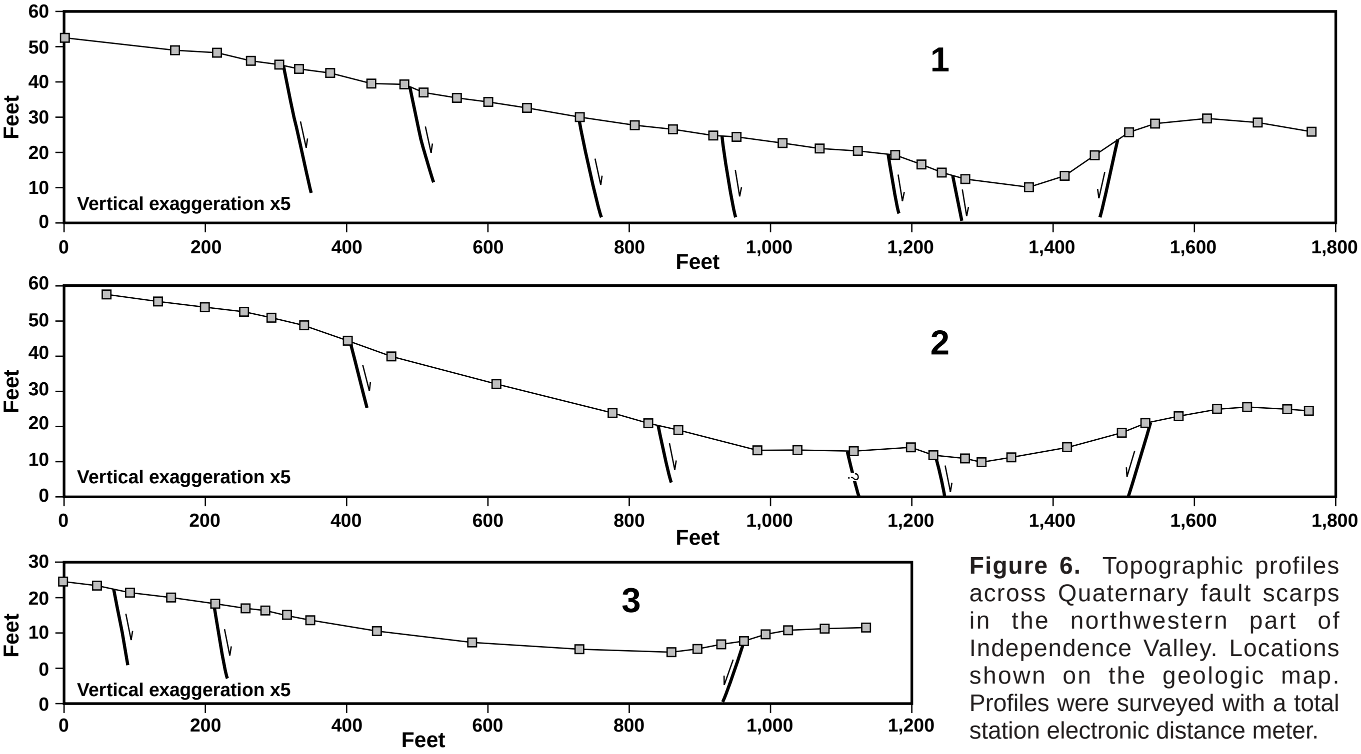

Figure 6. Topographic profiles across Quaternary fault scarps in the northwestern part of Independence Valley. Locations shown on the geologic map. Profiles were surveyed with a total station electronic distance meter.

(Tmd) of the Mount Neva intrusive episode. Veins in part occupy faults that make up the boundary of the Mount Blitzen center. Mineralization was contemporaneous with the Mount Neva intrusive episode; those intrusions were likely the heat source for hydrothermal circulation.

The Tuscarora district may be divided into two areas that contain precious-metal deposits: a low-silver zone to the south that is typified by comb-textured quartz veins, widespread silica-adularia alteration, and relatively low Ag/Au ratio; and a high-silver zone to the north that is characterized by replacement quartz and carbonate veins, narrow alteration zones, and relatively high Ag/Au ratio. On the basis of our work, gold contents in the two zones are similar; median gold content in samples from the low-silver zone is 0.232 ppm versus 0.341 ppm in the high-silver zone (table 3, page 10).

Low-Silver Zone

Mines and prospects in the low-silver zone are widely scattered over an area about 1,500 by 3,000 m that extends from the town of Tuscarora southwest to Battle Mountain (fig. 7) and Beard Hill (in the Mount Blitzen Quadrangle; Henry and Boden, 1998). Host rocks are rocks of the Pleasant Valley complex (Tps, Tpb, and Tpd) and early porphyritic dacite of the Mount Neva intrusive episode (Tmd). Mineralization is characterized by relatively low Ag/Au ratios (the median ratio is 14, table 3), stockwork to sheeted or en echelon fissure veins of finely granular to comb quartz, and widespread light-colored silica-adularia alteration. Carbonate minerals are not present, but lattice-bladed texture (quartz pseudomorphs after bladed carbonate crystals or carbonate cleavage) is. Sulfide minerals, mainly pyrite, are common in unoxidized rock, and arsenopyrite is present in some samples. Limonite, hematite, and manganese oxide minerals are locally abundant; argentojarosite was identified in one sample. Base metal sulfide minerals are rare.

The Dexter open-pit mine, which ceased activity in 1990, is flooded, but altered and veined rock in the west part of the pit is still available for study. Veins at other sites in the low-silver zone are exposed in outcrops and shallow workings, but mineralized and altered rock is obscured by pediment gravel in many areas. Principal vein systems are the Modoc and Eureka (fig. 7); more disseminated deposits are at Battle Mountain and the Dexter Mine.

Modoc Vein System

The Modoc vein system is a north-striking zone of veins about 300 m wide; individual veins strike north to N10° E, dip 45-60° to the west, and are arranged en echelon (fig. 7). Host rocks include volcaniclastic sedimentary rocks of the Pleasant Valley complex and early porphyritic dacite of the Mount Neva episode. Based on blocks of vein material on the main Modoc Mine dump, individual veins are as much as 30 cm thick.

The veins are mainly (a) crudely banded, sheeted to braided veins of white to gray quartz or (b) breccia zones with vein quartz matrices. Samples of vein quartz from the main Modoc Mine dump contain fragments of gray, finely granular quartz with abundant sulfide consisting of pyrite, sphalerite, galena, and acanthite. Sample C97-47 (table 3) contains early sphalerite that is partly replaced by acanthite and galena. The acanthite indicates late stage silver enrichment, possibly of supergene origin. The sulfide-bearing fragments are surrounded by white, fine granular to comb textured, sulfide-poor quartz with some fine drusy cavities.

On the Gold Bug claim, about 250 m north of the main Modoc Mine portal, comb quartz forms matrix in fault breccia and stockwork veins in propylitically altered rock. A sample of gold-rich vein quartz (C97-117, table 3) contains pyrite and chalcopyrite along with a little malachite.

The Modoc vein system lies within a north-trending zone of quartz-adularia alteration that is about 400 m wide. This broad alteration zone narrows to the north on the Gold Bug claim where it splits into several narrow zones along north-northeast- to north-northwest-trending veins and faults. To the south of the Modoc Mine this alteration zone widens and appears to merge with similar alteration to the south and southwest. Veins in this area include north to north-northwest-striking banded quartz veins with local lattice-bladed texture formed by replacement of carbonate by quartz.

Eureka Vein System

The Eureka vein system, about 1,200 m east of the Modoc Mine, is a north-trending zone consisting of individual north-northwest-striking veins that form an en-echelon pattern (fig. 7). These veins contain quartz with similar textures to those in the Modoc Mine veins. To the north (in the area of samples B97-1 and B97-2), the Eureka veins cut propylitically altered early porphyritic dacite (Tmd) with only minor amounts of associated silica-adularia alteration, but to the south the Eureka vein system lies along the eastern edge of a wide zone of silicification and adularization that appears to merge westward with similar alteration in the Modoc Mine area. As in the Modoc veins, samples from the Eureka veins contain gray sulfide-bearing quartz fragments set in white, sulfide-poor granular to comb quartz. Sulfide minerals in the Eureka veins consist mainly of pyrite and arsenopyrite. Electrum containing about 70 wt % gold occurs in the sulfide-poor quartz.

Battle Mountain Area

Workings on the east and southeast side of Battle Mountain are in stockwork pyrite ± quartz veins in adularized early porphyritic dacite. This area was recognized by earlier workers (e.g., Nolan, 1936) as having potential for low-grade disseminated gold mineralization and this was confirmed in the 1980s when a gold resource of 280,000 short tons at 0.05 troy oz/ton was delineated by drilling (Struhsacker, 1992). The relationship between this mineralization and quartz vein mineralization about 1,000 m to the northeast in the Modoc Mine area is not known, but related alteration on Battle Mountain may merge to the east with alteration south of the Modoc Mine.

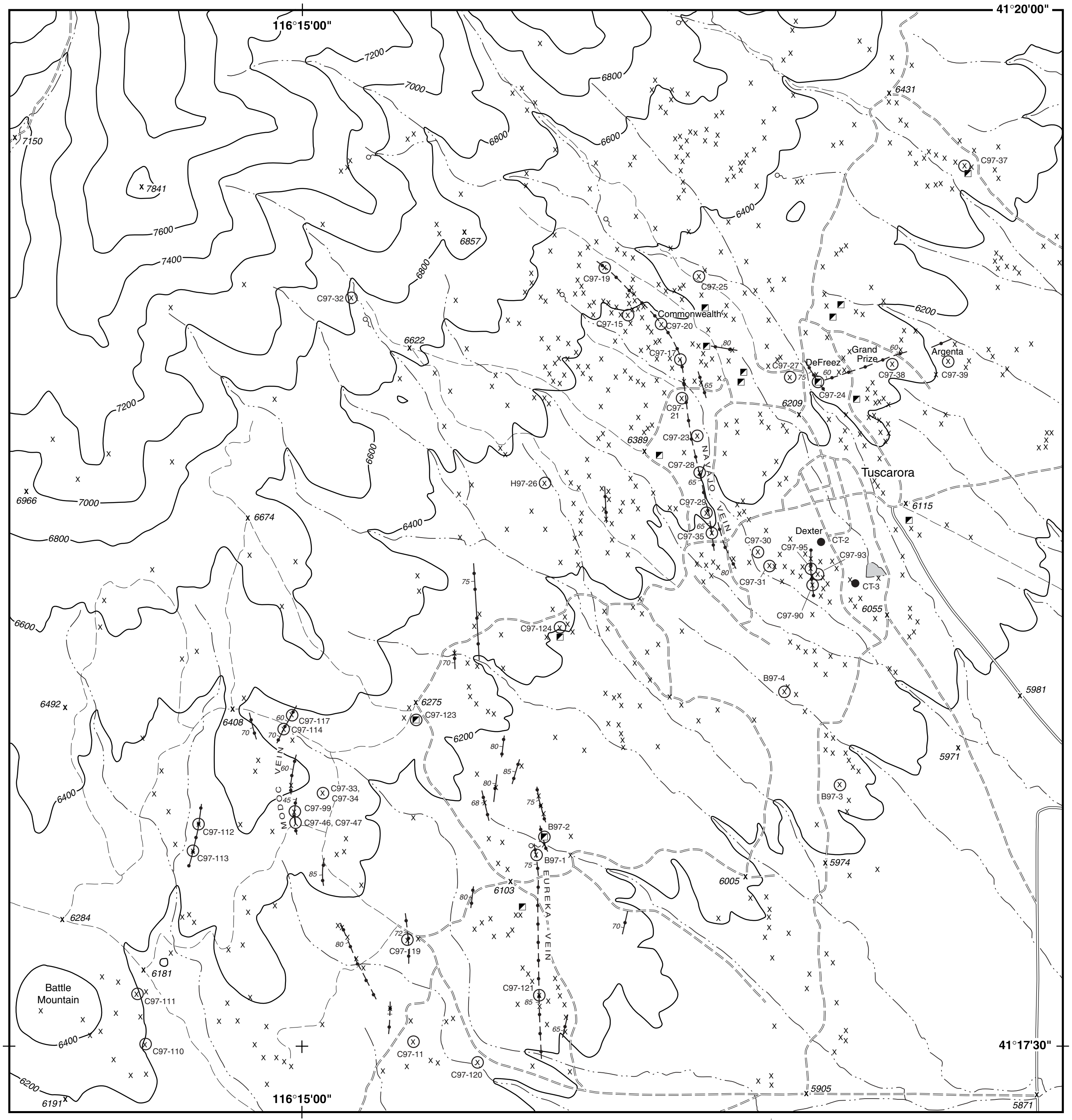

Figure 7. Locations of altered or mineralized samples analyzed for trace element concentrations.

Dexter Mine Area

The Dexter Mine has been the most productive property in the low-silver zone. Estimated historical production (1897-1935) was about 40,000 oz gold and 100,000 oz silver (based on data in Nolan, 1936, and LaPointe and others, 1991), and modern production (1987-1990) was about 34,000 oz gold and 185,000 oz silver (Tingley and Bonham, 1998).

As noted by Nolan (1936), gold-silver mineralization in the Dexter Mine area is associated with widespread silicification and adularization in bedded tuffaceous sedimentary rocks (Tps) that we have mapped as part of the Pleasant Valley complex. Most of the mineralization in the Dexter open-pit mine is in steeply dipping, silicified and adularized, lapilli-fall or pumice-flow tuffs and fine-grained tuffaceous sedimentary rocks. Crosscutting intrusive early porphyritic dacite occurs in drill core (CT-3) from beneath the Dexter open pit and along the north wall of the pit. In the latter area the dacite, which overlies the tuffaceous rocks along an east-striking, shallow north-dipping contact, is cut locally by west-dipping shear zones with adularia-silica alteration; however, the dacite is mostly propylitized and does not host ore. Emmons (1910) described the Dexter orebody as a shallow north-dipping “shoot” occurring along the above mentioned contact.

According to Nolan (1936), the Dexter orebody contained numerous randomly oriented veinlets, in places drusy, and locally contained adularia. He also noted that these veins were reported to be particularly gold-rich. Quartz veins in the Dexter pit include sparse, randomly oriented, limonitic comb quartz veins; quartz veins with relatively coarse adularia; and breccia zones cemented by finely granular to drusy quartz with minor pyrite. Abundant disseminated pyrite was noted in altered host rock clasts in one breccia that contains abundant hematite. In addition to the quartz veins, veins and shear zones with abundant limonite and hematite, but little or no quartz, occur in places, and Mn oxide veins were noted in drill core.

Precious metal minerals that we identified in samples from the Dexter pit include electrum, acanthite, and argentojarosite. A sample of silver-rich breccia from the west part of the Dexter pit (sample C97-90, table 3) contains fine pyrite cubes that contain 1-µ galena blebs. Some of the pyrite is replaced by acanthite, or rimmed by acanthite and argentojarosite, textures that suggest supergene silver enrichment.

The Young America Mine, which was located just north of the Dexter Mine and directly under the town of Tuscarora (Nolan, 1936), was reported by Whitehill (1876) to be a north-striking 1-m-wide vein, dipping 60° west, that produced bullion with 60% gold. The vein was described by Whitehill as being “well defined and very regular in its course.” Maps by Chevron Resources Company (unpub. data, 1990) and Crawford (1992) show a vein in this location that is projected nearly 1,000 m north-northwest from the Dexter pit to the Independence Mine in the silver zone (see below).

High-Silver Zone

The Tuscarora silver zone is an area of about 1,200 by 1,500 m centered about 500 m northwest of Tuscarora. Host rocks are volcaniclastic sedimentary and tuffaceous rocks of the Pleasant Valley complex (Tps) and early porphyritic dacite of the Mount Neva intrusive episode (Tmd). Mineralization in this area is typified by high Ag/Au ratios (the median ratio is 110, table 3), multiple vein types including silica-sulfide replacement veins, carbonate-sulfide fissure veins, and late-stage granular to comb quartz veins. Sulfide minerals are mainly pyrite, but base-metal and silver-bearing sulfides occur in high-grade ore. Iron and manganese oxide and hydroxide are locally abundant, and silver halide minerals were reported by early miners. Emmons (1910) reported that a single block of horn silver from the Commonwealth Mine, which was active between 1887 and 1891 (Nolan, 1936), sold for $30,000. Light-colored quartz-adularia alteration is present but not widespread in the high-silver zone.

Except for minor near-surface workings in the southern part of the Navajo vein, the east part of the Commonwealth vein, and at the De Frees Mine, mines in the silver zone are flooded and surface access is caved. Surface expression of the mineralization is poor, except along the south part of the Navajo vein. This lack of exposure and access, which has been the case since examination by Emmons (1910), hampers the study of the ore deposits, particularly their structure. However, good samples of high-grade ore and associated rock types were found on dumps in the silver zone.

Navajo Lode

The Navajo lode is a 900-m-long vein system that strikes about N10° W and dips steeply to moderately to the west. Several mines exploited the Navajo lode underground before the turn of the century, including the Navajo, Belle Isle, North Belle Isle and Nevada Queen Mines. Emmons (1910) included the Commonwealth and North Commonwealth Mines, which lie on a N60° W structure, in the Navajo lode, and reported total production for the Navajo lode at $15,000,000; however, this figure may be inflated because Nolan (1936) put recorded production for the Tuscarora district as a whole at less than $11,000,000.

The main Navajo shaft, which is about 500 m west of Tuscarora, is caved and surface outcrops at or near the portal are covered with mine waste. On the basis of waste lithology, country rock for the vein seems to be fine-grained volcaniclastic sedimentary rock (Tps), although early porphyritic dacite (Tmd) is exposed nearby. This is also the case at the Belle Isle Mine about 300 m to the north. The Navajo lode, or a subsidiary vein system, is exposed 100–500 m southwest and 150 m north of the Navajo shaft in a series of surface stopes and prospects.

In the workings southwest of the Navajo shaft, a N10° W, 65° W structure hosts silicified, limonitized, and hematized breccia about 50 cm thick in altered Tps. This breccia zone occupies a wider zone of shattered rock at least 3 m thick. In workings to the north of the Navajo shaft, a zone of fracturing is centered about a N15°–25° W, 58°–75° W shear zone that contains an 80-cm-wide zone of limonitized and hematized gouge and breccia. At the North Belle Isle Mine, Emmons (1910) described several narrow north-striking, 35°–80° W-dipping fissure veins merging into a shoot “several feet wide” about 30 m beneath the surface that yielded $1,000,000 worth of ore.

We collected loose blocks of replacement quartz-sulfide vein up to 10 cm thick on the dump at the Navajo Mine. A silver- and gold-rich sample of this rock (sample C97-29E, table 3) contains abundant pyrite, mostly in cubes but also as framboids, along with late vein-like masses of pyrargyrite with galena, acanthite, and electrum. Sample C97-35C (table 3) from the vein south of the Navajo shaft contains abundant cubic pyrite with inclusions of arsenopyrite, acanthite, and galena.

Other samples from dumps at mines along the Navajo vein include silicified breccia, carbonate-sulfide vein, and altered Mount Neva dacite with sulfide. Sample C97-20 (table 3) from the Queen Mine contains coarse pyrite with fine inclusions of galena, acanthite, and sphalerite, and late veinlets of pyrargyrite and galena.

Grand Prize Mine Area

The Grand Prize bonanza was discovered in 1876, and the Grand Prize Mine was operated until 1891, yielding about $2.6 million, the largest recorded production in the high-silver zone (Nolan, 1936). On the basis of descriptions in Whitehill (1876, 1878) the Grand Prize vein was about 2 m wide, dipped moderately northwest, and contained sulfide ore. Nolan (1936) described an east to east-northeast belt of orebodies including the Independence, Grand Prize, and Argenta Mines, and Crawford (1992) mapped east-northeast-striking veins that dip moderately northwest in the area. However, Emmons (1910) reported that the Independence and Grand Prize Mines were situated on lodes oriented approximately parallel with the north- to northwest-striking Navajo lode. Although underground workings are inaccessible and surface exposures poor, our field work showed that both east- and northwest-striking mineralized structures are present. The De Frees (Whitehill, 1876; Nolan, 1936) or De Frieze (Emmons, 1910) Mine, which is between the Independence and Grand Prize Mines, includes an inclined shaft driven on a northwest-striking mineralized structure that dips 75° southwest. An east-striking, steeply north-dipping structure mapped by us east of the Queen Mine may link the northwest-striking Commonwealth vein system at the north end of the Navajo Lode with east-northeast-striking Grand Prize structures.

Host rocks in the Grand Prize area are volcaniclastic sedimentary rock and early porphyritic dacite. Mineralized rock from the Independence, Grand Prize, De Frees, and Argenta Mines sampled by us include quartz-carbonate and carbonate veins with sulfides, silicified rock with sulfides, breccia with Mn oxide, and late cross-cutting comb quartz veins. Sulfide minerals identified in samples from the Independence and De Frees Mines include pyrite, sphalerite, galena, acanthite, and aguilarite. In addition, Mn oxide-rich ore from the De Frees Mine (sample C97-24, table 3) contains cryptomelane, Mn-Pb oxide, and native selenium.

Geochemistry

Chemical analyses of samples from the Tuscarora District are reported in table 3. For comparative purposes, samples from the two zones in the district are reported in separate data sets. In addition to the differences in Ag/Au ratios noted above, samples of mineralized and altered rock from the high and low-silver zones show some differences in both major and trace elements. For example, high-silver zone samples are enriched in Ca, Pb, Mn, Se, and Zn relative to low-silver zone samples. For many elements, the two data sets are similar. Both sets have low Bi, Mo, Te, and W contents; are slightly enriched in Hg and Tl; and are clearly enriched in As and Sb. Cu is generally low but is enriched in one sample from the Modoc vein system (C97-117, table 3).

Age of Mineralization

Six samples of adularia were analyzed for their $^{40}Ar/^{39}Ar$ ages (table 2; fig. 5). The samples were collected from both the low- and high-silver zones and from different vein orientations (see map). Samples H96-104 (North Commonwealth Mine; north-northwest Navajo vein) and H96-102 (east-northeast Grand Prize zone) are from the high-silver zone. Samples H96-98 (west end of Dexter pit), H96-93 (north end of north-striking Modoc vein), and H96-45 (Castile Mountain; Mount Blitzen Quadrangle) are from the low-silver zone. Sample H96-99 is from a north-northwest vein where it intersects the Dexter zone.

The ages range narrowly between 39.32±0.14 (2σ) and 39.24±0.13 Ma except for sample H96-45 from Castile Mountain, which is 39.14±0.13 (fig. 5). McKee and Coats (1975) reported a K-Ar age of 39.4±1.5 Ma (recalculated with the decay constants of Steiger and Jager, 1977) on adularia from the De Frees vein, in excellent agreement with our new ages. All ages are indistinguishable within their analytical uncertainties; the slightly lower age of sample H96-45 overlaps with ages of all other samples. The ages also overlap with the age of hornblende (sample H96-103; 39.43±0.26 Ma) from early porphyritic dacite of the Mount Neva intrusive episode, which hosts much of the ore. These data indicate that hydrothermal alteration, whether a single or multiple episodes, took very little time.

Relationship between High- and Low-Silver Mineralization

Nolan (1936) noted some of the differences in alteration and mineralization styles described above between low-silver and high-silver deposits and suggested that the differences arose from differences in host rocks. He speculated that the more widespread low-silver mineralization was favored in more permeable tuffaceous sedimentary rocks, whereas emplacement of more tightly constrained high-silver bonanza ore mostly took place in less permeable andesitic intrusive rock (our early porphyritic dacite of the Mount Neva intrusive episode). Although Nolan noted that more than one episode of hydrothermal activity or metal zoning during a single episode could account for the two types of deposits, he ascribed silver bonanza ore to more focused supergene silver enrichment of relatively low-silver protore in tightly constrained permeable zones along veins in the intrusive rock. He cited relatively restricted vertical range for this ore as evidence for such enrichment. The presence of late acanthite surrounding and replacing earlier sulfide (as noted above in samples from the Modoc vein, Navajo lode, and Dexter Mine) indicates that this process was a district-wide factor.

Although Nolan's proposed supergene process was a factor, differences in alteration style, vein mineralogy, ore texture, and geochemistry between the two ore types suggest primary hydrothermal differences. The absence of carbonate minerals in low-silver veins is an example. Carbonate minerals are rare or absent in the low-silver zone (although silica pseudomorphs after probable calcite are present);

abundant calcite and sparse rhodochrosite occur in high-silver deposits. Comb quartz fissure veins characterize the low-silver zone, whereas replacement veins typify ore in the high-silver zone and comb quartz veins that do occur there are late and barren. Late quartz-adularia overgrowth veins, which yielded the dated adularia, occur in both zones and were also found outside the metallized zones. Based on these observations, a possible scenario for district-wide mineralization includes early high-silver replacement veining, later low-silver fissure veining, and finally widespread quartz-adularia overgrowth veining. Alternatively, separate and unrelated high-silver and low-silver hydrothermal activity may have taken place. In either case, the $^{40}Ar/^{39}Ar$ ages of host rocks and adularia constrain mineralization to a brief interval (table 2; fig. 5). As pointed out by Henry and others (1998), ore-forming hydrothermal activity may be short lived and multiple episodes may have taken place during the ~100,000 years between the Mount Neva intrusive activity and quartz-adularia veining.

Other Mineral Prospects in the Quadrangle

Very small amounts of mercury were produced from cinnabar-native mercury-pyrite veins (Bailey and Phoenix, 1944) in lavas of Sixmile Canyon at the Red Bird Mine about 1 km northeast of the high-silver zone (sample C97-37, Figure 7). In addition, small amounts of breccia containing galena, sphalerite, and chalcopyrite occur on a small dump within the Mount Blitzen volcanic center about 1 km west of the high-silver zone (sample C97-32, fig. 7). Because of their settings, mineralogy, and composition, neither of these metal occurrences is obviously related to precious-metal mineralization within the district proper. The sample from the Red Bird Mine does not have detectable Ag and Au, and the sample from the small dump is highly enriched in Cu, Pb, and Zn (table 3).

Exploration Potential

Our geologic mapping of the Tuscarora and adjacent areas has shown that mineralization in the Tuscarora district took place along the southeast flank of the Mount Blitzen volcanic center, a fault-bounded basin filled with dacite domes and associated pyroclastic and volcaniclastic rocks. Mineralization closely followed intrusion of early porphyritic dacites of the Mount Neva episode, which is closely associated with the Mount Blitzen center, into lavas and tuffaceous rocks of the older Pleasant Valley volcanic episode. The Mount Neva dacite, at about 39.3–39.5 Ma, is roughly synchronous with similar intrusive rocks that occur in the highly productive gold deposits of the Carlin Trend about 30 km south of Tuscarora and are widespread elsewhere in the region (Henry and Boden, in press).

Mineralized veins in the Tuscarora district are dominantly controlled by north-northwest-striking faults and locally by east-northeast-striking faults. Faults with similar orientations bound parts of the Mount Blitzen volcanic center, where offsets and slickenlines indicate dominantly right-lateral slip along north-northwest faults and normal movements along east-northeast faults. This is consistent with regional northwest-southeast-directed extension, a condition favorable for the formation of open space to accommodate hydrothermal fluids.

Of the two styles of mineralization that took place in the district, the low-silver zone is considered to have the best potential for hosting unexploited mineralization. This conclusion is based on: 1) larger areas affected by this type of mineralization; 2) relatively low Ag/Au ratios and low base metal contents of productive vein and disseminated gold deposits elsewhere (e.g., Sleeper and Round Mountain, respectively); and 3) the presence of altered rocks and mineralized structures that project under pediment gravel along the southern and eastern borders of the district. By comparison, vein deposits in the high-silver zone, although of very high grade, are considerably smaller and more difficult to find.

Potential for a third type of mineral deposit in the Tuscarora district, more speculative, but possibly of more economic interest, is for Carlin-type deposits in Paleozoic rocks at depth. The Tuscarora district lies between the large Carlin-type deposits of the Carlin Trend and Independence Mountains (fig. 1). Paleozoic rocks form part of the east wall of the Mount Blitzen volcanic center as shown by exposures to the north of the district. It is possible that the known precious metal deposits, which have elevated As, Sb, Tl, and Hg (typically enriched in Carlin-type deposits), represent the upper parts of deep-seated Carlin-type gold deposits. The age of the Tuscarora mineralization is indistinguishable from that of many deposits of the Carlin Trend, which are now widely recognized to have formed in the Eocene between about 38 and 40 Ma (Hofstra, 1995; Emsbo and others, 1996; Leonardson and Rahn, 1996; Phinisey and others, 1996; Rota, 1996; Groff and others, 1997).

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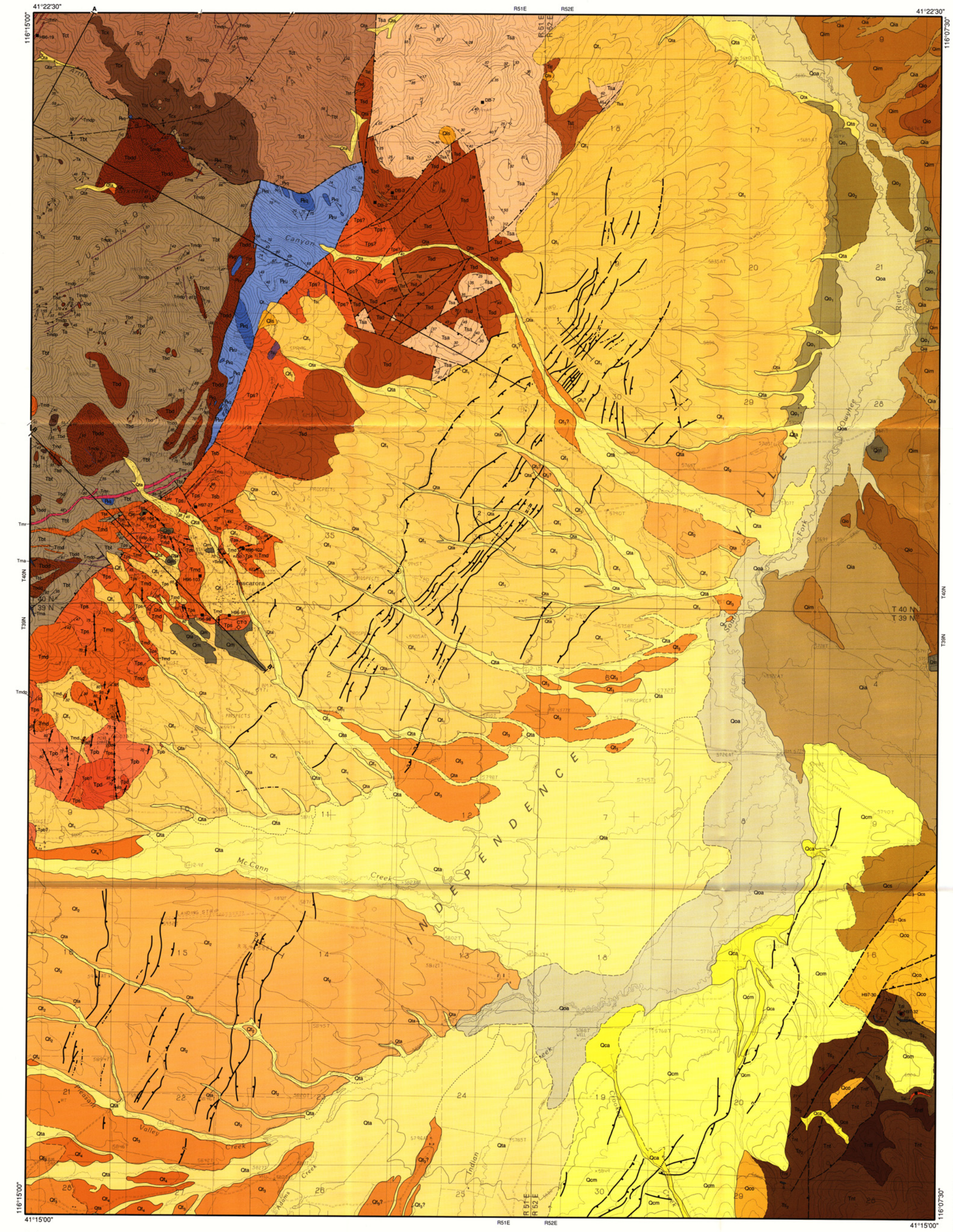
Prepared as part of the STATEMAP component of the National Cooperative Geologic Mapping Program in cooperation with the U.S. Geological Survey



GEOLOGIC MAP OF THE TUSCARORA QUADRANGLE, NORTHERN NEVADA

Christopher D. Henry, David R. Boden, and Stephen B. Castor

1999

Scale 1:24,000

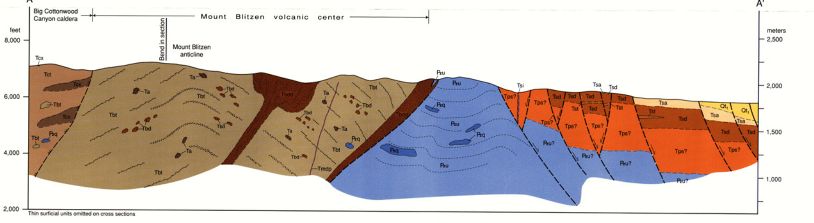
0 0.5 1 kilometer

0 0.5 1 mile

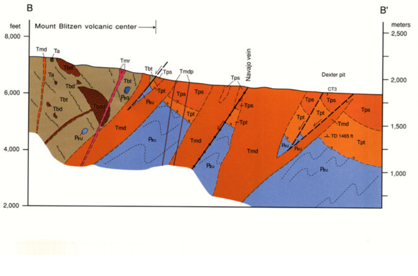
0 1000 2000 3000 4000 5000 feet

CONTOUR INTERVAL 40 FEET
SUPPLEMENTARY CONTOUR INTERVAL 20 FEET

Base map: U.S. Geological Survey Tuscarora 7.5' Quadrangle, 1987



Thin surficial units omitted on cross sections



Contact Showing dip, long dashes where approximately located, short dashes between alluvium of different drainages within same unit, around magebreccia blocks, or form lines on cross sections, dotted where concealed, queried where uncertain.

Fault Showing sense of displacement and dip; ball on downthrown side, dashed where approximately located, dotted where concealed, queried where uncertain; arrow shows trend of slickenlines. Arrows show relative direction of movement.

Quaternary fault Fault showing distinct topographic scarp in Quaternary unit, dashed where approximately located, queried where sense of diplacement is uncertain, dotted where concelaed.

Aerial photographic lineament Possible Quaternary fault but lacking definite topographic scarp.

Caldera margin Topographic or buried structural margin of Big Cottonwood Canyon caldera, dashed where approximately located, dotted where concealed.

Anticline axial trace Showing plunge, dashed where approximately located, queried where uncertain.

Vein coincident with normal fault Showing dip, dashed where approximately located.

Strike and dip of beds

20 Inclined — Vertical — 85 Overturned

Strike and dip of compaction foliation in ash-flow tuff

75 Inclined — Vertical — Horizontal

Strike and dip of flow bands in lava or intrusion

60 Inclined — Vertical

Columnar joints Showing bearing and plunge

Inclined minor fold Showing bearing and plunge of hingeline

Sample location for ^{40}Ar/^{39}Ar date or chemical analysis

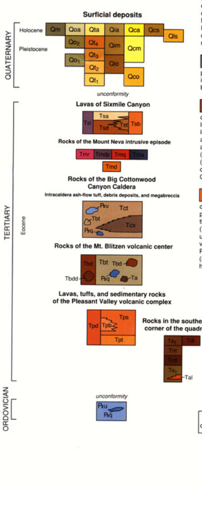
■ H96-103

Drill hole location

CT-3

Topographic profiles across Quaternary fault scarps

Probable sinter



SURFICIAL DEPOSITS

Quaternary

Qm **Man-made deposits** Mine dumps and leach piles in the Tuscarora mining district, and gravel piles and disturbed ground in alluvial fans of the Independence Mountains (Qi).

Qoa **Qo$_2$** **Qo$_1$** **Alluvium and terraces of the South Fork of the Owyhee River** Active to Pleistocene alluvial deposits of the river, subdivided on the basis of inferred age. Major fans deflect the river alternately to the eastern and western parts of the valley. **Qoa** Active channel and floodplain of the Owyhee River. Numerous anastomosing, meandering channels and abandoned meander loops are set 1 to 3 m below the floodplain. Consist mostly of clay to silt; local lenses of gravel containing clasts up to about 20 cm are exposed in channels. Very dark toned on aerial photographs because soil is saturated much of year. Generally cultivated as pasture. **Qo$_2$** Lower terrace of the Owyhee River. Surface is approximately 1 m above the active floodplain and is not noticeably dissected. Composed of clay to sand, similar to the active floodplain. Probably equivalent to Qt$_4$. **Qo$_1$** Upper terrace of the Owyhee River. Surface is 3 to 4 m above the active floodplain and highly dissected along flanks and by numerous minor drainages within the unit. The surface consists of pebbly silt, similar to surfaces of older fans, and gravel to 30 cm is exposed along drainages. Very light toned on aerial photographs. Age uncertain but may be approximately equivalent to Qt$_2$ or Qt$_3$.

Qta **Qt$_4$** **Qt$_3$** **Qt$_2$** **Qt$_1$** **Alluvium and fans of the Tuscarora Mountains** Complex series of active to late Pleistocene alluvial fans composed of unconsolidated fluvial and debris-flow deposits that developed along the east flank of the Tuscarora Mountains. They are subdivided on the basis of inferred age, from active channels (Qta) to oldest fan deposits (Qt$_1$); relative age is interpreted largely from elevation above active channels and amount of dissection. Clasts consist exclusively of volcanic rocks, except in Qta and Qt$_1$ in an arc between Brennan Gulch and about 2 km north of Sixmile Creek, where Paleozoic quartzite and lesser chert are a minor to the dominant component. Surfaces of fans have 5 to rarely 50% rock chips mostly 1 to 5 cm in a silty matrix. Qta is generally dark toned on aerial photographs, Qt$_4$ is distinctly lighter toned, and Qt$_3$, Qt$_2$, and Qt$_1$ are very light toned. **Qta** Unconsolidated alluvium in active channels of small to large drainages, which extend from highlands to the South Fork of the Owyhee River. Larger drainages, such as McCann and Sixmile Creeks, have anastomosing channels, ~1 to 5 m wide and up to 2 m deep, in floodplains up to 2 km wide. Smaller drainages have a single channel within a narrow floodplain. Maximum clast size in channels ranges from ~1 m within highlands to ~10 cm near the Owyhee River. Floodplains consist of clay, silt, and sand. Smaller drainages entering McCann Creek or the Owyhee River have distinct fans at their toes, where gradient drops abruptly. Larger drainages are generally cultivated as pasture. **Qt$_4$** Lowest alluvial fan remnants are approximately 1 m above active channels and show no obvious dissection. **Qt$_3$** Approximately 2 m above Qt$_4$ and showing distinct erosion along flanks, where broad swales less than 1 m deep locally expose slightly coarser gravel with clasts to 10 cm. **Qt$_2$** Approximately 4 m above Qt$_3$ and substantially dissected both on flanks and as numerous rills within unit. Incipient desert pavement is locally developed. Erosion along flanks exposes as much as 3 m of gravel with clasts to 20 cm and well-developed caliche. **Qt$_1$** Oldest, variably dissected alluvial fans with surfaces 10 to 30 m above Qta. Probably includes deposits spanning a wide age range. Fans south of Sixmile Creek are relatively little dissected and retain flat, nearly primary upper surfaces. Fans north of Sixmile Creek are highly dissected, to rounded surfaces with scattered exposure of coarse gravel (clasts to 1 m) along flanks. Well-developed caliche is exposed in shallow mineral exploration pits.

Qia **Qim** **Qio** **Alluvium and fans of the Independence Mountains** Complex series of active to late Pleistocene alluvial fans that are developed in the eastern part of Independence Valley adjacent to the west flank of the Indendence Mountains. They are subdivided on the basis of inferred age, from active channels (Qia) to intermediate age (Qim), to older fan deposits (Qio); relative age is interpreted largely from elevation above active channels and amount of dissection. Geomorphically similar to alluvium and fans of the Tuscarora Mountains, except that clasts consist exclusively of Paleozoic rocks, particularly pebbles of chert 1 to 4 cm in diameter, and no fans appear as old as Qt$_1$. **Qia** Unconsolidated alluvium in active channels of small to large drainages. Larger drainages, such as Taylor Creek and unnamed creeks in the northeastern corner of the quadrangle, have anastomosing channels, ~1 to 5 m wide and up to 2 m deep, in floodplains up to 1.5 km wide; smaller drainages have a single channel in a narrow floodplain. Maximum clast size in channels is about 10 cm because highlands lie several kilometers east of the quadrangle. Floodplains consist of clay, silt, and sand. Smaller drainages entering the Owyhee River have small fans at their toes, where gradient drops slightly. Generally dark toned on aerial photographs. Larger drainages are cultivated as pasture. **Qim** Intermediate age alluvial fans. Surfaces are 1 to 3 m above active channels and are slightly to moderately dissected. Commonly cultivated as pasture. **Qio** Older alluvial fans. Surfaces are 4 to 5 m above active channels. They are highly eroded along flanks and dissected by numerous small drainages. Very light toned on aerial photographs.

Qca **Qcs** **Qcm** **Qco** **Alluvium and fans of Crooked Creek** Complex series of active to late Pleistocene alluvial fans that are developed in the southeastern part of Independence Valley. They are subdivided on the basis of inferred age, from active channels (Qca) and secondary fans (Qcs), to intermediate age (Qcm), to older fan deposits (Qco); relative age is interpreted largely from elevation above active channels and amount of dissection. Geomorphically similar to alluvium and fans of the Tuscarora and Independence Mountains. Clasts consist of Paleozoic quartzite and chert with subequal to lesser amounts of Tertiary igneous rocks. **Qca** Unconsolidated alluvium in active channels of small drainages, which have distinct fans at their toes where gradient drops abruptly as they enter the Owyhee River. **Qcs** "Secondary" alluvial fans are developed along a large (10–15 m), highly dissected Pleistocene(?) fault scarp by reworking of older fan deposits (Qco). The fans distinctly grade to gullies eroded into the scarp and consist of clasts of Paleozoic rocks to 10 cm in a silty matrix. **Qcm** Intermediate age alluvial fans are 1 to 10 m above active channels. These range from nearly undissected to highly eroded, especially adjacent to fault scarps and along drainages. Relatively undissected surfaces consist of 5 to 15% pebbles from 2 to 8 cm in a silty matrix. Eroded areas show gravel composed of clasts to 30 cm with well-developed caliche interbedded with debris-flow deposits containing scattered cobbles in a muddy matrix. **Qco** Older alluvial fans cap higher ridges in the southeastern corner of the quadrangle. Most surfaces are deeply dissected and rounded. Clasts of Paleozoic rocks range up to 30 cm and of tuff of Big Cottonwood Canyon (Tct) to 1 m. Undissected surfaces dip gently (1° to 2°) to the southeast, probably as a result of tilting during Quaternary faulting.

Qls **Landslide deposits** Coarse, unconsolidated debris composed of local bedrock, developed especially where hard, massive rock overlies tuff or other soft rock. Clasts range from large blocks, up to 10 m in diameter, to silt. Generally no more than 20 m thick.

TERTIARY ROCKS

Eocene

Lavas of Sixmile Canyon

A series of andesitic to dacitic lavas exposed around Sixmile Canyon represent the youngest volcanic episode in the quadrangle. The lavas are in fault contact with tuff of Big Cottonwood Canyon (Tct) to the west, but dacite lava (Tsd) overlies tuff of Big Cottonwood Canyon (Tct) in the Cottonwood Peak Quadrangle to the north. Sixmile Canyon lavas are covered by alluvial fan deposits (Qt$_1$) in Independence Valley to the east and continue an unknown distance to the north. Sources for the lavas have not been identified but must be local. Sixmile Canyon lavas are petrographically similar to, overlap in age with, and may be extrusive equivalents of some Mount Neva dikes (Tma and Tmdp).

Tsi **Dacite dikes of Sixmile Canyon** Several dikes and more irregular, elongate intrusions cut volcaniclastic sedimentary rocks and tuff (Tps?) and dacite lava (Tsd) south of Sixmile Canyon. Dikes appear to intrude along faults and are hydrothermally altered. Phenocrysts (12%): plagioclase (12%) and biotite (<1%). Generally broken phenocrysts and wispy, streaky appearance of groundmass suggest partly fragmental emplacement.

Tsa **Andesite of Sixmile Canyon** Abundantly porphyritic andesite, possibly a single lava flow, makes prominent outcrops near the mouth of Sixmile Canyon and capping ridges on the north side. Well-developed platy parting that parallels flow layers is a distinctive outcrop feature. Distinguished from underlying dacite lava (Tsd) by lack of hornblende or biotite. Maximum exposed thickness is about 120 m. Phenocrysts (30–35%): plagioclase (23–28%, ≤6 mm), orthopyroxene (2–4%, ≤3 mm), clinopyroxene (2–3%, ≤4 mm), and opaques (1%, 0.1–0.3 mm).

Tst **Tuff and tuffaceous sedimentary rocks** Thin, discontinuous lenses of massive, nonwelded, pumiceous tuff and pebbly, tuffaceous sandstone are interbedded between andesite (Tsa) and dacite (Tsd) and between dacite flows.

Tsd **Dacite lava of Sixmile Canyon** At least two thick lava flows of porphyritic dacite make bold, crudely flow-layered outcrops that comprise the walls of lower Sixmile Canyon. Flows are interbedded with thin lenses of whitish- to reddish-pink, crystal-poor, lithic tuff and tuffaceous siltstone. Maximum exposed thickness is about 150 m. Phenocrysts (25-30%): plagioclase (18–24%, 1–5 mm), hornblende (5–7%, ≤3 mm), biotite (1–2%, ≤2 mm), orthopyroxene (0.5–1.5%, 0.2–1 mm), clinopyroxene (0.5%, 1–2 mm), and opaques (0.5%, 0.1–0.3 mm). Age: 39.25±0.32 Ma, hornblende, DB-3.

Tsb **Biotite dacite intrusion** Biotite-rich dacite makes a probable intrusion just north of the town of Tuscarora. Lack of basal breccia or vesicles, and presence of columnar joints that plunge perpendicular to the contact with volcaniclastic sedimentary rocks and tuff (Tps) suggest the body is a large dike or sill. Mostly unaltered, but propylitically altered and cut by calcite veins along fault contact with tuff of Mount Blitzen (Tbt). Phenocrysts (~40%): plagioclase (22%, 2-5 mm), biotite (2-4%, 1-3 mm, euhedral), chloritized pyroxene and hornblende (8-10%, ≤3 mm), and opaques (1%, ≤0.5 mm).

See accompanying text for references and a discussion of the geology of the Tuscarora Quadrangle.

Rocks of the Mount Neva Intrusive Episode

During the Mount Neva intrusive episode, several irregular intrusions and numerous dikes were emplaced into and near the margin of the Mount Blitzen volcanic center. Individual intrusions range from andesite to rhyolite, but most are dacite. An early porphyritic dacite (Tmd) was emplaced dominantly along the margin of the Mount Blitzen center. Subsequently, dikes intruded within the center. Between these two sets of intrusions, the large (6 km²), related Mount Neva granodiorite intruded Palezoic rocks and tuff of Mount Blitzen (Tbt) in the Mount Blitzen Quadrangle.

Late Dikes

Numerous intermediate to silicic dikes cut the tuff of Mount Blitzen (Tbt), tuff of Big Cottonwood Canyon (Tct), early porphyritic dacite (Tmd), and volcaniclastic sedimentary rocks and tuff (Tps) of the Pleasant Valley volcanic complex in the northwestern part of the quadrangle. Dikes mostly strike northeast and continue into the adjacent Mount Blitzen (where they are more abundant), Big Cottonwood Canyon, and Cottonwood Peak Quadrangles. Similar distribution, gradation in petrographic and chemical characteristics, and the presence of zoned dikes that grade inward from andesite or dacite to rhyolite suggest that these dikes are related and emplaced at about the same time.

Tmr **Porphyritic rhyolite** Coarsely, abundantly porphyritic rhyolite to rhyodacite crops out in two zones. One zone lies just within and approximately parallels the margin of the Mount Blitzen volcanic center near Tuscarora. The other cuts the northwestern corner of the quadrangle; dikes of this zone continue extensively to the southwest and northeast into the Mount Blitzen and Cottonwood Peak Quadrangles. Individual dikes are as much as 30 m wide and make en echelon steps. Phenocrysts (20–35%): plagioclase (10–20%, ≤1 cm), quartz (5–8%, ≤5 mm, variably resorbed, bipyramidal), hornblende (3–6%, ≤4 mm), biotite (3–5%, ≤5 mm), and sanidine (0–5%, ≤3 cm). Several dikes have more mafic margins, similar to porphyritic dacite or quartz-phyric porphyritic dacite; compositional contacts within dikes are gradational in some dikes but may be abrupt in others. These relations suggest nearly contemporaneous intrusion of the rhyolite and dacites. Age: 39.34±0.08 Ma, sanidine; 39.46±0.15 Ma, hornblende, H96-19.

Tmdp **Porphyritic dacite** Dark-gray porphyritic dacite occurs as 2- to 15-m-wide dikes that are widely distributed in the northern part of the quadrangle. Phenocrysts (most ~35%, but as little as 10%): plagioclase (5–22%, ≤6 mm), biotite (2–5%, <5 mm, euhedral), hornblende (2–4%, ≤4 mm), clinopyroxene (2–5%, ≤1 mm), magnetite (<1%, clots to 5 mm), quartz (0–1%, ≤2 mm) and possible altered orthopyroxene. Mafic minerals are commonly altered to chlorite ± calcite ± epidote. Fine-grained, dioritic inclusions are common. Age: 39.51±0.36 Ma, hornblende, DB-35, Mount Blitzen Quadrangle (Henry and Boden, 1998).

Tmq **Quartz-phyric porphyritic dacite** Similar to the porphyritic dacite (Tmdp) but also contains a few percent bipyramidal quartz to 3 mm. Age: 39.37±0.24 Ma, hornblende, DB-43, Mount Blitzen Quadrangle (Henry and Boden, 1998).

Tma **Porphyritic andesite** A few dikes of dark-gray, abundantly porphyritic andesite crop out at the western edge of the quadrangle, west of Tuscarora, and in Sixmile Canyon. Phenocrysts (30–50%): plagioclase (25–40%, ≤6 mm), clinopyroxene (3–5%, ≤3 mm), orthopyroxene (1–3%, ≤3 mm), and biotite (1–2%, ≤3 mm). Felty groundmass of plagioclase microlites. Dikes are commonly zoned to less porphyritic margins.

Early Intrusions

Tmd **Early porphyritic dacite** Early porphyritic dacite forms numerous thick, irregular-shaped intrusions and a few dikes that cut tuff of Mount Blitzen (Tbt) and tuff and volcaniclastic sedimentary rock (Tps). These are concentrated along and just outside the margin of the Mount Blitzen volcanic center near Tuscarora, where they are the most common vein host. Based on field relations in the Mount Blitzen Quadrangle, individual mapped intrusions are probably composite. Phenocrysts (25–30%): plagioclase (15–20%, ≤3 mm), hornblende (3–5%, 1–9 mm, conspicuous prismatic), biotite (1–3%, ≤2 mm), and clinopyroxene (≤1%, ≤1 mm). The rock is porphyritic-seriate; plagioclase grades continuously in size between groundmass and phenocrysts. Rounded inclusions of fine-grained diorite with sparse phenocrysts of plagioclase, hornblende, and pyroxene are notably abundant. Age: 39.43±0.26 Ma, hornblende, H96-103. Also, 39.58±0.40, hornblende, H96-63, Mount Blitzen Quadrangle (Henry and Boden, 1998).

Rocks of the Big Cottonwood Canyon Caldera

The Big Cottonwood Canyon caldera (Berger and others, 1991; Henry and Boden, 1998) formed during eruption of the voluminous tuff of Big Cottonwood Canyon (Tct) and is the youngest large volcano in the quadrangle. The caldera lies mostly within the Mount Blitzen and Big Cottonwood Canyon Quadrangles to the northwest, but its southeasternmost part extends into the northwestern corner of the Tuscarora Quadrangle. The caldera truncates the tuff of Mount Blitzen and the Mount Blitzen volcanic center and extends for an undetermined distance to the north and northwest. The eastern margin of the caldera is cut by a north-striking normal fault that drops the tuff beneath lavas of Sixmile Canyon to the east.

Intracaldera Ash-Flow Tuff, Debris Deposits, and Megabreccia

Tct **Tuff of Big Cottonwood Canyon** Compound cooling unit of light-gray, devitrified, lithic, densely to moderately welded, rhyolitic ash-flow tuff. Crops out exclusively within and along the topographic margin of the Cottonwood Canyon caldera in the northwestern part of the quadrangle. Intracaldera tuff may be several kilometers thick, based on its 15° to 25° westward dip across a 12-km-wide belt into the Mount Blitzen Quadrangle. Sequence upward from megabreccia-rich tuff, to 1-m-thick sandstone and conglomeratic sandstone, to lithic, megabreccia-poor tuff in Big Cottonwood Canyon Quadrangle (Henry and Boden, 1998) to the west suggests catastrophic eruption and major caldera collapse, followed by a brief hiatus, sedimentation, and renewed eruption. Phenocrysts (20–25%): quartz (6%, ≤3 mm), sanidine (6–7%, ≤2.5 mm), plagioclase (7–10%, ≤3 mm), biotite (1%, ≤2 mm), and hornblende (<1%, <1mm); individual fiamme, which are up to 25 cm long, contain ≤15% of the same phenocrysts. Commonly weakly propylitically altered. Age: 39.67±0.10, sanidine, H96-42; 39.67±0.10, sanidine, H96-80. Both samples in Big Cottonwood Canyon Quadrangle (Henry and Boden, 1998).

Tcx **Breccia and debris deposits** Lenses and irregular masses of massive breccia and poorly bedded debris-flow deposits occur within the tuff of Big Cottonwood Canyon near the caldera margin. Deposits consist of various older rocks, including tuff and dacite of Mount Blitzen (Tbt and Tbd), early andesite (Ta), and Paleozoic chert, quartzite, and siltstone, up to several meters in diameter (larger blocks are mapped as megabreccia). Where exposed, matrix consists of finer pieces of the same rocks, although some deposits may be extremely lithic ash-flow tuff. Commonly form poor outcrops and expressed as abundant weathered out clasts littering the surface. Interpreted as landslide debris from the caldera wall during eruption of the tuff and initial caldera collapse.

Tbt **Pzu** **Pzq** **Megabreccia** Large blocks of older rocks within the tuff of Big Cottonwood Canyon (Tct) are mapped as their individual rock type, including tuff of Mount Blitzen (Tbt), Paleozoic quartzite (Pzq), and Paleozoic chert (Pzu). Blocks range up to several hundred meters across and were not mapped if smaller than about 10 m. Blocks of tuff of Mount Blitzen include a quartz-bearing, biotite-rich, densely welded ash-flow tuff that could be a different tuff. Similar to the breccia and debris deposits (Tcx), megabreccia blocks are interpreted as landslides from the caldera wall.

Rocks of the Mount Blitzen Volcanic Center

The Mount Blitzen volcanic center occupies much of the northwestern part of the quadrangle and continues to the west in the Mount Blitzen Quadrangle. Numerous dacite lava domes and intrusions (Tbd) and dacitic ash-flow tuff and epiclastic deposits (Tbt) accumulated in a fault-bounded basin. The dacite locally intrudes the tuff, whereas the tuff commonly contains clasts to megablocks of dacite. These relations indicate the two units developed contemporaneously. The nature of the volcanic center is uncertain. The fault-bounded basin suggests a caldera, but the heterogeneous assemblage of tuff and reworked deposits within the basin is distinctly unlike typical massive, homogeneous intracaldera tuff such as the tuff of Big Cottonwood Canyon (Tct).

Tbd **Tbdd** **Dacite of Mount Blitzen** Sparsely to moderately porphyritic dacite forms numerous lava domes, shallow intrusions, and megabreccia blocks within or at the margins of the Mount Blitzen volcanic center. Phenocrysts (8–20%): plagioclase (5–15%, 1–4 mm), biotite (1–4%, 1–2 mm), clino- and orthopyroxene (<0.5%, 0.5 mm), and hornblende (≤0.5%, ≤1 mm); mafic minerals are generally chloritized. Domes are commonly flow laminated, spherulitic, and locally brecciated, particularly at their margins. Most dacite is propylitically altered with replacement of groundmass by fine-grained quartz and K-feldspar, biotite by chlorite and sericite, and plagioclase by clay and calcite. Disseminated limonite after pyrite is common, and oxidized examples are bleached white. A few, mostly larger (≥500 m in diameter) areas of outcrop are definite or probable lava domes or shallow intrusions in place (**Tbdd**). Many other outcrops, including most smaller ones, are coarse breccia blocks within the tuff of Mount Blitzen. Definite domes occur approximately 2 km northwest of Tuscarora and at the junction of Arthur and Sixmile Creeks. Definite intrusions include a long dike in the wall of the Mount Blitzen center south of Sixmile Canyon and a smaller dike just west of it. Age: 39.40±0.14 Ma, biotite, H96-92, Mount Blitzen Quadrangle (Henry and Boden, 1998).

Tbt **Tuff of Mount Blitzen** A heterogeneous, complexly interbedded mix of dacitic ash-flow tuff and various epiclastic deposits fills the fault-bound Mount Blitzen volcanic center. Devitrified, poorly to densely welded, and variably lithic- to pumice-rich tuff makes up most of the unit and appears to represent pyroclastic eruptions from or related to the dacite of Mount Blitzen (Tbd). Phenocrysts (15–30%): plagioclase (13–25%, ≤3 mm), biotite (0.5–2%, ≤2 mm), hornblende and clinopyroxene (≤0.5%, ~1 mm, preserved only in rare, unaltered samples). A local variant with 1–2% quartz phenocrysts crops out in the northwestern part of the quadrangle. Characteristic, green, flattened to ovoid, sparsely porphyritic pumice up to 5 cm long makes up a few to 30% of the tuff. Lithic fragments are mostly of dacite of Mount Blitzen (Tbd), which can comprise as much as 50% of tuff, but include Paleozoic rocks and various other igneous rocks. Megabreccia blocks up to several hundred meters in diameter are common near the margins of the basin. Interbedded epiclastic rocks range from massive breccia to well-bedded sedimentary rock. Breccias generally are thick, contain abundant, angular to subrounded clasts of dacite of Mount Blitzen as much as 2 m in diameter, and appear to be landslide or debris-flow deposits from the domes. Other rock types include coarse, massive to poorly bedded, plagioclase-rich, lithic sandstone and conglomerate with variable amounts of green pumice and well-bedded, graded sandstone and siltstone. Both tuff and epiclastic layers are discontinuous along strike. The unit is at least 1 km and possibly as much as 3 km thick, but the base is not exposed and complex stratigraphy, lack of marker beds, and uncertainty in repetition by faults preclude determining an accurate thickness. Propylitic alteration, characterized by replacement of plagioclase by albite, clay minerals, and calcite and of biotite and hornblende by chlorite, epidote, calcite, and iron oxides, is widespread. Age: 39.88±0.22 Ma, biotite, DB-28, Mount Blitzen Quadrangle (Henry and Boden, 1998).

Tbd **Ta** **Pzq** **Megabreccia** Large blocks of older rocks within the tuff of Mount Blitzen (Tbt) are mapped as their individual rock type. Blocks range up to several hundred meters across and were not mapped if smaller than about 5 m. Blocks are largest and most abundant near the margins of the basin. Most blocks are dacite of Mount Blitzen (**Tbd**), probably shed from nearby in-situ lava domes, or early andesite (Ta). Only one block is Paleozoic quartzite (**Pzq**), although Paleozoic rock fragments are common in the tuff of Mount Blitzen. **Ta early andesite** Porphyritic andesite lava flows. Only present as blocks within tuff of Mount Blitzen (Tbt) and as clasts in breccia and debris deposits (Tcx) of the Big Cottonwood Canyon caldera. Two petrographic types: andesite with pyroxene as the only or dominant mafic phenocryst, and dacite? with hornblende and biotite in addition to pyroxene. Phenocrysts (20–25%): plagioclase (19–24%, ≤3 mm), hornblende (0–3%, 1–7 mm), biotite (0–2%, ~1 mm), clinopyroxene (1–3%, ≤1.5 mm), and orthopyroxene (1–2%, ≤1 mm); phenocrysts commonly form glomerocrysts. Commonly altered, with all mafic minerals converted to chlorite and calcite. Similar to andesite lavas of the Pleasant Valley complex, but relative age and possible relation are uncertain.

Lavas, Tuffs, and Sedimentary Rocks of the Pleasant Valley Volcanic Complex

The Pleasant Valley volcanic complex consists mostly of tuff and volcaniclastic sedimentary rock (Tps) with a few dacite lava flows (Tpb) and one dacite dome or intrusion (Tpd). Moderately welded ash-flow tuff (Tpt) was penetrated by drill holes near Tuscarora but does not crop out. The complex is named for exposures of the rocks in the Mount Blitzen Quadrangle (Henry and Boden, 1998) and extends to the south into the China Camp and Sugarloaf Butte Quadrangles. Rocks in the Tuscarora Quadrangle are mostly distal deposits from source vents and domes in the upper part of Pleasant Valley in the Mount Blitzen Quadrangle, although the dacite intrusion may also have been a vent. Tuff and volcaniclastic sedimentary rock crop out extensively from the western edge of the quadrangle as far northeast as Sixmile Canyon. Biotite-bearing dacite lavas crop out only in the westernmost part of the quadrangle. Additional andesite and hornblende-phyric dacite lavas crop out in the Mount Blitzen Quadrangle. Pleasant Valley rocks are the oldest volcanic rocks in the quadrangle and directly overlie basal Tertiary conglomerate in the Mount Blitzen Quadrangle. All Pleasant Valley rocks in the Tuscarora Quadrangle are extensively propylitically altered. Age: 39.86±0.24, hornblende, H96-73; 39.69±0.28, hornblende, H96-86; both on hornblende-phyric dacite lavas in the Mount Blitzen Quadrangle (Henry and Boden, 1998).

Tpd **Dacite intrusion** Silicified, porphyritic dacite forms an apparent intrusion that cuts biotite-bearing andesite-dacite lava (Tpb) and volcaniclastic sedimentary rocks and tuff (Tps) just north of McCann Creek. The body is strongly flow banded and locally spherulitic near its margins and more massive and slightly coarser inward. Altered phenocrysts of plagioclase and biotite increase in abundance from 8-10% near the margin to 15–18% in the center. The rock is petrographically similar to the dacite of Mount Blitzen (Tbd) and may be related. However, unlike other Mount Blitzen dacites, it lies ~2 km outside the Mount Blitzen volcanic center.

Tps **Volcaniclastic sedimentary rocks and tuff** Poorly indurated, poorly exposed sedimentary deposits and tuff crop out in a 1–2-km-wide, northeast-striking, southeast-dipping belt between the Mount Blitzen volcanic center and overlying alluvium and fans of the Tuscarora Mountains (Qt). Most deposits are white, massive to well-laminated, tuffaceous sandstone and siltstone. Some massive, nonwelded, pumiceous tuffs are probably primary ash-flow tuffs or debris-flow deposits. Apparent thickness is ~350 m near Tuscarora, but the rocks may be repeated by faults.

Tpb **Biotite-bearing andesite-dacite lava** Poorly exposed biotite-bearing lava crops out in a small area of low hills just north of McCann Creek and may continue in the subsurface farther northeast. Total thickness and number of flows are unknown, but thickness is probably less than 50 m. Phenocrysts (20–30%): plagioclase (18–25%, ≤5 mm), clinopyroxene (1–3%, ≤2 mm), biotite (1–2%, <1.5 mm), and orthopyroxene (1–2%, ≤1 mm).

Tpt **Dacite ash-flow tuff** Poorly to moderately welded ash-flow tuff was encountered in a 1,465-foot (446 m) deep drill hole (CT-3) in the Dexter pit. The tuff does not crop out and is shown only in cross section B-B'. The rock is commonly brecciated and pervasively propylitically altered. Plagioclase phenocrysts are altered to clay minerals, and no mafic phenocrysts are preserved. The tuff contains as much as 15% moderately flattened, green pumice up to 2 cm long and scattered fragments of porphyritic igneous rocks and Paleozoic shale. Thickness may be as much as 300 m, but the drill hole did not reach the base and the tuff is repeated by faults and cut by early porphyritic dacite (Tmd).

Rocks in the Southeastern Part of the Quadrangle

The tuff of Nelson Creek, first recognized in the Toe Jam Mountain Quadrangle to the west (Henry and Boden, in press), is interbedded with very poorly exposed tuffaceous sediments and minor dacite and andesite lava or shallow intrusions in the southeastern corner of the quadrangle. The rocks are commonly silicified and have undergone weak local hydrothermal alteration. Siliceous sinter forms several 1 to 2 m thick, mottled (or pelletal?), chalcedonic to opaline, white to varicolored to locally black (organic?) layers in the tuffaceous sedimentary rocks. One layer has nearly vertical tubes at base, possibly former reed stems.

Ts$_2$ **Upper sedimentary sequence** Mostly fine, massive to finely laminated sandstone to siltstone and sparsely porphyritic, pumiceous tuff that is either nonwelded ash-flow tuff or tuffaceous debris deposits. These deposits may be in part correlative with volcaniclastic sedimentary rocks and tuff (Tps) of the Pleasant Valley volcanic complex.

Tdi **Dacite** Porphyritic dacite is present as clustered boulders and minor subcrop in two locations: a narrow band along the downthrown side of a major, northeast-striking fault and a small pod surrounded by tuffaceous sedimentary rock (Ts$_2$). Whether the dacite is intrusive or extrusive is unclear, so it may be contemporaneous with or younger than the host sediments. The dacite is glassy (hydrated) to rarely devitrified, faintly flow banded, and finely vesicular. Phenocrysts (25–30%): plagioclase (20–25%, mostly 1–2 but up to 5 mm), clinopyroxene (6%, 1–3 mm), orthopyroxene (2%, ≤2 mm), biotite (1%, ≤2 mm), hornblende (<1%, to 5mm), and opaques (<1%, 0.1 mm) in a glassy, microlitic matrix.

Tnt **Tntf** **Tuff of Nelson Creek** Ash-flow tuff that is probably correlative with the tuff of Nelson Creek of the Toe Jam Mountain Quadrangle (Henry and Boden, in press) crops out in the southeastern part of the quadrangle. We mapped two facies, a basal nonwelded, moderately porphyritic tuff (Tntf) and an overlying, densely welded, more abundantly porphyritic tuff (Tnt), that are probably a single cooling unit. The contact between the two appears to be gradational. Composite thickness is at least 120 m, most of which is the upper densely welded part. **Tnt** Densely welded tuff is devitrified and locally silicified, weathers gray to light red, and contains sparse fragments of finely porphyritic andesite and Palezoic chert and shale to 1 cm. Phenocrysts (30–35%): plagioclase (25%, ≤4 mm), quartz (2–3%, ≤3 mm), sanidine (1–2%, ≤3 mm), biotite (3–4%, ≤2 mm), and hornblende (1–3%, to 3 mm). 39.92±0.11 Ma, sanidine, H97-30. **Tntf** Underlying nonwelded tuff is devitrified, weathers white, and contains 5% fragments of porphyritic igneous rocks to 1 cm and 2–3% fine pumice to 1 mm. Phenocrysts (20%): plagioclase (15–20%, mostly ≤2, rarely 3 mm, altered) and biotite (1%, ≤2 mm, generally oxidized). Sanidine and quartz are at most minor.

Ts$_1$ **Lower sedimentary sequence** Similar to the upper sedimentary sequence (Ts$_2$) but also containing lenses of poorly to moderately bedded, coarse, pebbly sandstone and conglomerate and coarse, debris-flow deposits or lithic tuff. Clasts in sandstone and conglomerate are porphyritic igneous rocks and Paleozoic chert to 5 mm. The debris deposits or tuff contain 30 to 50% clasts to 25 cm of porphyritic felsic igneous rocks and Paleozoic chert and shale in a tuffaceous matrix with sparse grains of feldspar, quartz, and biotite. Fragments of petrified wood are locally common.

Tal **Andesite** A black, flow-banded andesite crops out as a short lenses within tuffaceous sedimentary rock (Ts$_1$) just below outflow tuff of Nelson Creek (Tntf and Tnt). Planar flow bands strike dominantly N45°E and dip steeply to the northwest. The body may be a lava flow or a thick dike, so may be contemporaneous with the sediments or younger. It is petrographically similar to and may be a distal part of the Pleasant Valley volcanic complex. Phenocrysts (25%): plagioclase (18%, ≤4 mm), clinopyroxene and orthopyroxene (5%, ≤2 mm), hornblende (<1%, 0.5 mm), and opaques (2%, 0.1 mm).

PALEOZOIC ROCKS

Paleozoic rocks form a narrow, fault-bounded wedge in the northwestern part of the quadrangle. Pods of quartzite (Pzq) reside within a matrix of siltstone, chert, and minor sandstone and limestone (Pzu). The quartzite is almost certainly correlative with the Ordovician Valmy Formation, but Devonian conodonts were found in limestone in undivided siltstone and chert (Pzu) at one locality near Sixmile Canyon (Coats, 1987). The total sequence appears to be thick, but no accurate estimate of thickness is possible because these rocks are highly, possibly isoclinally, folded and probably thrust faulted.

Beds dominantly strike west to northwest and dip to the north, which is aberrant to the regional northeast to east-northeast strike (Henry and Boden, 1998). The unusual attitude probably reflects substantial (~50°) eastward tilting along the eastern margin of the Mount Blitzen volcanic center during formation of the Mount Blitzen anticline.

Pzu **Undivided siltstone and chert** Heterogeneous, generally recessive mix of siltstone or argillite, chert, and minor sandstone and limestone forms poor outcrop. Siltstone is finely laminated, tan to black (carbonaceous?), rarely micaceous, and locally in graded beds with fine sandstone. Chert mostly consists of thick- (10–30 cm) to thin-bedded, commonly nodular, black to reddish-brown to pale-greenish-gray, "glassy" to variably recrystallized chert. Individual chert beds are separated by thin (≤1 cm) siltstone layers, which were squeezed out during folding in many areas. Limestone is fine grained, dark gray, and commonly petroliferous.

Pzq **Quartzite** Massive, resistant, light-tan to medium-gray orthoquartzite forms numerous pods and lenses within undivided siltstone and chert (Pzu). Quartzite appears to be composed almost exclusively of well-sorted and well-rounded, 0.25 to 0.5 mm, commonly strained quartz grains that are strongly silica cemented. Quartzite bodies are mostly a few meters to about 0.5 km long and 1 to 100 m thick; they generally parallel strike of the host siltstone. Many bodies are "boudins" within variably sheared siltstone matrix and have faulted, commonly slickenlined surfaces. However, a few lenses appear to be interbedded with siltstone. The discontinuous nature of the beds may reflect both depositional pinch out and tectonic disruption.

Field work done in 1996 and 1997.

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