Text and references to accompany Nevada Bureau of Mines and Geology Map 110

GEOLOGY OF THE MOUNT BLITZEN QUADRANGLE

ELKO COUNTY, NEVADA

by

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INTRODUCTION

The Mount Blitzen Quadrangle lies in the northern Tuscarora Mountains in western Elko County in northeastern Nevada (figs. 1, and 2). The quadrangle covers the southeastern part of the Tuscarora volcanic field (TVF), which is the largest Eocene volcanic field in Nevada. Mapping of the Mount Blitzen Quadrangle is part of a broader project to understand Eocene magmatism and tectonism and their significance for major sedimentary-hosted gold deposits in the region. The origin of such deposits, especially in the Carlin trend and Independence Mountains (fig. 1), has long been controversial, but recent work shows that many formed in the Eocene, contemporaneously with extensive but little studied Eocene igneous activity (Brooks and others, 1995a, b; Thorman and others, 1995; Phinisey and others, 1996). Although some reconnaissance mapping and regional volcanic studies had been done (Berger and others, 1991; Boden and others, 1993; Brooks and others, 1995a), no volcanic centers, Eocene or otherwise, had been mapped in detail in northeastern Nevada before this work. Previous geologic maps of the TVF 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).

Reconnaissance in the TVF indicated that it includes several volcanic centers that were active between about 42 and 38 Ma (Berger and others, 1991; Crawford, 1992; Boden and others, 1993). Volcanic rocks of the TVF erupted through complexly deformed Paleozoic rocks, similar to those that crop out extensively to the south in the southern part of the Tuscarora Range 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 TVF on the north and northwest. Independence Valley, a broad alluviated basin drained by the South Fork of the Owyhee River, lies east of the TVF.

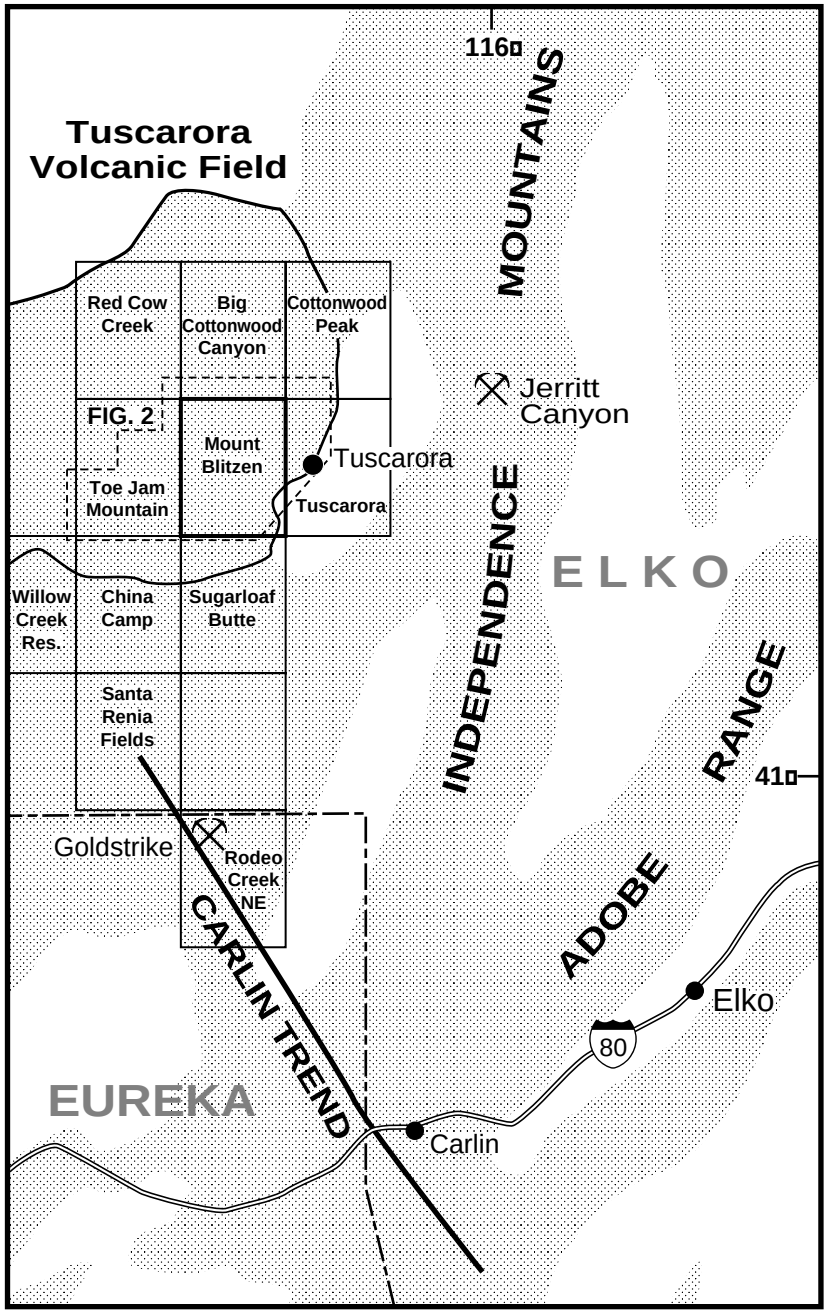
Rock units in the Mount Blitzen Quadrangle include highly folded and probably thrust faulted Paleozoic chert, siltstone, and quartzite; a complex assemblage of Eocene volcanic and intrusive rocks erupted during at least six episodes of activity; and Quaternary fluvial and alluvial fan deposits along drainages and in the western part of Independence Valley (fig. 2).

PALEOZOIC ROCKS

Stratigraphy

Paleozoic rocks that occupy the fault-bound wedge in the western part of the quadrangle include two distinct packages. A northern package contains pods of quartzite within a matrix dominated by siltstone and chert and is at least in part Ordovician. A southern package consists of siltstone, chert, and minor sandstone, limestone, and conglomerate and is at least in part Silurian to Devonian. The southern package was divided into siltstone-dominated (Pzs) and chert-dominated assemblages (Pzc). In the northern package, siltstone and chert were combined as Paleozoic rocks undivided (Pzu), and quartzite lenses (Pzq) were broken out. Both packages 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). Because both packages are intensely folded and probably thrust faulted, their true thicknesses are unknown. Volcanic rocks, especially basalt lavas, which occur in similar sequences in the Independence Mountains (Churkin and Kay, 1967) and other nearby areas, were not recognized here.

Most quartzite pods appear to be boudins a few meters to about 0.5 km long and 1 to 100 m thick within siltstone.



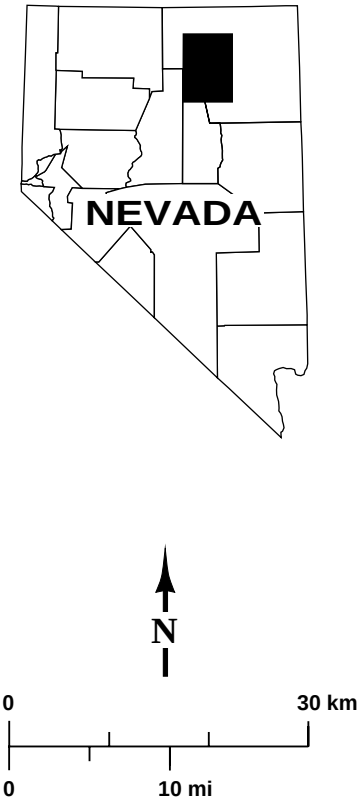


Figure 1. Location map of the Tuscarora volcanic field showing its relation to the Carlin trend, Independence Mountains, and quadrangles discussed in the text.

The pods have faulted, commonly striated surfaces and are surrounded by variably deformed siltstone. However, a few quartzite bodies are definitely or probably 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.

Although no fossils have been found in either the quartzite or its host rocks in the Mount Blitzen Quadrangle, similar quartzite-bearing sequences in northeastern Nevada are assigned to the (middle) Ordovician Valmy Formation (Merriam and Anderson, 1942; Roberts, 1964; Ketner, 1975; Miller and Larue, 1983). Quartzite in the Independence Mountains, termed the McAfee quartzite, is interbedded with graptolite-bearing, middle Ordovician shale and chert (Churkin and Kay, 1967; Miller and others, 1984; Adams, 1996). Churkin and Kay (1967) and Miller and Larue (1983) concluded that the McAfee quartzite accumulated on the continental slope contemporaneously with deposition of

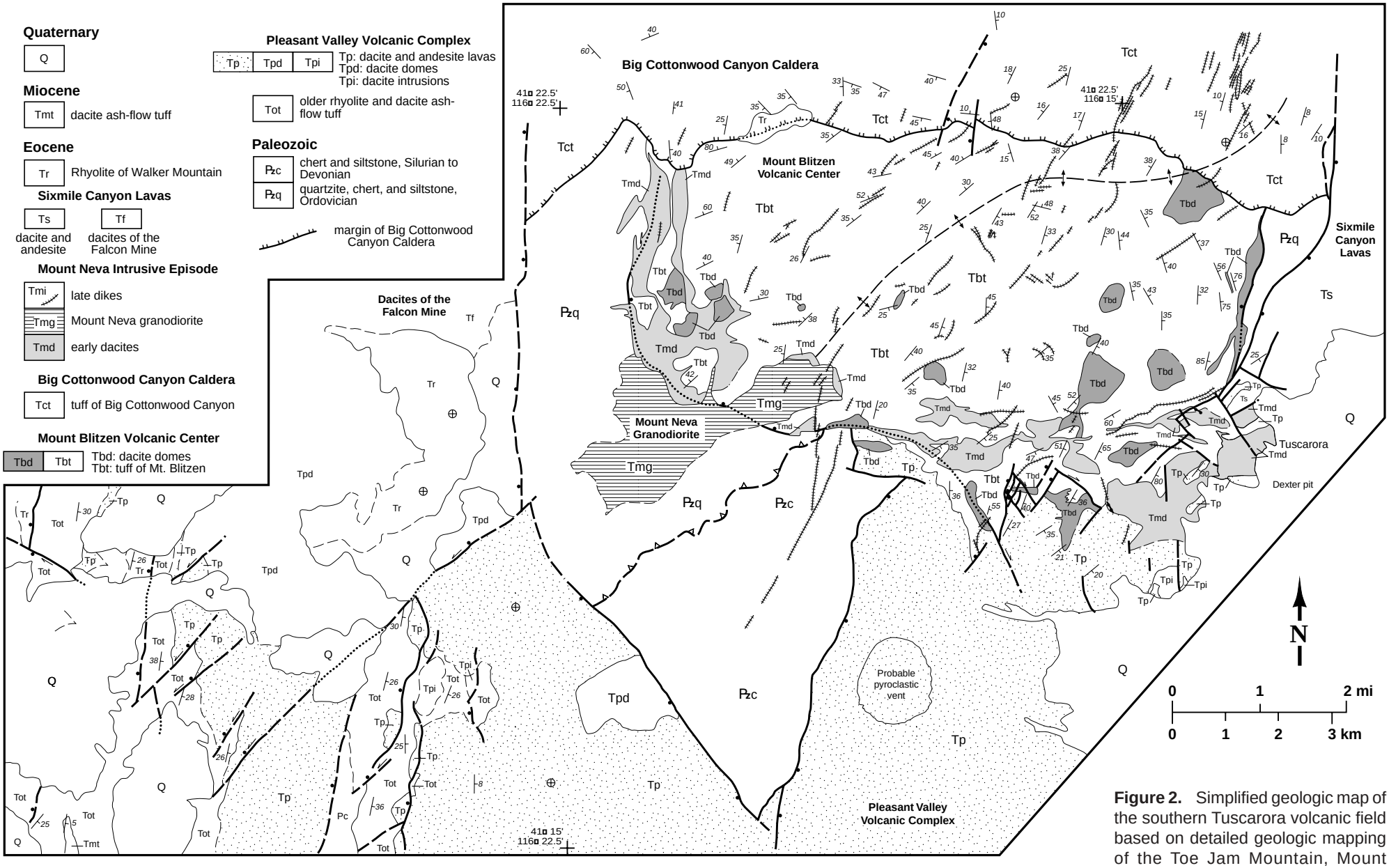


Figure 2. Simplified geologic map of the southern Tuscarora volcanic field based on detailed geologic mapping of the Toe Jam Mountain, Mount Blitzen, and Tuscarora Quadrangles (west to east).

Eureka Quartzite on the shelf to the east. Single-crystal U-Pb ages of zircon grains within Valmy and Eureka quartzites support this correlation and suggest that both were derived from the Precambrian craton of southern Canada (Smith and Gehrels, 1994). Coats (1987) found Devonian fossils in limestone within a quartzite-bearing sequence in Sixmile Canyon in the Tuscarora Quadrangle approximately 2.5 km to the east. Therefore, the northern, quartzite-bearing package in the Mount Blitzen Quadrangle may include rocks ranging from Ordovician through Devonian in age.

The southern package consists of siltstone and chert with minor sandstone, limestone, and pebbly conglomerate. Limestone beds containing Middle Silurian or Early Devonian conodonts were found at three locations (table 1; A.E. Saucier, personal commun., 1996). Conodonts from sample Anet1 are probably Middle Silurian, those from Anet2 are late Early Devonian, and those from Anet3 could range from Middle Silurian to Early Devonian in age. Similar rocks were mapped as the lower member of the Seetoya sequence in the Independence Mountains to the east (fig. 1), where fossils (graptolites) in a black shale at one locality indicate an Early Silurian age (Kerr, 1962). This suggests that Lower Silurian rocks could also be present in the Mount Blitzen Quadrangle.

Structure

Both packages of Paleozoic rocks are strongly and similarly deformed. Beds and numerous outcrop-scale folds dominantly strike northeast to east-northeast (fig. 3; section C-C′). The folds mostly plunge gently to the northeast and are overturned to the southeast. Outcrop-scale thrust faults, all in the southern package, dip gently to the northwest, and striae on the quartzite pods trend mostly northwest or southeast. These data are consistent with major shortening with transport toward the southeast. We interpret the combined structural and stratigraphic-age data to indicate that the Ordovician quartzite-bearing package is thrust over the Silurian-Devonian quartzite-free package along a major, northwest-dipping fault zone. Additional thrust faults having lesser displacement are undoubtedly present but can be shown only schematically on section C-C′. A few northwest-trending folds may indicate a separate, later(?) phase of deformation. The timing of deformation can only be constrained as post-Devonian and pre-Eocene in the Mount Blitzen 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)

Numerous northeast-striking, high-angle faults showing horizontal slickenlines cut Paleozoic rocks in the southern area. The faults are difficult to trace through the monotonous and poorly exposed chert and siltstone. However, apparent offsets suggest dominantly left-lateral motion, and displacement may be as much as 1 km. These faults do not appear to cut Tertiary rocks.

Regional Comparison

Similar stratigraphic-structural relations of quartzite-bearing and quartzite-free siltstone and chert packages are present both to the south and east (fig. 4). Minor folds in Ordovician and Silurian siliceous rocks in the southern Tuscarora Mountains trend dominantly north-northeast and are attributed to the Late Devonian-Early Mississippian Antler orogeny (fig. 3; Evans and Theodore, 1978). Minor folds plunging gently to the north-northwest may represent a later, Mesozoic(?) episode of deformation (Evans and Theodore, 1978). Quartzite-bearing siliceous rocks lie north of, and may be thrust over, quartzite-free rocks in the Santa Renia Fields Quadrangle, approximately 20 km south-southwest of the Mount Blitzen Quadrangle (T.G. Theodore, personal commun., 1997). The small area of Paleozoic rocks in the Tuscarora Quadrangle includes probable Ordovician quartzite and Devonian limestone (Coats, 1987). In the Independence Mountains to the east, quartzite-bearing rocks (the McAfee quartzite of Churkin and Kay, 1967, and the upper member of the Seetoya sequence of Kerr, 1962) lie north of the chert, siltstone, calcarenite, and mudstone of the lower member of the Seetoya sequence. Outcrop-scale folds and thrust faults in Seetoya chert strike dominantly east (fig. 3; Kerr, 1962; Daly and others, 1991). Quartzite crops out at and north of Double Mountain, approximately 20 km east of the Independence Mountains, whereas chert, shale, and siltstone occur to the south (Ketner, 1975; Coats, 1987). Finally, Ordovician quartzite crops out in the northern Snake Mountains, approximately 75 km east of the Independence Mountains, and “grades” southward into Ordovician and Silurian chert and siltstone (Gardner, 1968; Coats, 1987).

Table 1. Paleontologic data of Paleozoic rocks

Sample	Conodonts	Age
Anet 1	Middle Silurian (?) fragments	Silurian
Anet 2	*Polygnathus* cf. *inversus* Klapper & Johnson, 1975 *Pandorinellina* cf. *steinhornensis steinhornensis* (Ziegler, 1956)	late Early Devonian (Emsian)
Anet 3	*Ozarkodina excavata excavata* (Branson & Mehl, 1933)	Middle Silurian to Early Devonian
Samples collected by A. E. Saucier; identifications by N. M. Savage. Courtesy of Homestake Mining Company		

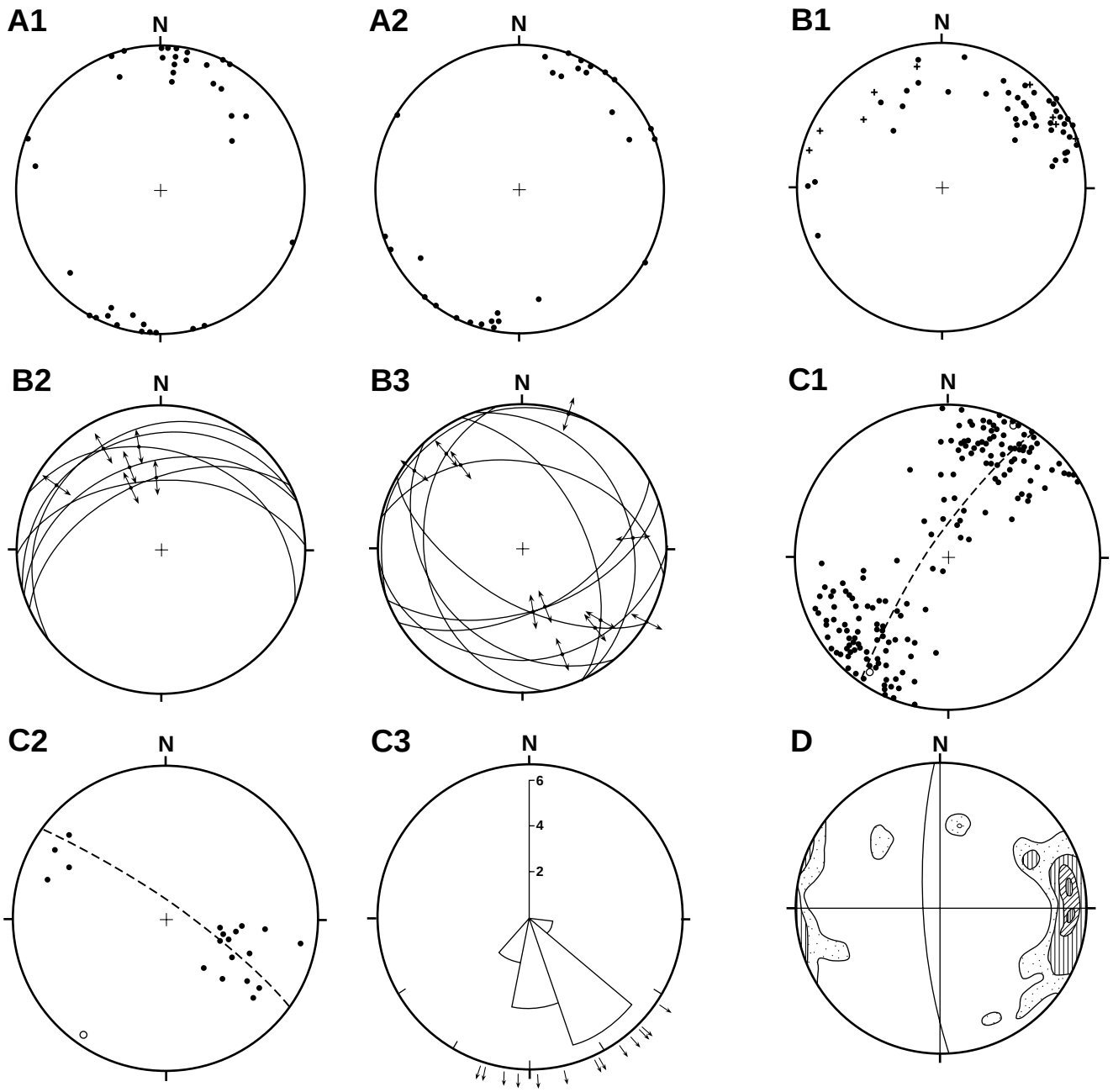


Figure 3. Equal-area stereonets showing structural data from Paleozoic rocks in the Mount Blitzen Quadrangle and surrounding areas. Locations shown on figure 4. **(A)** Rodeo Creek NE Quadrangle (Evans and Theodore, 1978). **(A1)** Hinge lines at 27 localities north of the Carlin Mine. **(A2)** Average orientation of hinge lines at 22 localities, north of A1. **(B)** Mount Blitzen Quadrangle. **(B1)** Hinge lines: • southern siltstone (Pzs) and chert (Pzc) package, + northern quartzite (Pzq) and undivided (Pzu) package. **(B2)** Small thrust faults and slickenlines. **(B3)** Faults and slickenlines on quartzite pods (Pzq). **(C)** Northern Independence Mountains, Schoonover sequence (Miller and others, 1984). **(C1)** Hinge lines. **(C2)** Poles to thrust fault planes. **(C3)** Calculated slip directions on small-scale thrust faults. **(D)** Southern Independence Mountains, Seetoya sequence, poles of axes of drag folds in chert (Kerr, 1962). Contours at 2, 5, 8, and 11%.

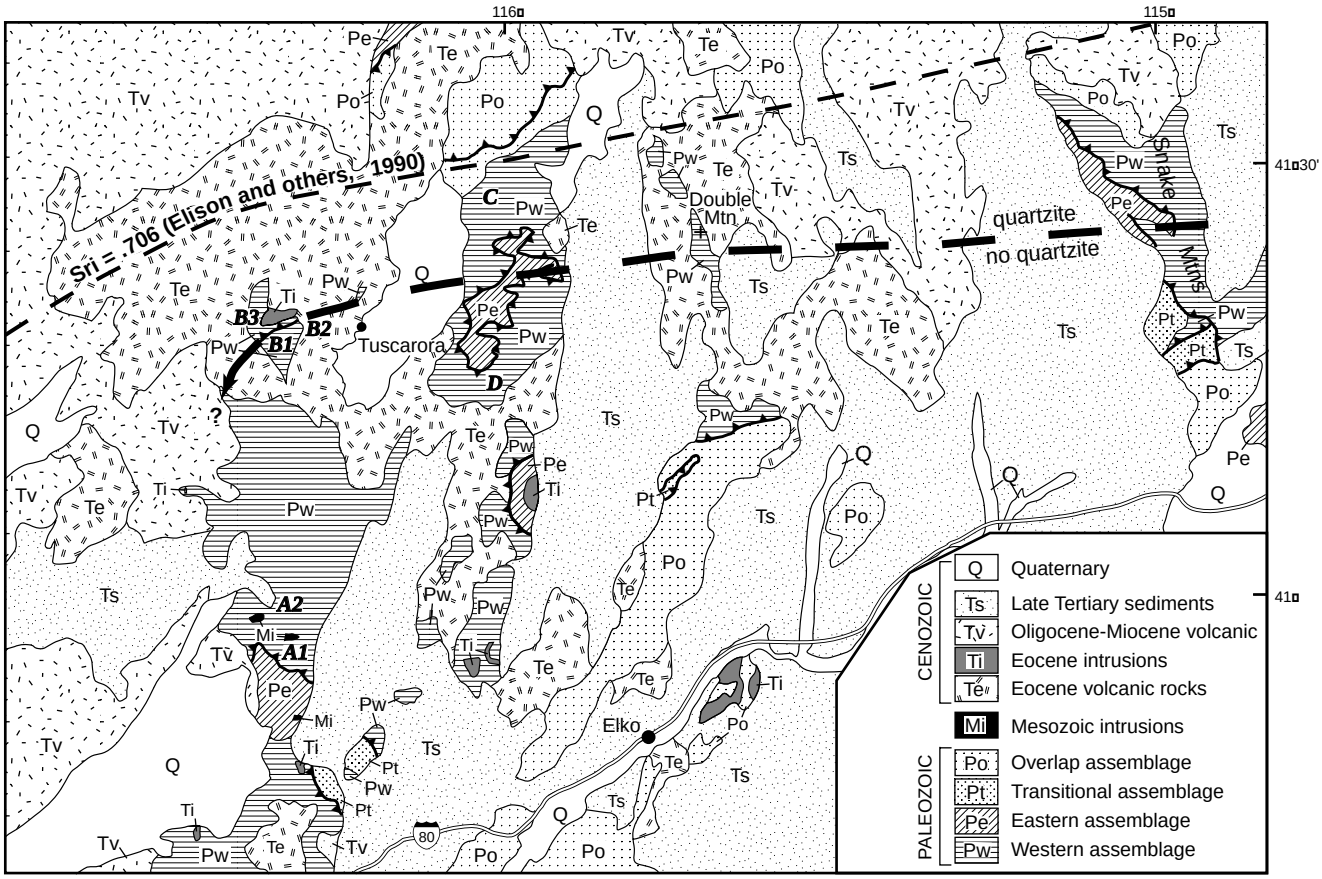
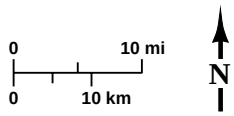


Figure 4. Simplified geologic map showing distribution of quartzite-bearing (Ordovician) and quartzite-free (Devonian-Silurian±Ordovician) western assemblage (upper-plate) rocks of the Roberts Mountain allochthon. Numbers refer to structural data in figure 3.



These data suggest that a belt of quartzite-bearing, mostly Ordovician rocks lies north or northwest of, and has been thrust to the southeast or south over, Silurian-Devonian siliceous rocks in a large area of western and central Elko County. The dominant structural grain changes from more northerly in the Carlin trend to east-northeast and northeast in the Mount Blitzen Quadrangle and northern Independence Mountains to possibly easterly in the southern Independence Mountains, Double Mountain, and Snake Mountains (fig. 4). Saucier (1997) noted that the whole upper plate of the Roberts Mountains allochthon shows similar curvature and that another quartzite-bearing belt lies southeast of the Mount Blitzen Quadrangle. If these structures formed at the same time, this pattern may reflect deformation along the boundary between continental crust to the south and east and oceanic crust to the north and west. This boundary, which is interpreted from isotopic data on Mesozoic and Cenozoic plutonic rocks (Farmer, 1988; Elison and others, 1990), strikes north through central Nevada but bends to the east across northeastern Nevada. Both the Antler and late Paleozoic Sonoma orogenic belts parallel the boundary (Oldow, 1984; Miller and others, 1992; Poole and others, 1992), and the structures may represent more than one episode of deformation.

TERTIARY ROCKS

Basal Tertiary Conglomerate (Tc)

Conglomerate and minor sandstone composed of subrounded to angular clasts of chert, quartzite, argillite, minor limestone, and minor porphyritic igneous rocks is the oldest Tertiary rock in the quadrangle. Most clasts are less than 20 cm in diameter, but quartzite boulders up to 1.3 m are present. The conglomerate is approximately 10 m thick near the southern edge of the quadrangle and probably several tens of meters thick northwest of Battle Mountain, where the section is repeated by several faults. Similar conglomerate varying widely in thickness crops out throughout Elko County (Coats, 1987).

The conglomerate records erosion of the Paleozoic rocks and largely preceded local volcanism. The presence of a few felsic, porphyritic igneous clasts and possibly minor volcaniclastic matrix indicates that upper parts of the conglomerate were deposited contemporaneously with earliest volcanism. Although Coats (1987) reported that conglomerate overlies tuff north of Berry Creek, conglomerate is faulted against tuff of Mount Blitzen (Tbt) in the outcrop he probably described. The conglomerate is certainly in part Eocene and may be entirely so.

Tertiary Igneous Rocks

At least six episodes of Tertiary (mostly Eocene) magmatism occurred in and around the Mount Blitzen Quadrangle (fig. 2). From oldest to youngest, these episodes are: (1) andesitic to dacitic lavas and tuffaceous sedimentary rocks of the Pleasant Valley volcanic complex (~39.9 to 39.7 Ma); (2) dacitic domes, small-volume pyroclastic-flow deposits, and epiclastic deposits of the Mount Blitzen volcanic center (between 39.8 and 39.7 Ma); (3) rhyolitic ash-flow tuff of the Big Cottonwood Canyon caldera (39.7 Ma); (4) a granodiorite pluton and andesitic to rhyolitic dikes and small intrusions of the Mount Neva intrusive episode (39.5 to 39.3 Ma); (5) andesitic and dacitic lavas of Sixmile Canyon; and (6) a rhyolitic lava dome and small intrusions (35.1 and 33.8 Ma). All but the Sixmile Canyon lavas crop out in the Mount Blitzen Quadrangle. Outcrop, petrographic, chemical, and $^{40}Ar/^{39}Ar$ age data (figs. 5, 6, and 7; tables 2 and 3) suggest that each of these sequences consists of genetically related rocks erupted from sources within or near the quadrangle. One rhyolitic tuff, possibly from a more distant source, and some andesite lava may have preceded the Pleasant Valley rocks.

Early Tertiary Andesite and Ash-flow Tuff

A rhyolitic ash-flow tuff (Tt) crops out in a small area along the north-northeast-striking fault that separates Paleozoic rocks from rocks of the Pleasant Valley volcanic complex and appears to underlie biotite-bearing andesitic lava (Tpb) of the Pleasant Valley rocks. Correlation of the tuff with other units and possible sources are unknown, although the presence of clasts of Paleozoic rocks up to 25 cm in diameter suggests a nearby source. The tuff may represent some of the earliest volcanic activity in the region.

Early andesite (Ta) mostly occurs as blocks within the tuff of Mount Blitzen (Tbt) throughout the western and northern part of the Mount Blitzen volcanic center. These blocks presumably were shed from lava that formerly cropped out along the margins of the center. Massive andesite that is not obviously surrounded by tuff in upper Rock Creek may be in place. Early andesite is petrographically and chemically similar to andesite lavas of the Pleasant Valley complex, but correlation is uncertain, and the blocks extend well beyond the known distribution of the Pleasant Valley rocks.

Pleasant Valley Volcanic Complex

The Pleasant Valley volcanic complex consists of andesitic to dacitic lavas, a dacite dome, tuff and volcaniclastic sedimentary rocks, and coarse breccia. The lavas are extensive throughout the southern part of the Mount Blitzen Quadrangle (fig. 2) and continue south and west into the Sugarloaf Butte, China Camp, and Toe Jam Mountain Quadrangles (fig. 1). In contrast, much of the tuff and breccia is concentrated around a probable vent in upper Pleasant Valley.

The Pleasant Valley complex is the oldest of the major volcanic sequences in the quadrangle. Lavas rest directly upon basal Tertiary conglomerate (Tc) in two locations and upon Paleozoic rocks at two other locations in upper Pleasant Valley and Berry Basin. $^{40}Ar^{39}Ar$ ages indicate the complex is about 39.9 to 39.7 Ma old. Hornblende ages from a flow that rests upon conglomerate in the south-central part of the quadrangle and from a flow within the sequence in the southwestern part are 39.86 ± 0.24 and 39.69 ± 0.28 Ma, respectively (fig. 7; table 3; samples H96-73 and H96-86; all ages ± 2σ). 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. 7; table 3; sample H96-32).

Two probable sources for Pleasant Valley rocks occur in the quadrangle (fig. 2). Additionally, many of the lavas were likely fed by dikes, although no such dikes are exposed. The biotite dacite dome (Tpbd) between Lewis and Nelson Creeks must have arisen from a source, possibly a dike, directly beneath it. A probable vent in upper Pleasant Valley has a discontinuous rim of coarse breccia (Tpx) composed mostly of vitrophyric blocks of pyroxene andesite (Tpa) with some clasts of biotite-bearing lava (Tpb). Clasts are up to 4 m in diameter, and several show radial cooling joints or breadcrust texture. The breccia surrounds an almost closed basin underlain by poorly exposed tuff (Tps), some of which appears to be primary pyroclastic material. Paleozoic rocks crop out around the southwestern and southern edges of the basin, in part at higher elevations than the breccia or tuff. Debris consisting of clasts of Paleozoic rocks (Tpp) forms a distinct lens interbedded with the andesite breccia south and east of the basin. These features suggest that breccia around the basin is a coarse proximal, pyroclastic deposit that erupted through the central basin. The andesite blocks apparently were hot and possibly partly molten. The central basin may have been cored explosively through the Paleozoic rocks. The lens of Paleozoic debris could be either a pyroclastic deposit or a debris-flow deposit shed from a rim of Paleozoic rocks that surrounded the vent. This area was called a tuff cone by Berger and others (1991), although pyroclastic vent would be a better term. An unlikely alternative is that the breccia is a rock-avalanche deposit shed from Pleasant Valley lavas that formerly overlay Paleozoic rocks on the upthrown side of the normal fault to the west. However, breccia characteristics are more consistent with a primary, pyroclastic origin than with an avalanche origin. Furthermore, this would require that the fault be active during deposition of Pleasant Valley rocks, for which we have no evidence.

The various petrographic flow types interfinger complexly and are laterally discontinuous. Pyroxene andesite lavas (Tpa) are most abundant and extensive. Hornblende-phyric andesite flows (Tph) occur at the base of the sequence near the southern edge of the quadrangle and northwest of Battle Mountain and higher in the sequence south of Pleasant Valley Creek and in the upper part of Nelson Creek. Several flows of biotite-bearing lavas (Tpb) are present south of Castile Mountain and between Lewis and Nelson Creeks, where they surround and may be related to the biotite dacite dome (Tpbd). Discontinuous lenses of volcaniclastic

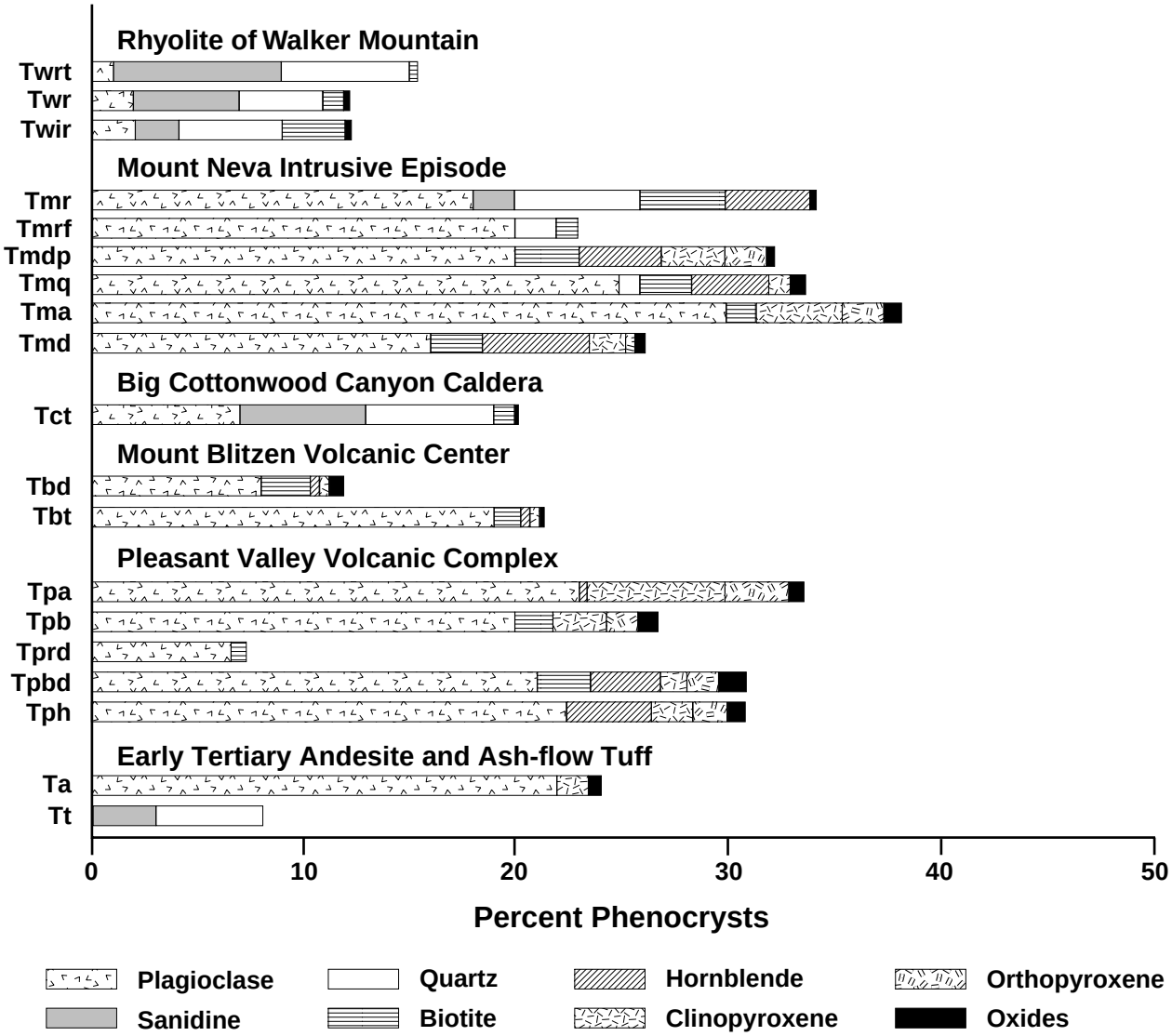


Figure 5. Phenocryst abundances in Tertiary igneous rocks of the Mount Blitzen Quadrangle.

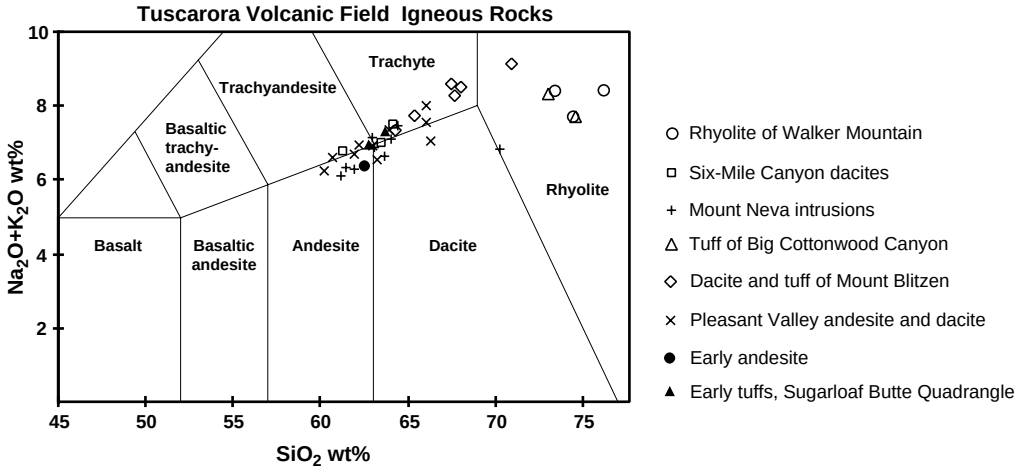


Figure 6. Total alkalies - silica plot of Tertiary igneous rocks of the Tuscarora volcanic field, Nevada. Classification follows Le Bas and others (1986). Major elements normalized to 100% volatile free.

Table 2. Chemical analyses of the Tuscarora volcanic field

Sample	H96-31	H96-32	H96-73	H96-86	H96-43	H96-48	DB-31-LC	DB-32NC	H96-66	H96-92	DB-23-TJ	DB-27-RC	DB-28-RC	H96-80	H96-57	H96-63	H96-103	H96-72A	H96-19	DB-43-BH	DB-35-MC	DB-2-LSM	DB-3-LSM	DB-7-LSM	DB-19-WM	H96-59	H96-65
Map unit	Tt1	Tt2	Tph	Tph	Tpa	Tpb	Tpbd	Tpa	Ta	Tbd	Tbd	Tbt	Tbt	Tct	Tmd	Tmd	Tmd	Tmg	Tmr	Tmq	Tmdp	Tsd	Tsd	Tsd	Walker Mtn	Twr	Twir
116° W. Long	15.1'	15.1'	19.9'	21.2'	17.2'	16.2'	22.3'	22.2'	20.5'	18.3'	20.7'	21.0'	21.5'	20.6'	15.9'	21.3'	13.6'	21.6'	14.9'	17.1'	17.5'	12.2'	12.1'	11.3'	23.2'	19.4'	20.5'
41° N. Lat	13.4'	13.4'	15.4'	16.2'	16.7'	16.6'	17.3'	17.0'	21.9'	19.1'	19.6'	20.3'	20.7'	24.5'	19.1'	21.3'	19.0'	19.3'	22.4'	18.1'	18.6'	21.3'	21.4'	21.9'	19.3'	22.5'	21.6'
Quadrangle	SB	SB	MB	MB	MB	MB	MB	MB	MB	MB	MB	MB	MB	BCC	MB	MB	T	MB	T	MB	MB	T	T	T	TJM	BCC	MB
SiO_2	62.87	63.76	60.75	61.99	66.08	66.06	62.99	60.29	62.51	67.72	70.96	67.50	65.43	73.08	64.51	61.21	63.09	64.09	70.29	61.96	61.54	64.21	63.55	61.27	73.45	76.24	74.52
TiO_2	0.81	0.81	0.83	0.87	0.77	0.63	0.77	0.95	0.81	0.54	0.31	0.47	0.59	0.21	0.67	0.90	0.77	0.73	0.42	0.84	0.70	0.79	0.76	0.87	0.26	0.07	0.20
Al_2O_3	17.38	18.13	18.38	17.20	17.58	16.26	16.62	17.35	17.16	16.20	15.18	16.97	17.58	14.48	16.45	16.25	16.61	16.15	14.68	16.07	15.75	17.12	16.87	17.01	14.39	13.23	13.93
FeO*	4.16	3.35	4.45	5.12	2.21	3.45	5.23	5.89	5.11	3.02	2.41	2.40	3.90	1.80	4.50	5.48	5.25	4.93	2.84	5.41	5.62	4.19	4.78	5.53	1.88	1.13	1.43
MnO	0.09	0.05	0.09	0.09	0.04	0.07	0.09	0.09	0.08	0.06	0.09	0.05	0.13	0.02	0.08	0.07	0.10	0.08	0.08	0.12	0.11	0.05	0.07	0.09	0.02	0.02	0.05
MgO	2.33	1.49	2.43	2.37	1.64	1.53	2.36	3.38	2.13	0.98	0.32	0.70	1.22	0.63	2.03	4.10	2.66	2.26	1.80	3.91	4.47	1.40	1.90	2.78	0.18	0.13	0.52
CaO	5.14	4.82	6.11	5.36	3.88	3.79	4.74	5.47	5.54	3.06	1.48	3.18	3.23	1.38	4.02	5.58	4.40	4.37	2.91	5.11	5.25	4.45	4.76	5.34	1.35	0.67	1.51
Na_2O	3.51	3.90	3.53	3.40	3.87	3.90	3.03	3.48	3.03	3.87	4.28	4.06	4.50	2.97	3.93	3.89	3.58	3.62	2.51	3.00	3.46	3.96	3.19	3.73	3.47	3.17	3.07
K_2O	3.42	3.39	3.09	3.29	3.68	4.13	3.89	2.75	3.35	4.40	4.88	4.56	3.24	5.38	3.56	2.21	3.30	3.50	4.33	3.31	2.87	3.54	3.82	3.04	4.93	5.31	4.67
P_2O_5	0.31	0.30	0.34	0.31	0.25	0.18	0.28	0.36	0.28	0.14	0.08	0.11	0.17	0.06	0.23	0.32	0.25	0.26	0.15	0.27	0.23	0.30	0.31	0.34	0.08	0.03	0.08
Total	98.34	98.39	97.54	98.45	98.72	97.62	98.46	98.57	96.62	98.53	98.54	97.99	98.02	98.62	97.37	98.06	97.80	97.73	97.31	97.27	97.91	99.08	97.53	98.48	99.09	99.59	97.24
c	12	14	18	12	11	9	15	17	13	8	4	6	13	4	9	14	14	11	10	13	14	12	11	13	6	2	3
V	97	103	118	130	91	80	123	145	119	59	11	38	49	19	102	149	117	102	58	120	130	110	105	123	17	0	21
Cr	19	22	23	13	23	21	30	118	8	5	0	5	2	0	14	85	25	19	15	92	193	16	13	23	2	0	6
Ni	8	10	9	4	11	9	9	39	5	4	8	8	7	9	9	32	9	7	12	37	39	4	5	11	7	9	10
Cu	5	10	10	5	6	5	2	12	2	2	0	2	1	6	8	0	7	12	1	12	24	11	1	10	2	8	1
Zn	75	90	95	84	103	62	80	82	76	59	67	51	158	40	72	35	82	41	51	67	74	84	77	84	39	37	45
Ga	23	23	21	20	22	20	18	18	22	20	21	17	20	19	20	18	22	19	20	21	21	22	21	20	17	22	19
Rb	92	89	97	62	108	121	103	65	80	122	134	128	87	139	103	75	98	98	127	89	65	98	105	86	215	288	236
Sr	747	759	845	758	603	528	657	612	686	487	361	556	733	292	618	655	596	588	304	617	697	683	665	693	191	43	1181
Y	21	20	23	20	27	23	22	21	18	22	24	21	17	15	20	21	20	22	14	19	18	20	21	20	27	19	24
Zr	238	248	188	178	228	255	205	197	209	264	274	255	261	225	212	188	200	204	147	173	180	211	209	203	165	102	155
Nb	15.4	15.4	13.3	13.2	14.9	16.7	14.6	13.5	13.4	17.7	18.1	15.6	14.9	13.4	14.2	13.7	13.8	14.8	13.7	13.4	10.6	14.6	15.0	13.9	17.2	20.0	23.2
Ba	1450	1574	1219	1412	1606	1693	1454	1251	1672	1819	1859	1835	1733	2819	1489	1287	1478	1385	1102	1331	1282	1488	1491	1384	939	164	1485
La	60	66	43	36	56	46	41	43	49	54	64	37	60	77	38	48	39	53	50	52	52	53	41	44	79	38	39
Ce	95	87	84	65	82	74	82	56	82	77	88	75	72	96	73	54	77	87	42	49	68	79	69	69	87	51	41
Pb	12	19	15	19	18	20	18	12	26	21	24	21	11	21	20	4	20	9	24	12	15	18	16	16	34	45	38
Th	14	15	12	8	13	14	11	8	11	14	17	15	10	21	14	8	11	12	16	12	10	13	10	9	32	45	16

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: SB-Sugarloaf Butte, MB-Mt. Blitzen, BCC-Big Cottonwood Canyon, T-Tuscarora, TJM-Toe Jam Mountain

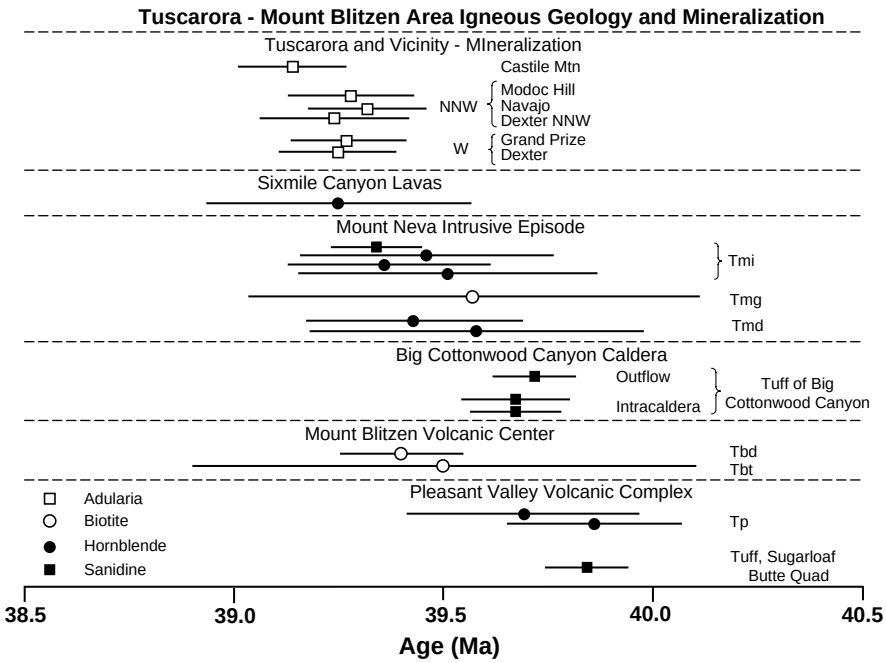


Figure 7. $^{40}Ar/^{39}Ar$ ages (±2σ) of igneous rocks and mineralization in the Tuscarora volcanic field. Rocks are in stratigraphic order determined from field relations. Sanidine and adularia give the most precise and reliable ages, hornblende is next, and biotite is the least precise.

Table 3. $^{40}Ar/^{39}Ar$ ages of Tertiary igneous rocks, Tuscarora volcanic field

Sample No.	Rock type	Quadrangle	Mineral	Age Method	Age (Ma)	±2σ
Rhyolite of Walker Mountain						
H96-65	Porphyritic rhyolite dike (Twir)	Mount Blitzen	sanidine	single crystal	33.77	0.10
H96-59	Porphyritic rhyolite lava dome (Twr)	Mount Blitzen	sanidine	single crystal	35.05	0.10
DB-19	Porphyritic rhyolite lava (Twr)	Toe Jam Mountain	sanidine	single crystal	35.29	0.10
Mount Neva Intrusive Episode						
Late dikes						
H96-19	Porphyritic rhyolite (Tmr)	Tuscarora	sanidine	single crystal	39.34	0.08
"			hornblende	plateau	39.46	0.30
"			biotite	integrated age	39.2	0.4
"			plagioclase	plateau	39.17	0.22
DB-35	Porphyritic dacite (Tmdp)	Mount Blitzen	hornblende	plateau	39.51	0.36
DB-43	Quartz-phyric porphyritic dacite (Tmq)	Mount Blitzen	hornblende	single step	39.37	0.24
Mount Neva pluton						
H96-72A	Granodiorite (Tmg)	Mount Blitzen	biotite	plateau	39.37	0.30
"			"	integrated age	39.6	0.6
Early porphyritic dacite (Tmd)						
H96-63		Mount Blitzen	hornblende	plateau	39.58	0.40
H96-103		Tuscarora	hornblende	plateau	39.43	0.26
Big Cottonwood Canyon caldera						
Tuff of Big Cottonwood Canyon (Tct)						
H96-42	Intracaldera tuff	Mount Blitzen	sanidine	single crystal	39.67	0.10
H96-80	Intracaldera tuff, single pumice	Big Cottonwood Canyon	sanidine	single crystal	39.67	0.10
96WC28	Outflow tuff	Willow Creek Reservoir	sanidine	single crystal	39.72	0.08
Mount Blitzen Volcanic Center						
DB-28	Tuff of Mount Blitzen (Tbt)	Mount Blitzen	biotite	plateau	39.88	0.22
"			"	integrated age	39.5	0.6
H96-92	Dacite of Mount Blitzen (Tbd)	Mount Blitzen	biotite	plateau	39.40	0.14
"			"	integrated age	39.03	0.36
Pleasant Valley Volcanic Complex						
H96-86	Hornblende-phyric andesite lava (Tph)	Mount Blitzen	hornblende	plateau	39.69	0.28
H96-73	Hornblende-phyric andesite lava (Tph)	Mount Blitzen	hornblende	plateau	39.86	0.24
Tuff of Sugarloaf Butte (Tt_1)		Sugarloaf Butte	sanidine	single crystal	39.84	0.10

sedimentary rocks, including debris-flow deposits, appear to have filled around the dome and adjacent to flow margins. The sedimentary and debris deposits are thicker and form a more continuous sequence north of Battle Mountain, where only a few, probably distal lavas are present.

Pleasant Valley lavas range from about 60 to 66% SiO_2 (fig. 6; table 2) and are similar to other Eocene, intermediate rocks in the quadrangle and throughout northeastern Nevada (Brooks and others, 1995a, b; M.W. Ressel and D.C. Noble, written commun., 1997). Pleasant Valley lavas are moderately alkalic and potassic. Major and trace element concentrations form tight, linear arrays that support a genetic relation between the flows. The one analyzed sample of early andesite (Ta) is compositionally similar to Pleasant Valley lavas, which allows a genetic tie.

Mount Blitzen Volcanic Center

The Mount Blitzen volcanic center is the largest volcanic complex of the quadrangle and extends eastward into the Tuscarora Quadrangle (fig. 2). Previous reconnaissance studies identified the Mount Blitzen center as a stratovolcano (Berger and others, 1991), a caldera (Crawford, 1992), or a volcano-tectonic graben (Boden and others, 1993). The divergence in these interpretations is consistent with the complex geology and unusual aspects of the Mount Blitzen center.

The Mount Blitzen center is a fault-bounded basin filled with a variety of dacitic intrusive and extrusive rocks. 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 western and southern margins of the center and part of the eastern margin in the Tuscarora Quadrangle. Extensive intrusion by dacite of Mount Blitzen (Tbd) and by early dacite (Tmd) and the Mount Neva granodiorite (Tmg) of the Mount Neva intrusive episode obscure much of the original character of these boundaries. Highly brecciated Paleozoic rock (Tbpx) along the western margin may have developed along one of the faults.

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; Sections A-A′ and B-B′). Therefore, 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 the younger Big Cottonwood Canyon caldera (fig. 7; table 3). Biotite, which gives relatively imprecise ages by the $^{40}Ar^{39}Ar$ method, was analyzed from one dacite dome (sample H96-92; plateau age = 39.40±0.14 Ma; integrated age = 39.03±0.36 Ma) and one tuff (sample DB-28; plateau age = 39.88±0.22 Ma; integrated age = 39.5±0.6 Ma).

The dacitic domes occur throughout the center but are most abundant along the margins. A few intrude older rocks outside the center. All bodies are petrographically fairly uniform and have about 10 to 15% phenocrysts mostly of plagioclase and lesser 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 many 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. Characteristic, green, flattened to ovoid, sparsely porphyritic pumice up to 5 cm long is a ubiquitous component, making up as much as 30% of the 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 various igneous rocks. The phenocryst assemblage is similar to that of the dacite domes, but tuffs are notably more porphyritic. Otherwise similar tuff containing 1 to 2% quartz phenocrysts crops out in the northeastern and east-central part of the quadrangle. The pyroclastic deposits are reasonably 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. In an example just north of the head of Sixmile Canyon, north-dipping, well-bedded sedimentary rocks are adjacent to and partly surrounded by southeast-dipping tuff and coarse epiclastic

rocks. The contact is covered but can be located within a few meters and is not a fault. The north-dipping rocks are probably a block within the southeast-dipping rocks.

Megabreccia blocks up to several hundred meters in diameter are common. They are most abundant near the margins of the center but are present throughout the tuff of Mount Blitzen. All but one block consists of dacite of Mount Blitzen (Tbd) or early andesite (Ta). One block of Paleozoic argillite approximately 50 m across is present in the southern part of the center.

Megabreccia within the Mount Blitzen center is similar to that within conventional rhyolitic ash-flow calderas, for example, the Big Cottonwood Canyon caldera (see below). Blocks of early andesite can be reasonably interpreted to have slumped from outcrop in the walls, where they formerly rested upon Paleozoic rocks. However, many andesite blocks, including bodies several hundreds of meters in diameter, are distant from 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 lack of Paleozoic blocks is puzzling given its abundance in the walls of the center and as small Paleozoic lithic fragments in tuff. Possibly Paleozoic rocks were largely buried by early andesite during much of the activity of the center.

Active dacitic volcanism on Montserrat in the West Indies provides a modern analog to Eocene activity in the Mount Blitzen center. Numerous modern to prehistoric andesitic to dacitic domes on Montserrat have generated equally numerous small-volume pyroclastic flows (Bulletin of the Global Volcanism Network Volumes 21 and 22; Montserrat Volcano Observatory http://www.geo.mtu.edu/volcanoes/west.indies/soufriere/govt/). Many of the domes form extrusive spines, similar to the classic example of Mount Pelee on Martinique (LaCroix, 1904), that subsequently collapse to provide large to small blocks within surrounding pyroclastic or epiclastic deposits. Thus dacitic dome formation and pyroclastic-flow and epiclastic deposition are occurring contemporaneously and over an extended period. Montserrat differs from Mount Blitzen in that volcanism is not filling a faulted basin, and most Montserrat deposits are likely to be eroded with little preservation in the geologic record.

The Mount Blitzen center has some characteristics of a caldera, and was so designated by Crawford (1992). It is a deep, roughly circular, fault-bounded basin filled with a thick sequence of volcanic rocks that commonly contain megabreccia. It is decidedly unlike 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 southern margin of the caldera and a narrow strip of intracaldera tuff are in the northern part of the Mount Blitzen 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, and its full extent in any direction is unknown. The eastern part is cut off by a north-striking normal fault in the Tuscarora and Cottonwood Peak Quadrangles (Henry and others, in prep.). 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 reveal that the tuff erupted ~39.7 Ma (fig. 7; table 3; samples H96-42, H96-80, and 96WC28).

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. Large pumice fragments have the same phenocryst assemblage but are noticeably less porphyritic than host tuff. All outcrop of this tuff in the Mount Blitzen Quadrangle is within the Cottonwood Canyon caldera. Unless repeated by unrecognized faults, this 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 as much as 25 km to the southwest, in the Willow Creek Reservoir Quadrangle, and tentatively about 25 km to the southeast, in the southeastern part of the Tuscarora Quadrangle.

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 several hundred meters in diameter were mapped as their original rock type. Clast types are tuff and dacite of Mount Blitzen (Tbt and Tbd) and early andesite (Ta). Blocks mapped as tuff of Mount Blitzen include a quartz-bearing, biotite-rich, densely welded ash-flow tuff that could be either the quartz-bearing variety or an entirely different tuff. Clasts of Paleozoic chert (Pzc) and quartzite (Pzq) occur in tuff in the Big Cottonwood Canyon, Cottonwood Peak, and Tuscarora Quadrangles. (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. However, the common presence of Paleozoic fragments in debris deposits is curious, because Paleozoic rocks do not crop out in the adjacent caldera wall except to the east in the Tuscarora Quadrangle.

Characteristics of ash-flow tuff in the southern part of the Big Cottonwood Canyon Quadrangle, which is included with this map, 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 pluton, several other irregular intrusions, and innumerable dikes were emplaced into and directly adjacent to the Mount Blitzen volcanic center (fig. 2). Field relations demonstrate that most of the dikes and possibly the other intrusions postdate activity in the Big Cottonwood Canyon caldera, which is confirmed by $^{40}Ar/^{39}Ar$ ages. R.R. Coats assigned the name Mount Neva to a peak near the western edge of the Mount Blitzen Quadrangle. At 8,591 feet, it is the second highest peak in the quadrangle after McCann Creek Mountain (8,602 feet).

Intrusions of the Mount Neva episode developed in three distinct pulses determined from field relations: (1) early porphyritic dacite (Tmd), (2) the Mount Neva granodiorite (Tmg and Tmgp), and (3) late dikes (Tmr, Tmrf, Tmdp, Tmq, Tma). $^{40}Ar/^{39}Ar$ ages on two samples of early dacite, one sample of granodiorite, and three samples of late dikes indicate these intrusions were emplaced between about 39.5 and 39.3 Ma (fig. 7; table 3). Sanidine from a late rhyolite dike (Tmr; sample H96-19) gives the most precise age of 39.34±0.08 Ma.

Early dacites form numerous irregular intrusions along the western and southern margins of the Mount Blitzen volcanic center and a few dikes within the center. Our mapping in the Tuscarora Quadrangle has identified similar bodies in the Tuscarora mining district that may lie along the eastern margin of the center. This distribution indicates that the intrusions rose along the faults that bound the center. The complex distribution and intrusive relations of early dacite along the western margin and local variations in petrographic characteristics suggest that dacite there consists of several individual intrusions. Dikes of the early dacite dominantly strike east, unlike the late dikes, which strike almost exclusively north-northeast.

Most early dacite is petrographically and compositionally uniform (figs. 5 and 6; table 2), typified by abundant, large (to 1 cm long), prismatic hornblende and a porphyritic-seriate texture in which phenocrystic and groundmass plagioclase is gradational. The dacite shares some petrographic similarities with the Mount Neva granodiorite, and some dacite may be an early, border phase of the granodiorite. One noticeable variant is more sparsely porphyritic and has a fine, sugary groundmass. Also, early dacite along the western margin locally contains more biotite than hornblende.

The Mount Neva granodiorite (Tmg), the largest intrusion of the quadrangle, cuts across the southwestern margin of the Mount Blitzen volcanic center. It is about 5 km by 1 to 2 km and elongate east-northeast. The subsurface shape of the intrusion is unknown, but steep contacts suggest a stock. Lack of deflection of surrounding tuff of Mount Blitzen (Tbt) and Paleozoic rocks suggest mostly passive emplacement.

A porphyritic border phase (Tmgp) with a fine groundmass of interlocking quartz and feldspar is developed extensively along the southern and eastern sides of the intrusion. It was mapped separately only where several hundred meters thick along the northeastern edge. Elsewhere, it is only a few tens of meters thick.

Numerous late dikes, ranging in composition from andesite to low-silica rhyolite (figs. 5 and 6; table 2), were the last manifestations of the Mount Neva episode. Although divided into five map units on the basis of phenocryst assemblage and inferred composition, field data and $^{40}Ar^{39}Ar$ ages indicate they were emplaced contemporaneously and are probably genetically related. Petrographic characteristics are broadly gradational (fig. 5). Moreover, many dikes are composite and grade inward from andesite (Tma) or dacite (Tmdp) at the margins to rhyolite (Tmr). 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. Chemical analyses are consistent with chemical continuity, but not enough different petrographic types have been analyzed for full evaluation.

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. Specific types of dikes form distinct belts. For example, porphyritic rhyolite (Tmr) forms a 1-km-wide belt through the middle of the center, and porphyritic dacite (Tmdp) forms a similar belt through the western part. Dikes of porphyritic rhyolite and porphyritic dacite also 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 of

porphyritic rhyolite and finely porphyritic rhyolite (Tmrf) cross the southwestern margin of the center, 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 northeast. Dips are generally steep but difficult to determine precisely for most dikes. However, several dikes for which attitudes can be determined dip toward the center, roughly perpendicular to the tilted tuff of Mount Blitzen (i.e., they dip as shallowly as 60° northwest in the southeastern part and 55° southeast in the northwestern part). This attitude allows the dikes to have been emplaced as vertical sheets before tilting. Alternatively, the dikes were emplaced along fractures that developed perpendicular to layering in the tuff. The distribution of dikes suggests they may be apophyses from a larger intrusion that underlies the Mount Blitzen center.

Rhyolite of Walker Mountain

A rhyolite lava dome (Twr) and related tuff (Twrt) that overlie the ring fracture of the Big Cottonwood caldera and three rhyolite dikes (Twir) intruded just south of the southern margin of the caldera constitute the rhyolite of Walker Mountain. These are named for more extensive exposures of similar rhyolite lava on Walker Mountain in the Toe Jam Mountain Quadrangle just a few kilometers to the west. The lava underlies tuff, and both contain phenocrysts of smoky quartz, sanidine, plagioclase, and biotite. The lava and tuff probably represent related eruptions along the ring fracture. The flow and tuff appear to be subhorizontal and to rest unconformably upon moderately tilted tuff of Big Cottonwood Canyon, which indicates they were emplaced after tilting of the tuff. Three north to north-northeast-striking dikes intruded Paleozoic rocks, early dacite (Tmd), or the tuff of Mount Blitzen just south of the caldera. The dikes are petrographically similar to each other and to the lava dome and tuff; two dikes also contain smoky quartz. Sanidine $^{40}Ar/^{39}Ar$ ages are 35.05 ± 0.10 Ma for the lava (table 3; sample H96-59) and 33.77 ± 0.10 Ma for the easternmost dike (Twir; sample H96-65), which shows that they are 4 to 6 Ma younger than all other volcanism in the Mount Blitzen Quadrangle.

During mapping, we interpreted the rhyolites to be ring-fracture eruptions related to the Big Cottonwood Canyon caldera because of their location along or just outside the ring fracture and their petrographic similarity to the tuff of Big Cottonwood Canyon. However, the much younger age of the rhyolites demonstrate that they can not be late eruptions from the caldera magma chamber. Similar rhyolite in the Toe Jam Mountain Quadrangle makes up one or more lava domes that cap Walker and Toe Jam Mountains and crop out in several fault blocks still farther west. Rhyolite in the Toe Jam Mountain Quadrangle has the same phenocryst assemblage of smoky quartz, sanidine, plagioclase, and biotite, and one has a $^{40}Ar^{39}Ar$ age of 35.29 ± 0.10 Ma (sample DB-19). Combined data from both quadrangles suggest a late Eocene, early Oligocene pulse of effusive rhyolites.

CENOZOIC STRUCTURE

Both igneous processes and regional extension have affected the structure of the rocks of the Mount Blitzen Quadrangle. In some cases, especially in regards the Mount Blitzen volcanic center, the relative contribution of each 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). However, both the origin of the basin and the cause of tilting of the tuff of Mount Blitzen are uncertain. The 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. The southeastern boundary is more complex with several north-northwest and northeast-striking segments. From preliminary mapping in the Tuscarora Quadrangle the eastern boundary strikes north-northeast.

Most boundaries appear to be high-angle faults. Paleozoic rocks that make up most of the margins of the Mount Blitzen center must be substantially downdropped into it. Extensive intrusion by early dacite (Tmd) and the Mount Neva granodiorite (Tmg) of the Mount Neva intrusive episode along these boundaries and by dacite of Mount Blitzen (Tbd) along part of the eastern boundary obscure much of the original character of these faults. Highly brecciated Paleozoic rock (Tbpx) along the western margin may have developed along one of the faults.

The complex southeastern boundary appears to consist of northeast-striking, northwest-dipping, moderately dipping normal faults, which are segmented by north-northwest-striking, high angle, probable strike-slip faults. Basal Tertiary conglomerate (Tc) and lavas (Tph and Tpa) and volcaniclastic rocks (Tps) of the Pleasant Valley episode strike northeast and dip southeastward, away from the Mount Blitzen center. Dip is as much as 40° near the margin and decreases away from it. These characteristics suggest that rocks within the center dropped down along the northeast-striking normal faults and were translated laterally along the north-northwest-striking faults. Interpretation of this geometry is complicated because layered rocks within the Mount Blitzen center also strike northeast and dip southeastward, in many cases more steeply than the older rocks.

We favor a volcanic-subsidence origin, somewhat like caldera collapse, for the Mount Blitzen volcanic center with some influence of regional extension. This point is discussed more below.

The Mount Blitzen Anticline

The tuff of Mount Blitzen makes 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 complicated by two systematic variations and, to a lesser extent, by the local, probably depositional variations in attitude described above. In an approximately 8-km^2 area along the eastern margin of the quadrangle just north of Mount Blitzen and extending into the Tuscarora Quadrangle, the tuff of Mount Blitzen strikes to the north or slightly west of north and dips to the east. In addition, rocks along the eastern and southeastern margin parallel the margin and steepen toward it. Rocks more than about 1 km away from the margin dip about 40° but steepen to vertical and locally slightly overturned near the margin. In contrast, tuff in the western and southern parts of the Mount Blitzen center strikes obliquely into the margin and does not noticeably steepen toward it.

Continuation of the anticline outside the Mount Blitzen center is uncertain. To the north, 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 a small area represented by only three measurements in the easternmost part of the caldera, the tuff of Big Cottonwood Canyon dips to the east-southeast. Thus, the anticline could continue into the caldera, but, in both areas, dips in the tuff of Big Cottonwood Canyon are distinctly less than in the tuff of Mount Blitzen. In the central and western parts of the caldera, west of a north-northeast-striking normal fault, the tuff of Big Cottonwood Canyon dips mostly to the southwest. This attitude is distinctly different from the northwest-dipping tuff of Mount Blitzen immediately to the south (fig. 2).

To the south, measured structures in Paleozoic rocks that make up the western and part of the eastern margin of the Mount Blitzen center suggest they have not been tilted in the Tertiary (Section C-C′). Throughout the Paleozoic outcrop, small folds are subhorizontal to gently east-northeast plunging, and rocks dip shallowly to moderately, mostly to the north-northwest. The lack of plunge does not preclude tilting, because tilting would likely have occurred along an east-northeast axis. However, similarity in dip along the north-south length of the Paleozoic outcrop argues against differential tilting as seen in the Mount Blitzen center. Minor southeast dips are more readily interpreted as a result of pre-Tertiary folding.

Still farther south, rocks of the Pleasant Valley complex in the southern part of the quadrangle are nearly flat lying (sections C-C′ and D-D′). However, these same rocks are tilted to the southeast adjacent to the southeastern margin of the Mount Blitzen center. The nature of the transition between the nearly flat-lying and tilted rocks is obscure, because rocks in the transition area in and north of Berry Basin consist mostly of poorly exposed, massive lava and breccia.

Structures Related to Mid-Cenozoic? to Late Cenozoic? Extension

High-angle faults that bound the west and east sides of the wedge of Paleozoic rocks probably resulted from mid- to late Cenozoic extension. The eastern fault strikes north-northeast and can be traced for about 8 km, from the southern edge of the Mount Blitzen center southward to the south end of the quadrangle (fig. 2). The topographic expression of the fault suggests that it dips steeply to moderately eastward. It separates Paleozoic rocks on the west from downdropped Tertiary rocks of the Pleasant Valley volcanic complex on the east. The amount of displacement is unknown, but the presence of two areas of Paleozoic outcrop on the downthrown side indicate at least 300 m of normal slip. The fault appears to end northward at the Mount Blitzen center.

The western fault strikes north-northwest for about 8 km from the southern edge of the quadrangle northward into the Toe Jam Mountain Quadrangle (fig. 2). The fault then turns to a northerly trend for another 8 km. The western fault separates Paleozoic rocks from Pleasant Valley rocks along the north-northwest segment. Farther north, younger but probably still Eocene volcanic rocks are on the downthrown side. Displacement is at least 500 m, down to the west. Topographic expression and small faults in Paleozoic rocks near the main fault indicate the main fault dips moderately, approximately 45° to 55°, to the west. At several locations in the Nelson Creek and Lewis Creek drainages, small faults show as many as three sets of slickenlines. The oldest recognized slickenlines consistently show a large component of right-lateral strike slip; striations plunge northwest to west-northwest. The youngest slickenlines show almost pure dip slip and plunge southwest. The timing of fault motion on either the western or eastern faults and of these slickenlines is known only to be post-39.8 Ma, the age of the Pleasant Valley lavas. Volcanic rocks on the downthrown side of the western fault in the Toe Jam Mountain Quadrangle are as young as 35.3 Ma (rhyolite of Walker Mountain).

The western and eastern faults intersect in a complex and poorly understood area at the south edge of the Mount Blitzen Quadrangle. It is difficult to trace either fault farther south through massive, monotonous andesite lava of the Pleasant Valley complex. Possibly displacement on the two faults was approximately equal and of opposite sense. Therefore, displacement to the south of their intersection would be at most minor.

Interpretation of the Mount Blitzen Volcanic Center

Both the physical characteristics and evolution of the Mount Blitzen volcanic center are similar to those in well-documented calderas (Smith and Bailey, 1968; Lipman, 1984). However, certain aspects are decidedly unlike typical calderas. The contribution of regional extension to its origin and evolution is a significant uncertainty.

The following characteristics of the Mount Blitzen center are similar to those of calderas. It is a deep, roughly circular, fault-bounded basin filled with a thick sequence of volcanic rocks including ash-flow tuff. The tuff contains abundant large blocks (megabreccia) slumped from the walls of the center. The thickness of fill and presence of

megabreccia indicates that pyroclastic eruption, subsidence of the basin, and slumping from the walls were contemporaneous, and $^{40}Ar/^{39}Ar$ dating demonstrates that these events were rapid, taking probably no more than 0.1 Ma. In turn, the contemporaneity and rapidity indicate that subsidence of the basin resulted from withdrawal from an underlying magma chamber. The abundant early porphyritic dacites (Tmd) along the margins of the center are equivalent to ring-fracture intrusions found in almost all calderas. Late dikes represent additional postcollapse magmatism and may be apophyses from a large underlying intrusion that domed the tuff of Mount Blitzen to form the anticline. If so, the anticline is comparable to resurgent domes in calderas.

The critical difference between the Mount Blitzen center and typical calderas is that the heterogeneous, complexly interbedded assemblage of small-volume tuffs and reworked deposits is distinctly unlike typical massive, more homogeneous intracaldera tuff. The tuff of Big Cottonwood Canyon (Tct), which distinctly fills its own caldera, is a more typical intracaldera tuff. One possibility is that the Mount Blitzen basin collapsed incrementally during progressive eruption of the dacitic rocks, instead of in a single, catastrophic eruption. This would imply that the basin developed over possibly tens of thousands of years, in contrast to the nearly instantaneous development of typical calderas. Our age constraints allow either alternative. A second possibility, that the Mount Blitzen center collapsed catastrophically during eruption of a voluminous ash-flow tuff that underlies the tuff of Mount Blitzen, seems less likely. In this case, the dacitic rocks would all be late, postcollapse fill of the caldera. Although many calderas are filled by late dome deposits, we have no evidence for an underlying intracaldera tuff or for equivalent outflow tuff anywhere in the Mount Blitzen region. However, much of the surrounding country is not mapped in detail.

Northwest-oriented extension may have been an additional but minor factor in generating the Mount Blitzen basin. Eocene, northwest-oriented extension contemporaneous with volcanism has been recognized in several parts of the northeastern Great Basin, including the Bull Run area 25 km northeast of the Mount Blitzen Quadrangle (Clark and others, 1985; Brooks and others, 1995a; Janecke and others, 1997). For example, the Panther Creek half graben in the Challis volcanic field, Idaho has been interpreted to reflect rapid regional extension contemporaneous with major pyroclastic volcanism (Janecke and others, 1997). The southeastern margin of the Mount Blitzen basin provides the greatest evidence for involvement of extension. Several northeast-striking normal faults there are down to the northwest, into the center, and are segmented by three northwest-striking, right-lateral faults. This geometry is consistent with the basin being a down-dropped area partly resulting from northwest extension. However, the rest of the preserved basin is more equant in map view, and most boundaries are oblique to possible northwest extension. Moreover, the Mount Blitzen basin is apparently symmetrical. In contrast, known Eocene extensional basins, including the Bull Run basin and the Panther Creek half graben, are half graben. The rapidity of basin development is the most telling argument against extension being the dominant factor in its origin. $^{40}Ar/^{39}Ar$ dates on Pleasant Valley rocks and the tuff of Big Cottonwood Canyon constrain all subsidence and filling of the Mount Blitzen basin to ~0.1 Ma, between about 39.8 and 39.7 Ma (fig. 7). A volcanic-collapse basin can easily form in this little time, but tectonic-extensional basins take much longer.

We also favor an igneous origin for the Mount Blitzen anticline, by doming from an underlying intrusion, although extension may have been an additional factor. The anticline parallels and closely coincides with the late dikes, which must have arisen from a deeper magma chamber. The anticline is on strike with the Mount Neva granodiorite (Tmg). Although the Mount Neva intrusion appears to have been emplaced passively, its presence further suggests that another large intrusion could underlie the Mount Blitzen center. The anticline is restricted to the Mount Blitzen center and possibly to the southern part of the Big Cottonwood Canyon caldera. This indicates a cause related to the Mount Blitzen center and unrelated to regional events.

Timing and geometric characteristics of the anticline are inconsistent with an alternative origin as a result of tilting during northwest extension, either as a roll-over structure in the hangingwall of a detachment-style fault or between two, oppositely dipping listric faults. If tilting resulted from motion on the western and eastern boundary faults of the Mount Blitzen center, basin formation, filling, and tilting would all have to have occurred within ~0.1 Ma. This is an impossibly short time for all these event to occur tectonically. Also, if extension were contemporaneous with deposition of the tuff of Mount Blitzen, the tuff should show progressive shallowing of dip upsection (i.e., fanning dips). Instead, dip increases upsection toward the east side. If tilting were later (i.e., if the tuff of Big Cottonwood Canyon is also tilted), tilting can not be related to the boundary faults, which are truncated by the tuff. In this case, tilting would not be related to any mapped faults. Additionally, the anticline does not extend outside the center and so must not be a regional event. The domain of east-dipping rocks in the eastern part of the center is inconsistent with northwest-oriented extension but is consistent with an igneous dome. Northwest-oriented extension may have been a contributing factor in that the preferred, northeast strike of late dikes, the Mount Neva intrusion, and the anticline suggests that the least principal stress was northwest at the time.

ECONOMIC GEOLOGY

Three distinct types of altered and mineralized rocks are found in the Mount Blitzen Quadrangle: (1) volcanic-hosted quartz-pyrite ± adularia ± calcite veins at Beard Hill, Castile Mountain, Battle Mountain, and Modoc Hill; (2) mercury workings in andesitic/dacitic lavas of the Pleasant Valley volcanic complex in Berry Basin; and (3) quartz-barite veins in Paleozoic chert, shale, and sandstone. Additionally, minor

quartz-epidote veins with bleached halos are locally developed in the ~39.4 Ma Mount Neva granodiorite, particularly its northeastern part. Weak propylitization of rocks of the Mount Blitzen volcanic center is pervasive but cannot be attributed to any discrete zone of hydrothermal activity.

Volcanic-Hosted Au-Ag Mineralization of Beard Hill, Castile Mountain, Battle Mountain, and Modoc Hill

This area is the southwestern end of the Tuscarora Au-Ag district (fig. 2). Host rocks consist mainly of lavas and tuffs of the Pleasant Valley volcanic complex. However, some tuff of Mount Blitzen underlies the northern part of Beard Hill, and Battle Mountain is cored by a flow-layered, modestly porphyritic biotite-plagioclase-bearing plug or dome resembling the Mount Blitzen dacite. Unpublished company data indicate that the altered rocks in this area have low Ag/Au and negligible base metals, which is characteristic of the southern and western parts of the Tuscarora district. $^{40}Ar/^{39}Ar$ dates have been determined on six samples of adularia from the Tuscarora district, including two samples from the Mount Blitzen Quadrangle. The ages range from 39.32±0.14 (2σ) to 39.14±0.13 Ma, with all but one ≥39.24 Ma; all ages overlap within analytical uncertainty.

Beard Hill

Outcrops on Beard Hill consist of tuff of Mount Blitzen (Tbt) on the north and west sides and porphyritic pyroxene dacite flows (Tpa) and local lithic-pumice lapilli tuff (Tps) of the Pleasant Valley complex. These rocks are cut by north- to north-northeast-striking dikes of porphyritic quartz-bearing dacite (Tmq) of the Mount Neva intrusive episode. A northwest-striking, right-lateral transfer fault, which makes up part of the margin of the Mount Blitzen volcanic center, bounds Beard Hill on the northeast, and several northeast-striking faults cut through the hill.

Narrow quartz-pyrite (now limonite) veins and veinlets form a 2,600-m-long, north-striking, steeply west-dipping zone. Wall rocks are bleached and probably partly replaced by fine-grained quartz and adularia adjacent to the veins. However, we identified no definite adularia.

Beard Hill is pockmarked by numerous old prospect pits, shallow shafts, and minor adits. No historic production is known. Thirteen RC (reverse circulation) holes were drilled in the early and middle 1980s but intersected only scattered, narrow zones carrying ore-grade values (Struhsacker, 1992).

Castile Mountain

Castile Mountain is a prominent conical hill that lies between McCann and Pleasant Valley Creeks in the southeastern part of the quadrangle. It is underlain by a coarse, possible pyroclastic fall breccia (Tpx) composed of altered pyroxene dacite probably derived from the interpreted vent to the west.

Rocks are widely bleached, and the groundmass is partly replaced by a mixture of fine-grained quartz and possible adularia. A recent excavation on the east side of the summit exposes north-striking, near vertical fractures coated by fine-grained drusy quartz and adularia. The adularia yielded a $^{40}Ar/^{39}Ar$ age of 39.14±0.13 Ma, which is the youngest age of the six adularia samples dated from the Tuscarora district.

The area has been explored by Cruson and Panze, Shell, FMC, and Chevron. Eight widely spaced rock samples from the summit area and the spur on the northeast side had ≥340 ppb Au (Struhsacker, 1992). Shell and Chevron drilled 10 widely spaced RC and conventional rotary holes. One hole on the northeast side of the summit intersected a 6-m zone that contained 352 ppb Au (Struhsacker, 1992). Much of the mountain is covered by a ≥100 ppm As soil anomaly.

Battle Mountain

Battle Mountain lies just north of McCann Creek near the eastern edge of the quadrangle. It is composed of very altered, flow-layered, sparsely porphyritic, biotite-plagioclase dacite that is probably part of the Pleasant Valley complex (Tpb). The rock is pervasively bleached, moderately silicified, and probably adularized. Feldspars are turbid and commonly partly leached with open space lined by fine drusy quartz. Biotite is either replaced by sericite or altered beyond recognition. Locally, as much as 1% disseminated limonite after pyrite is present. Near vertical north-northwest fractures near the summit are coated by drusy quartz and adularia.

A 90-m-long, southwest-trending adit on the lower east flank of Battle Mountain crosses several north-striking, high-angle faults filled with limonitic gouge. Local clay-rich punky zones probably reflect supergene acid attack from the oxidation of pyrite. An 18-m channel sample in the adit, obtained by exploration personnel of Alma-American, carried 0.04 ounces per ton (opt) Au (Struhsacker, 1992). Nolan (1936) reported assays of 0.06 opt Au and 1–2 opt Ag from a 90 x 150-m area on the southern part of Battle Mountain, labeled Beard Hill on his Plate 1.

Modoc Hill–Modoc West

Modoc Hill is approximately 1.2 km northeast of Battle Mountain and continues eastward into the Tuscarora Quadrangle. Several adits and shafts, some still accessible, are on the south and east sides. Production is unknown. The hill is underlain by variably bedded tuffs and tuffaceous sedimentary rocks (Tps) of the Pleasant Valley volcanic complex. These rocks generally dip 30–50° southeast and are cut by early dacite (Tmd) of the Mount Neva intrusive episode and by a north-striking, west-dipping dike of porphyritic dacite (Tmdp).

Modoc Hill is the northern end of a 1.6-km-long zone of discontinuous north-northeast and north-northwest, west-dipping, Au-bearing quartz-pyrite-adularia-calcite veins. Intervening wall rock is strongly silicified to weakly or

moderately bleached. A provisional vein paragenesis is: (1) early cockscomb vein quartz occurs as clasts in (2) sulfidic sugary quartz that is in places cut by (3) chalcedonic to drusy quartz veins. These late quartz veins form local stockworks or breccias with clasts of sulfidic sugary quartz. (4) Vug-filling bladed calcite (typically replaced by quartz) and sulfide-poor drusy quartz is last. The relative timing of adularia is unclear as it coats fractures outboard of the main vein zones. Adularia in the main part of the Tuscarora district is commonly coated with minor pyrite. Adularia from the northernmost part of this vein zone yielded a $^{40}Ar/^{39}Ar$ age of 39.30±0.14 Ma.

Modoc West lies to the southwest of Modoc Hill in the drainage between Battle Mountain and Modoc Hill and is the site of a small, shallow gold resource discovered in 1988–89. Exploration drilling delineated a resource of 280,000 tons at a grade of 0.05 opt Au distributed over 200 m of strike (Struhsacker, 1992). Silver grades are typically < 0.5 opt. Ore is localized in the hanging wall of a north-northeast-striking, west-dipping quartz-pyrite-adularia vein zone. Wall rocks consist of variably bleached and silicified reworked pumice-lithic lapilli tuff (Tps) of the Pleasant Valley sequence. This area is also the westernmost occurrence of historic eluvial placer workings in the Tuscarora district.

Berry Basin Mercury Workings

Minor workings, with probably little or no production, lie in the south-central part of the quadrangle in Berry Basin about 1.5 km northwest of Castile Mountain. The main host rock is a porphyritic biotite-bearing pyroxene-plagioclase dacite flow (Tpb) of the Pleasant Valley volcanic complex.

The principal working consists of a 9-m-wide excavation exposing variably bleached and limonite-stained dacite. Biotite is only weakly altered. Most of the alteration is centered along west- to northwest-striking fractures and shears that dip steeply (65–70°) south. The most impressive structure is a 1-m-thick jarosite-cemented breccia with local fracture or clast coatings of cinnabar. Clasts in breccia appear different than host biotite-bearing dacite as they are less porphyritic and may include fragmental rhyolite that contains scattered lithic fragments.

Mineralization in Paleozoic Rocks

Two types of deposits are present in the fault-bounded block of Paleozoic sedimentary rocks in the western part of the quadrangle. Quartz-barite veins occur along northeast-striking faults in the ridge between the headwaters of Lewis and Berry Creeks. Struhsacker (1992) reported that one vein lies in the footwall of a 65-85° northwest-dipping, finely porphyritic rhyolite dike (Tmrf) that cuts the Paleozoic rocks. The dike is bleached and mildly argillized, and the vein contains as much as 2 ppm Au and 200 ppm Ag along with high As and Sb (Struhsacker, 1992). Echo Bay drilled 11 RC holes in the late 1980s, and Western States drilled two 1,500-foot (457-m) vertical RC holes presumably to test the same zone in 1996. Results of these drilling programs are not available. The vein mineralogy (quartz and barite) and geochemical signature (high Ag/Au, As, and Sb) are similar to characteristics of volcanic-hosted veins of the Divide Mine, which lies just north of the northwestern corner of the Mount Blitzen Quadrangle.

Gossany siliceous breccias are developed locally along gently northwest-dipping thrust faults, including the major thrust that separates quartzite-bearing from quartzite-free rocks. In the NE1/4 sec. 32 and NW1/4 sec. 33, T 40 N, R 50 E, this zone appears to have been prospected for turquoise. Previous sampling of these zones by mining companies indicates that they are enriched in base metals but not in precious metals.

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REFERENCES

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

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

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

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

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

Cas, R.A.F., and Wright, J.V., 1987, Volcanic successions: modern and ancient: Allen and Unwin, London, 528 p.

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

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

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

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

Cruson, M.G., and Limbach, F.W., 1985, Progress report, Cow Creek prospect, Elko County, Nevada: Nevada Bureau of Mines and Geology Information Office file, File 75, Item 11, 21 p.

Daly, W.E., Doe, T.C., and Loranger, R.J., 1991, Geology of the northern Independence Mountains, Elko County, Nevada, *in* Raines, G.L., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., eds., Geology and ore deposits of the Great Basin: Reno, Nevada, Geological Society of Nevada, p. 583-602.

Elison, M.W., Speed, R.C., and Kistler, R.W., 1990, Geologic and isotopic constraints on the crustal structure of the northern Great Basin: Geological Society of America Bulletin, v. 102, p. 1077-1092.

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

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

Farmer, G.L., 1988, Isotope geochemistry of Mesozoic and Tertiary igneous rocks in the the western United States and implications for the structure and composition of the deep continental lithosphere, *in* Ernst, W.G., ed., Metamorphism and crustal evolution in the western United States, Rubey Volume 7: Prentice-Hall, Englewood Cliffs, New Jersey, p. 87-109.

Gardner, D.H., 1968, Structure and stratigraphy of the northern part of the Snake Mountains, Elko County, Nevada [Ph.D. thesis]: University of Oregon, Eugene, 264 p.

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

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

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

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

Ketner, K.B., 1984, Recent studies indicate that major structures in northeastern Nevada and the Golconda thrust in north-central Nevada are of Jurassic or Cretaceous age: Geology, v. 12, p. 483-486.

Ketner, K.B., and Smith, J.F., Jr., 1982, Mid-Paleozoic age of the Roberts thrust unsettled by new data from northern Nevada: Geology, v. 10, p. 298-303.

LaCroix, A., 1904, La Montagne Pelee et ses eruptions: Masson et Cie, Paris, 662 p.

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

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

Lipman, P.W., 1984, The roots of ash flow calderas in western North America: windows into the tops of granitic batholiths: Journal of Geophysical Research, v. 89, p. 8801-8841.

McKee, E.H., and Coats, R.R., 1975, K-Ar age of ore deposition, Tuscarora mining district, Elko County, Nevada: Isochron/West, no. 13, p. 11-12.

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

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

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

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

Miller, E.M., Miller, M.M., Stevens, C.H., Wright, J.E., and Madrid, R.J., 1992, Late Paleozoic paleogeographic and tectonic evolution of the western U.S. Cordillera, *in* Burchfiel, B.C., Lipman, P.W., and Zoback, M.L., eds., The Cordilleran Orogen: Conterminous U.S.: The Geology of North America, Geological Society of America, Boulder, Colorado, v. G-3, p. 57-106.

Nolan, T.B., 1936, The Tuscarora mining district, Elko County, Nevada: University of Nevada Bulletin, v. 30, 36 p.

Oldow, J. S., 1984, Spatial variability in the structure of the Roberts Mountains allochthon, western Nevada: Geological Society of America Bulletin, v. 95, p. 174-185.

Phinisey, J.D., Hofstra, A.H., Snee,. L.W., Roberts, T.T., Dahl, A.R., and Loranger, R.J., 1996, Evidence for multiple episodes of igneous and hydrothermal activity and constraints on the timing of gold mineralization, Jerritt Canyon district, Elko County, Nevada, *in* Coyner, A.R., and Fahey, P.L., eds., Geology and Ore Deposits of the American Cordillera: Geological Society of Nevada Symposium Proceedings, Reno/Sparks, Nevada, April 1995, p. 15-39.

Poole, F.G., Stewart, J.H., Palmer, A.R., Sandberg, C.A., Madrid, R.J., Ross, R.J., Jr., Hintze, L.F., Miller, M.M., and Wrucke, C.T., 1992, Latest Precambrian to latest Devonian time; Development of a continental margin, *in* Burchfiel, B.C., Lipman, P.W., and Zoback, M.L., eds., The Cordilleran Orogen: Conterminous U.S.: The Geology of North America, Geological Society of America, Boulder, Colorado, v. G-3, p. 9-56.

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

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

Sibbett, B.S., 1982, Geology of the Tuscarora geothermal prospect, Elko County, Nevada: Geological Society of America Bulletin, v. 93, p. 1264-1272.

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

Smith, M., and Gehrels, G., 1994, Detrital zircon geochronology and the provenance of the Harmony and Valmy Formations, Roberts Mountains allochthon, Nevada: Geological Society of America Bulletin, v. 106, p. 968-979.

Smith, R.L., and Bailey, R.A., 1968, Resurgent cauldrons: Geological Society of America Memoir 116, p. 613-662.

Struhsacker, E.M., 1992, Tuscarora project, Elko County, Nevada: Prospect Summaries: Unpublished Consulting Report for Corona Gold, 21 p. plus figures and plates.

Thorman, C.H., Brooks, W.E., Snee, L.W., Hofstra, A.H., Christensen, O.D., and Wilton, D.T., 1995, Eocene-Oligocene model for Carlin-type deposits in northern Nevada: Geological Society of Nevada Symposium, April 1995, Reno/Sparks, Nevada, p. 75