Text to accompany Nevada Bureau of Mines and Geology Map 165

GEOLOGY OF THE VIRGINIA CITY QUADRANGLE

WASHOE, STOREY, AND LYON COUNTIES, AND CARSON CITY, NEVADA

by

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INTRODUCTION

The Virginia City Quadrangle is an area of nearly 150 km^2 centered about 25 km southeast of Reno (fig. 1). It encompasses a significant part of the southern Virginia Range (fig. 2), and includes the historic towns of Virginia City, Silver City, and Gold Hill (fig. 3), as well as suburban developments in Steamboat Valley, along the Geiger Grade Highway (State Route 342), and areas northeast of Geiger Summit.

Virginia City is the best known of Nevada's historic mining towns. Epithermal deposits of the Comstock district, which includes Virginia City, were major sources of precious metals during the late 19th and early 20th centuries, producing 192 million ounces of silver and 8.25 million ounces of gold. Most of this production was from bonanza deposits along the famous Comstock Lode during the period 1860-1890 (Bonham and Papke, 1969).

Because of its economic impact, the Virginia City area has been the subject of intense geologic study beginning with the work of Richthofen (1865), King (1870), and Becker (1882) and continuing to the present. Despite the large amount of previous work, including 49 K-Ar and fission-track ages (Vikre et al., 1988; Ashley et al., 1979; Whitebread, 1976; Silberman and McKee, 1972; Bonham and Papke, 1969), the age and extent of many of the area's rock units were unclear, and age relationships between magmatism and mineralization were imprecisely known. Our new geologic mapping and $^{40}Ar/^{39}Ar$ dating define several distinct Miocene magmatic and hydrothermal events in the area. On the basis of this new information, the volcanic stratigraphy has been revised, and the chronologic relationship between magmatism and mineralization in the area is better constrained.

Major rock units in the quadrangle are (1) Mesozoic metaigneous and metasedimentary rocks that have been intruded

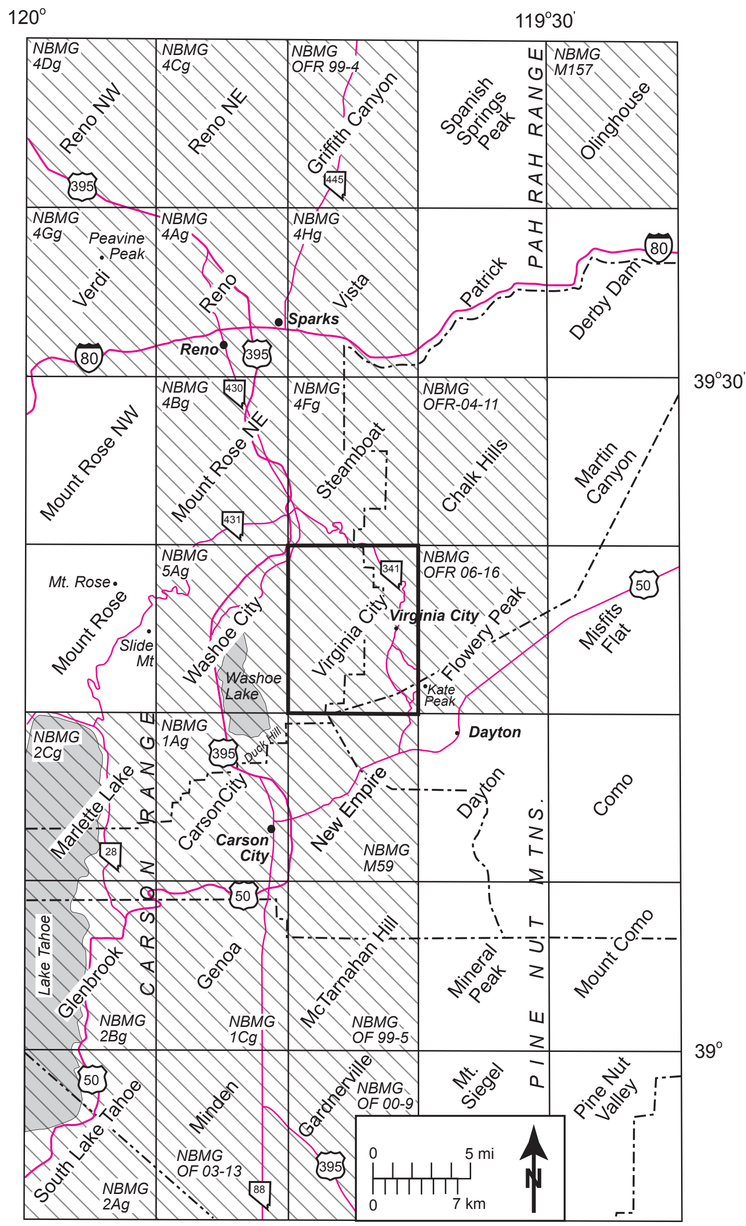

Figure 1. Regional map showing location of the Virginia City Quadrangle and nearby published 1:24,000-scale geologic maps (hachured).

by Cretaceous granitic rocks, (2) Oligocene to lower Miocene (27–23 Ma) rhyolitic ash-flow tuffs erupted from distant sources to the east, and (3) an extensive, middle Miocene package of intermediate volcanic and intrusive rocks, which are the major hosts for the famous Comstock Lode and related mineralization. The Miocene rocks had been divided into several formal stratigraphic units (Gianella, 1936; Calkins and Thayer, 1945; Thompson, 1956), but our new mapping and $^{40}Ar/^{39}Ar$ dating demonstrate the need for major revision of the stratigraphy. This report documents the field relations and ages and describes our revised stratigraphy.

Previous geologic mapping in the area includes a 1:62,500 map of the Virginia City 15-minute Quadrangle (Thompson, 1956), as well as earlier studies that contributed to that map (Gianella, 1936; Calkins and Thayer, 1945). Hudson (2003) presented simplified remapping of the Comstock district. A preliminary version of the geologic map of the quadrangle was released as an open-file report (Hudson et al., 2003); this map supersedes that report.

Geologic field mapping of most of the quadrangle was performed between 2000 and 2003. However, about 30% of the map, mostly in the Virginia City, Silver City, and American Flat areas, is based on more detailed field mapping by the first author performed between 1985 and 2000. The geologic mapping was performed using aerial photographs (mainly color aerial photographs at a scale of approximately 1:19,000 from Spencer B. Gross, Inc. of Reno), and topographic maps. Parts of the map, mostly in the vicinity of the Comstock Lode, were mapped by the first author at 1:6,000 and 1:12,000 on enlarged topographic base maps.

Additional subsurface data came from boreholes by several exploration companies and from the Becker Collection, a rock collection at the National Museum of Natural History, Smithsonian Institution, assembled as part of a historic study (Becker, 1882).

Mineral contents (tables 1, 2, and 3) reported for igneous rocks were estimated visually from thin sections and rock slabs. Igneous rock names are based on the IUGS classification (Le Maitre et al., 2002).

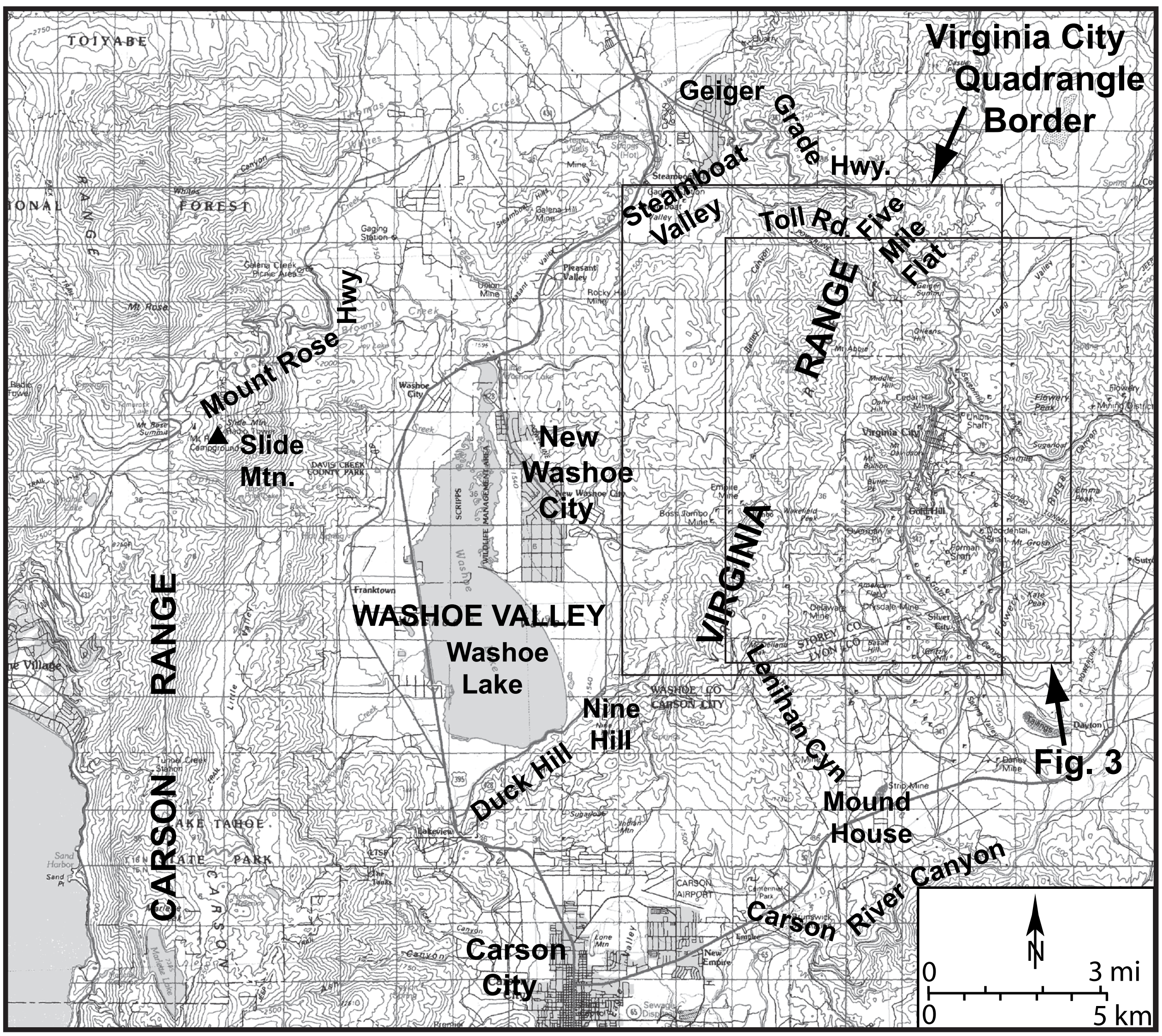

Figure 2. Map showing locations discussed in the text and unit descriptions that are in the area of the Virginia City Quadrangle.

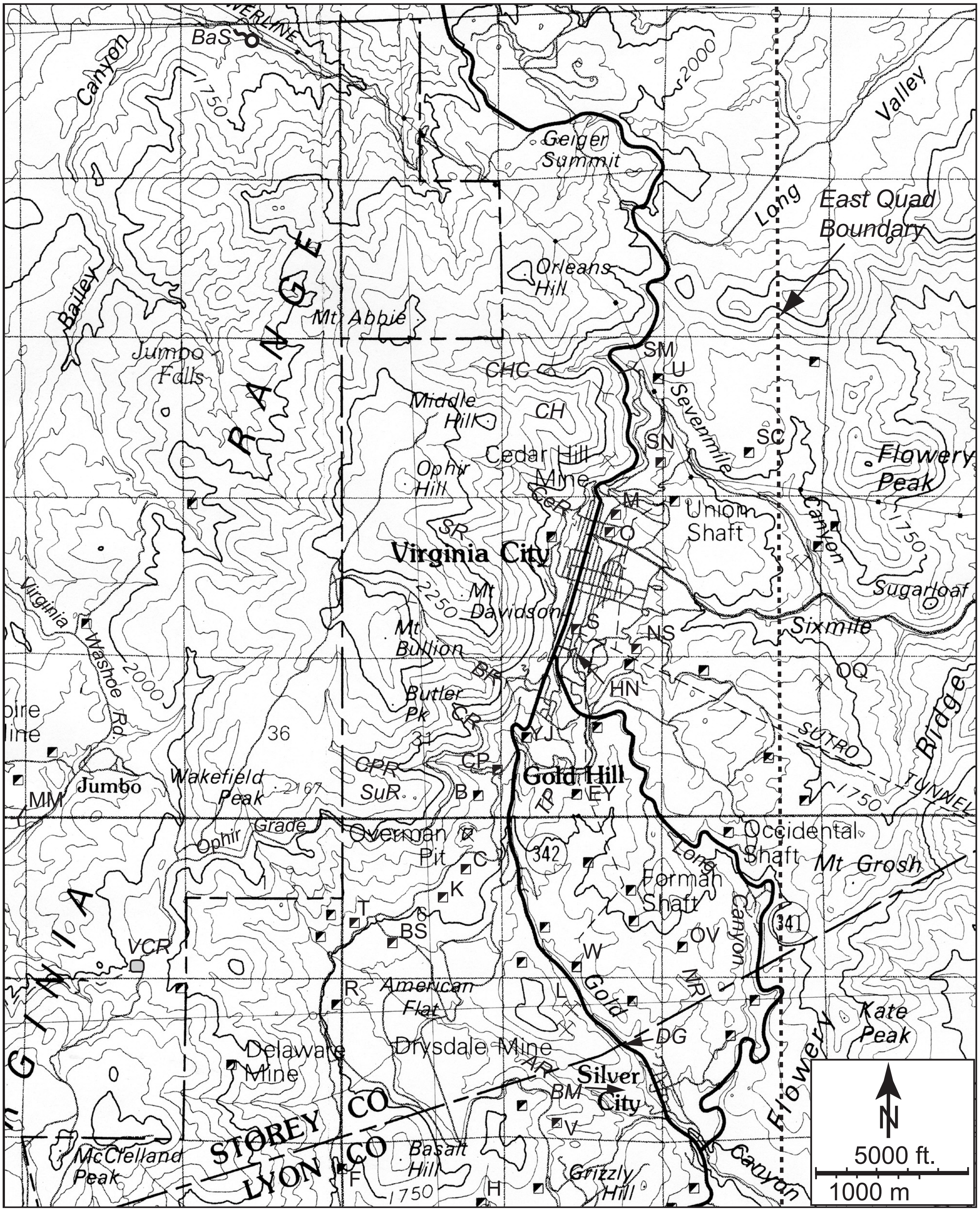

Figure 3. Locations of mines and geographic features used in the unit descriptions and text that are in and just east of the Virginia City Quadrangle.

Mine locations: BS, Baltimore Shaft; B, Belcher Mine; C, Caledonia Mine; CP, Crown Point Mine; EY, East Yellow Jacket Shaft; F, Florida Shaft; HN, Hale and Norcross Tunnel; H, Haywood Mine; K, Knickerbocker Shaft; L, Lucerne Cut; MM, Mahoney Mine; M, Mexican Mine; NS, New Savage Mine; OQ, Occidental Quarry; O, Ophir Mine; OV, Overland Mine; R, Rock Island Mine; S, Savage Shaft; SC, Scorpion Shaft; SN, Sierra Nevada Mine; SM, Sutro Mine adit; T, Tyler Mine; U, Utah Shaft; V, Vulcano Mine; W, Woodville Shaft; YJ, Yellow Jacket Mine.

Geographic locations: AR, American Ravine; BaS, Bain Spring; BM, Basalt Mesa; BR, Bullion Ravine; CH, Cedar Hill; CHC, Cedar Hill Canyon; CeR, Cedar Ravine; CR, Confidence Ravine; CPR, Crown Point Ravine; DG, Devils Gate; NR, Negro Ravine; SR, Spanish Ravine; SuR, Suicide Rock; TP, Twin Peaks; VCR, Virginia City reservoir.

Table 1. Petrographic data for Miocene igneous units of the Virginia City Quadrangle.

		PHENOCRYSTS											Xen	Matrix	Void	Plag	
UNIT/FORMATION	**Map Symbol**	**Plag %**	**Cpx %**	**Opx %**	**Hbd %**	**Biot %**	**Op %**	**Ol %**	**Or%**	**Qtz%**	**Ap %**	**Other**	**%**	**%**	**%**	**An**	**Notes**
McClellan Peak Basalt	Qmpb	5	10			<1	<1	15			tr			70	0-5	65	matrix contains glass
Big boulder debris flow	Tbdf dark clasts	25	5-15	3-5	0-1		1-4							35-70	0-20	45-67	matrix mostly brown gls
Occidental dacite	Tod	20-25			5-10	3-4	<1			1-2	tr			60-65			matrix pilotaxitic to granular
Andesite porphyry dikes	Tia	5-20	2-12		0-10		1-4									n.d.	
Flowery Peak magmatic suite																	
	Tfba	21			7	2	1	tr		tr				59		47	
	Tfha																
	Tfhax	16	.7	1.5	7	tr	.8						4	70		65	
	Tfbha	21			7	2	1							65-70		47	
	Tfbi	25	tr		2-8	<1-5	1-3						5	60-65			
	Tfp breccia clasts	20-30	0-6	0-4	3-20	0-1	0-3							45-60	0-25	43-47	
	Tfp flows	20-30?	0-4	rare	5-15	0-10	1-5						0-5	50-80		35-60	
	Tbhap	20-30?	0-4	rare	5-15	tr-10	1-5			0-2	tr	zr		50-80		40-60	
Intrusions of Flowery Peak or	Thap	30-65	0-1		10-15		1-2							?		andesine	
Virginia City magmatic suites	Tri	<15				1			<15	0-5						n.d.	
Virginia City magmatic suite																	
Intrusions																	
Davidson Diorite	Tdd	60-70	10-15	2-3	0-3	0-1	2-4		5-10	5-12	tr	zr, sph		0		35-45	subequigranular
Davidson porphyry	Tdap	25-30	10-12	1-3		0-tr	2-4				tr			10-70		andesine	
	Thpap	20-40	3		10-20		2-4									andesine	
	Tphap	15-30	1-4		1-4		2-4									n.d.	
	Thp	15-25	0.5		20-40		2									50	
Rhyolitic volcanic rocks																	
Biotite ash-flow tuff	Tabt	5				3			2	tr			0-40				2-20% pumice
Biotite rhyolite	Tbr	5				4							<1				
Virginia City volcanic rocks																	
Steamboat Valley seq.	Tvsu	20-30	3-10	2-5	0-7	0-1	1-3	0-2			tr					44-53	
	Tvsl lahar clast	20-35	2-8	4-10	tr-1		2-4				0-tr		2-5	45-60	0-5	62-70	
	Tvsl flows	20-35	3-7	1-5	tr-2		2-5				0-tr		0-5	45-65	0-15	55-67	
	Tvsv	20-40	7-9	1-7	0-tr		2-3				0-tr			40-50	10	68-78	
Kate Peak Formation	Tvka flows	25-30	0-5	tr-2	2-7		3-4						0-6	60-65		44-56	
	Tvka px and flows	25-60	1-15	0-4	0-15	0-tr	3-4	0-1						60-75		40-50	
	Tvkb	30-40	0-5	rare?	2-5	1-3	3-4									35-50	
Bailey Canyon seq.	Tvbfl lahar clasts	18-40	5-15	4-5	0-7	0-tr	1-2							25-70	10-25	55-70	
	Tvbfl px and flow	28	3	7			2							60		65	
	Tvbh flows	20-38	1-4	0-2	5-15	0-2	2-4				0-tr		0-tr	48-70	0-15	44-48	
Alta Formation	Tva, undiv flows	20-50	2-10	0-2	0-10		<1-5				0-tr		0-4	40-70		45-65	commonly seriate
	Tva, px andesite	30-50	5-15	0-3	0-1		2-3				0-tr			50-60		47-67	
	Tva with biot	30-50	5-10	0-5		<1	2-4							40-60		andesine	
	Tvah	20-30	3		5-10		2							55-70		43-66	seriate
Phenocryst-poor andesite	Tap flow	4-10	0-tr		1-3	0-tr	tr-1			0-tr	0-tr		0-6	90-95		38-42	
American Ravine Andesite	Tara	2-5			1-20		1-3							n.d.			
Silver City magmatic suite																	
	Tsba	30-35	3-5		5	2-3	3-4							45-50		50-60	
	Tsa hbd-rich bx	20-25			20-25		2							50-55		n.d	seriate
	Tsa 2-px flows	32-38	5-7.5	1-2.5	0-tr		2-3							50-60		60-67	
	Tsa hbd flows	15-45	2-15		<2-7		2-7							60-80		35-55	
	Tshp	20-30			10-15	0-tr	1-3							55-65		43	
	Tsh flows	2-5			10-20		tr-0.5							75-88		55-77	

Table 2. Petrographic data for Tertiary ash-flow tuffs of the Virginia City Quadrangle.

		Map				PHENOCRYSTS								Lithics	Pumice
Unit/Formation	**Member**	**Symbol**	**Plag %**	**Cpx %**	**Opx %**	**Hbd %**	**Biot %**	**Op %**	**Anr %**	**San%**	**Qtz%**	**Ap %**	**Other**	**%**	**%**
unnamed lithic tuff		Tut	5				2			3	1			15-30	5
Santiago Canyon Tuff		Tst	5-20			3	5			5-10	10-15		sph		10-20
Eureka Canyon Tuff		Tet	tr-3				<1			4-5	4				5-10
Nine Hill Tuff		Tnt	?						3-4	2-3	1				10-40
Lenihan Canyon Tuff		Tlt	12-20			1	2-5			3-5	3-5			<1	?
Mickey Pass Tuff	Guild Mine	Tgm	0-10				1-3	<1		3-10	3-15			tr	10

Table 3. Petrographic data for Mesozoic igneous units of the Virginia City Quadrangle.

Map Symbol	Plag %	Ksp%	Qtz%	Px %	Hbd %	Biot %	Op %	Ap %	Sph%	Matrix %	Plag An	notes
TKp	70-75				20-25		3	tr				seriate texture
Kqd	65-70	4	15-20		4	6	1	tr	tr		20-34	
Kgd	45-55	15-25	20-30		tr-4	3-6	1	tr	tr-0.5		25	
Kqm	>60	>20	10		2-3	2-3	1		<1			
Kfg	30				10		<2?	tr?	<1?	55		matrix qtz + Ksp, minor biot
Kgp	60			?	15		.5	tr		25		matrix 30% qtz & 60% Ksp
Kg	40	35	20			5		0.5	0.5		15-30	
Jm	65			35			2					plag & px 1-3 mm
Jm porph	40			60			2					px phenos to 60 mm

$^{40}Ar/^{39}Ar$ DATING

Table 4 shows 31 new $^{40}Ar/^{39}Ar$ ages of igneous rocks obtained on hornblende, plagioclase, biotite, or sanidine phenocrysts, and 16 new alteration ages obtained on adularia from veins, alunite from silica ledges, or on sericite (fine-grained muscovite). Phenocrysts and alteration minerals were concentrated to >99 percent purity using magnetic and density separation, leaching with dilute HF (feldspars only), and hand picking. Samples were irradiated at Texas A&M University and analyzed at the New Mexico Geochronology Research Laboratory (methodology in McIntosh et al., 2003). Fish Canyon sanidine with an age of 28.02 Ma (Renne et al., 1998) was used as a neutron fluence monitor. All samples except sanidine and alunite were heated incrementally in a low-blank, resistance furnace, generally in ten to twelve 8-minute increments between about 700°C and 1650°C. Individual sanidine grains were fused with a CO_2 laser. Alunite was heated incrementally with the CO_2 laser using a wide beam and progressively increasing the power. Calculated ages and $\pm 2\sigma$ uncertainties are listed in table 4.

All but five of the new $^{40}Ar/^{39}Ar$ ages were from spectra that show clear plateaus, defined as at least three contiguous steps that agree within analytical uncertainty and comprise more than 50% of the ^{39}Ar released. Isochron ages agree closely with plateau ages for these samples. Five samples gave disturbed spectra that did not plateau. Four of these gave good isochron ages that indicated small amounts of excess ^{40}Ar. The spectrum for sericite from sample VCH-1055 was slightly disturbed. A weighted mean of 11 of 15 steps comprising 91.7% of ^{39}Ar gave an age of 18.11±0.54 Ma. A somewhat imprecise isochron for this sample is indistinguishable at 18.5±0.4 Ma. Although the analytical data for this sample are of only moderate quality, the data do demonstrate that an episode of alteration occurred contemporaneously with the earliest intermediate volcanic episode (Silver City magmatic suite).

Adularia ages are particularly precise. Plateau and isochron ages are nearly identical and define three distinct times of low-sulfidation mineralization. In contrast, alunite ages were more variable, apparently reflecting varied K contents. All samples consist of mixes of quartz, natroalunite, and minamiite [$(Na,Ca,K)_2Al_6(SO_4)_4(OH)_{12}$] and may have had some mineral contaminants such as illite. Samples H02-142 and H02-144 with relatively high K gave good plateaus and indistinguishable isochrons. Other samples, largely natroalunite with lower K contents, gave more irregular spectra with relatively large uncertainties. Isochron and weighted mean ages of 15.50±0.40 and 14.72±0.64 Ma of alunite sample VC-14C agree within analytical uncertainty but can be interpreted differently (see the section on alteration below).

Our new dating largely supplants the previous K/Ar and fission-track dating of the Tertiary rocks and mineralization, so the discussion here mostly does not repeat them. All ages that we do discuss have been calculated using the new decay constants and isotopic abundances given by the International Union of Geological Sciences Subcommission on Geochronology (Steiger and Jager, 1977); if the age is recalculated from originally reported data, this is noted by the words “new constants.”

Table 4. $^{40}Ar/^{39}Ar$ ages of igneous rocks from the Virginia City Quadrangle. Locations are in North American Datum, 1927 (NAD27). *Sample not in Virginia City Quadrangle.

						Map	Latitude		Longitude	
Sample No.	**Method**	**Age (Ma)**	**± 2σ**	**Material**	**Rock Unit**	**Symbol**	**Deg.**	**Min.**	**Deg.**	**Min.**
Igneous rock ages										
C02-21*	plateau	12.91	0.18	hornblende	Occidental dacite	Tod	39	18.02	119	37.21
H02-139	plateau	14.20	0.43	plagioclase	Flowery Peak magmatic suite	Tfba	39	22.40	119	37.71
H02-138	isochron	14.51	0.12	hornblende	Flowery Peak magmatic suite	Tfhax	39	22.39	119	37.78
H02-136	plateau	14.58	0.12	hornblende	Flowery Peak magmatic suite	Tfbha	39	21.41	119	39.67
H02-140	plateau	14.82	0.17	hornblende	Flowery Peak intrusive	Tfbi	39	19.85	119	40.10
COM-962	plateau	14.39	0.20	hornblende	Flowery Peak magmatic suite	Tfp	39	20.06	119	38.10
H01-2	plateau	14.75	0.22	hornblende	Flowery Peak magmatic suite	Tfp	39	19.25	119	38.54
C00-126A	plateau	14.89	0.20	hornblende	Flowery Peak magmatic suite	Tfp	39	21.65	119	42.86
C02-14*	plateau	14.53	0.11	hornblende	Flowery Peak intrusive	Tbhap	39	18.36	119	36.32
H01-1	plateau	14.72	0.14	biotite	Flowery Peak? intrusive	Tbhap	39	19.24	119	38.52
COM-960C	plateau	14.53	0.42	hornblende	Flowery Peak intrusive	Thap	39	18.74	119	39.33
COM-966	plateau	15.32	0.12	biotite	Davidson Diorite	Tdd	39	18.30	119	39.92
C01-19	plateau	15.35	0.22	plagioclase	Virginia City magmatic suite	Tvsu	39	21.24	119	44.34
COM-963	plateau	15.43	0.26	hornblende	Virginia City magmatic suite	Tvka	39	15.95	119	37.52
VCH-1037	plateau	15.79	0.20	hornblende	Virginia City magmatic suite	Tvbh	39	19.05	119	44.70
COM 910	plateau	15.23	0.20	hornblende	Virginia City magmatic suite	Tva	39	17.10	119	39.49
C05-226	isochron	15.49	0.41	hornblende	Virginia City magmatic suite	Tva	39	19.93	119	39.07
C05-219	plateau	15.55	0.18	hornblende	Virginia City magmatic suite	Tva	39	20.13	119	39.83
H01-5	plateau	15.78	0.32	hornblende	Virginia City magmatic suite	Tva	39	17.36	119	39.14
VCL-15	isochron	15.80	0.40	plagioclase	Virginia City magmatic suite	Tva	39	16.88	119	39.82
C01-20	isochron	15.82	0.13	hornblende	Virginia City magmatic suite	Tvah	39	18.20	119	42.56
H01-6	plateau	17.69	0.22	hornblende	Silver City magmatic suite	Tsa	39	16.37	119	38.88
C00-51	isochron	17.87	0.30	plagioclase	Silver City magmatic suite	Tsa	39	16.72	119	41.96
H01-8	plateau	17.94	0.32	hornblende	Silver City magmatic suite	Tsa	39	15.32	119	38.86
C00-112	plateau	18.25	0.36	hornblende	Silver City magmatic suite	Tsa	39	16.64	119	41.59
VCH-1057	isochron	18.00	0.16	hornblende	Silver City magmatic suite	Tsba	39	16.92	119	41.68
C00-84	plateau	18.02	0.24	hornblende	Silver City magmatic suite	Tshp	39	16.83	119	42.61
C00-79	plateau	17.43	0.32	hornblende	Silver City magmatic suite	Tsh	39	16.42	119	43.87
C00-47	plateau	18.32	0.32	hornblende	Silver City magmatic suite	Tsh	39	16.68	119	42.80
VCL-29	single xl	26.77	0.06	sanidine	Lenihan Canyon Tuff	Tlt	39	15.04	119	42.75
VCL-27	single xl	27.12	0.10	sanidine	Guild Mine Mbr., Mickey Pass Tuff	Tgm	39	15.11	119	42.60
Alteration and vein mineral ages										
C02-15*	plateau	13.33	0.04	adularia	quartz-adularia alteration		39	19.22	119	35.62
CN85-25*	plateau	13.36	0.05	adularia	quartz-adularia vein		39	19.44	119	35.25
H00-51	plateau	13.39	0.04	adularia	adularia coated fractures		39	17.22	119	37.88
C02-20	plateau	13.40	0.04	adularia	adularia coated fractures		39	18.00	119	37.54
C02-19*	plateau	13.53	0.03	adularia	adularia coated fractures		39	18.66	119	37.38
H00-61	plateau	14.06	0.04	adularia	quartz-adularia vein		39	16.24	119	38.90
H00-62	plateau	14.08	0.05	adularia	quartz-adularia vein		39	18.88	119	38.97
H01-4	plateau	14.10	0.06	adularia	quartz-adularia vein		39	17.72	119	39.47
NS-402	plateau	14.17	0.06	adularia	quartz-adularia vein		39	18.16	119	39.18
C02-72	plateau	15.49	0.04	adularia	quartz-adularia coated fractures		39	17.42	119	43.12
VH02-1	plateau	13.49	0.70	alunite	quartz-alunite alteration		39	22.38	119	39.90
H02-144	plateau	15.26	0.14	alunite	quartz-alunite alteration		39	17.66	119	38.84
C02-69	plateau	15.32	0.37	alunite	quartz-alunite-pyrite alteration		39	18.00	119	43.00
H02-142	plateau	15.40	0.29	alunite	quartz-alunite alteration		39	18.34	119	40.66
VC-14C	isochron	15.50	0.40	alunite	quartz-alunite-pyrite alteration		39	19.14	119	38.13
"	weighted mean	14.72	0.64	"	"		"	"	"	"
VCH-1055	wtd. mean	18.11	0.54	sericite	sericite after biotite		39	17.58	119	43.57

ROCK ANALYSES

Chemical analyses of most rock samples (appendix 1) were performed by the Nevada Bureau of Mines and Geology (NBMG), and Nuclear Activation Services Inc. (NASI) of Ann Arbor, Michigan. Major elements were determined by X-ray fluorescence (XRF). Ferric and ferrous iron were determined by titration by D.M. Hudson. Trace elements were determined at NBMG by XRF, and at NASI by a combination of instrumental neutron activation (INAA), XRF, and directly coupled plasma emission (DCP). Eight samples were analyzed by Acme Laboratories, Vancouver, Canada, using inductively coupled plasma-emission spectroscopy (ICP-ES) for major oxides and inductively coupled plasma-mass spectroscopy (ICP-MS) for trace elements, and six were analyzed by the Washington State University Geochemical Laboratory using XRF (major oxides) and ICP-MS (trace elements). In addition, three samples were analyzed by the USGS using XRF (major oxides) and six-step emission spectroscopy (trace elements). Appendix 2 gives locations for chemically analyzed samples for which locations are not given in table 4.

STRATIGRAPHY

MESOZOIC ROCKS

METASEDIMENTARY AND METAIGNEOUS ROCKS

The oldest rocks in the map area are metasedimentary and metaigneous units that appear to be part of a large pendant-like body surrounded by Cretaceous granitic plutons. On the basis of lithology and stratigraphic position, we correlate a unit of metasiltstone, metaconglomerate, and minor marble with the Triassic and Jurassic Gardnerville Formation; overlying sandstone is correlated with the Jurassic Preachers Formation.

The Gardnerville Formation, the oldest exposed unit, is mostly siltstone and very fine-grained sandstone (JŦgs), but contains other rock types including limey beds (JŦgm). The age of the Gardnerville Formation cannot be established in the Virginia City area. No fossils were located in this study, and the locally strong metamorphism would probably obscure most fossils. Elsewhere, the Gardnerville Formation is Late Triassic to Early Jurassic (Proffet and Dilles, 2008; Wyld and Wright, 1993; Stewart, 1997).

The Preachers Formation (Jp) is exposed in a small area near the south edge of the quadrangle. It is quartzite that unconformably overlies the Gardnerville Formation in southern Douglas County about 50 km south of the Virginia City Quadrangle (Noble, 1962; Hudson, 1983, and unpubl. data) where it is presumed to be Lower Jurassic (Noble, 1962). The Preachers Formation is considered equivalent to the quartzitic sandstone member of the Middle and (or) Early Jurassic Ludwig Mine Formation in the Yerington area about 50 km southeast of the Virginia City Quadrangle (Proffett and Dilles, 2008).

Metaigneous rocks consist of rhyolite porphyry dikes (Jrp) and mafic rocks (Jm). Dikes of Jrp cut the Gardnerville Formation and are probably Jurassic and predate the gabbro (Jm), because they contain fairly strong cleavage, like that in the enclosing Gardnerville Formation. Such cleavage is absent in the overlying gabbro.

We interpret the metagabbro and metabasalt unit (Jm) as an intrusive and flow complex. The protolith for most of Jm was apparently massive, shallow(?) mafic intrusive rock. Part of the gabbro intrusion may be a sill or lopolith. The age of Jm is uncertain; it apparently intrudes Jurassic rocks and is intruded by Late Cretaceous granitic rocks. We believe it is most likely Jurassic. Mafic volcanic rocks of the Middle Jurassic Tuttle Lake Formation and Humboldt mafic complex, 70 km to the west and 150 km to the northeast, respectively (Hanson and Hargrove, 1999; Johnson, 2000) may be equivalent to Jm.

CRETACEOUS PLUTONIC ROCKS

Cretaceous granitic rocks crop out in three of the map quadrants and are known from the subsurface in the fourth. Isotopic dating of the granitoid rocks in the region indicates that they are all Cretaceous. The most widespread granitoid units in the quadrangle, Kgd and Kqm, are probably gradational and have minimum ages of ~86-88 Ma. A K-Ar date on biotite of 76.6 Ma (recalculated, but no uncertainty or decay constants given) was reported for correlative rock in the Washoe City Quadrangle to the west by Marvin and Cole (1978), but they suggested that this is a minimum, and that a K-Ar age on biotite from a contact hornfels of 85.7 Ma (recalculated) is a more probable intrusive age. The best age estimate is a hornblende K-Ar age of 87.6±4.0 Ma from the Utah Mine dump in Virginia City; coexisting K-feldspar gave an obviously low age of 62.6±2.2 Ma (both ages recalculated from Vikre et al., 1988).

The Becker Collection includes Cretaceous (?) granitic rocks from the Sierra Nevada Mine that include hornblende biotite granite, hornblende biotite granodiorite, leucogranite, leucogranite pegmatite, and leucogranite aplite. The age of these rocks is assumed to be Cretaceous based upon similarity to granitic rocks of known Cretaceous age in the area.

MIOCENE-OLIGOCENE TUFFS AND SEDIMENTARY ROCKS

The Mesozoic basement of the Virginia City Quadrangle is locally overlain by a regionally extensive 27–23 Ma (Oligocene and earliest Miocene) silicic ash-flow tuff sequence, which was deposited in a paleovalley (Davis et al., 2000; Garside et al., 2005; Henry and Faulds, in prep.) cut into the basement near the southern edge of the quadrangle (fig. 4). Bingler (1977, 1978) described the stratigraphic order and nomenclature of some of the tuffs in the New Empire Quadrangle to the south and near the south border of the Virginia City Quadrangle, and Bingler et al. (1978) reported K-Ar ages for tuffs in the area. Proffett and Proffett (1976) reported on stratigraphy of Oligocene tuffs in the Yerington area about 50 km southeast of Virginia City. Fluvial gravels and sands present locally beneath the tuffs were mapped separately where possible, or their presence at the lower contact is indicated by a symbol if the units were too thin to show separately. These sedimentary units take a part of their unit designation letter symbol from the overlying tuff (e.g., Tsg below Ts), and some were correlated based on the oldest tuff clasts observed. Gravels that can be only tenuously connected to their overlying tuff have queried unit symbols on the map.

The oldest ash-flow tuff unit in the Virginia City Quadrangle is the Oligocene Guild Mine Member (Tgm) of the Mickey Pass

Tuff. It underlies the Lenihan Canyon Tuff on the south side of a tuff-filled Oligocene paleovalley on McClellan Peak. It also forms poor exposures west of American Flat where it is as much as 50 m thick and pinches to the north on an irregular surface developed on Mesozoic gabbro. In the Comstock District, the tuff is weakly hydrothermally altered. Based on our re-examination of the stratigraphy and petrography of the Mickey Pass Tuff near the type area at Yerington (Proffett and Proffett, 1976) and new $^{40}Ar/^{39}Ar$ age determinations, the Guild Mine Member there consists of a lower, quartz-poor ash-flow tuff (27.19±0.08 Ma, unit one of Proffett and Proffett, 1976) and a thicker, upper, quartz-rich tuff (27.12±0.06 Ma, units 2, 3, 4) (Garside et al., 2002). The upper Guild Mine tuff is present in the Virginia City Quadrangle and gave a $^{40}Ar/^{39}Ar$ age of 27.12±0.10 Ma (VCL-27, table 4). The lower Guild Mine tuff crops out at Duck Hill, several kilometers southwest of the quadrangle (fig. 2), where it has a $^{40}Ar/^{39}Ar$ age of 27.30±0.07 Ma (Henry and Faulds, in prep.). The lower tuff may be present in the Virginia City Quadrangle, but we did not map it separately.

The Lenihan Canyon Tuff (Tlt) disconformably overlies Tgm. Bingler (1978) defined its type area west of Lenihan Canyon at the south edge of the quadrangle. On and north of McClellan Peak, it is found on both sides of a paleovalley that was later largely filled with Santiago Canyon Tuff (Tst). To the southeast, it pinches out against an Oligocene erosional surface and fills a narrow paleocanyon now approximately occupied by

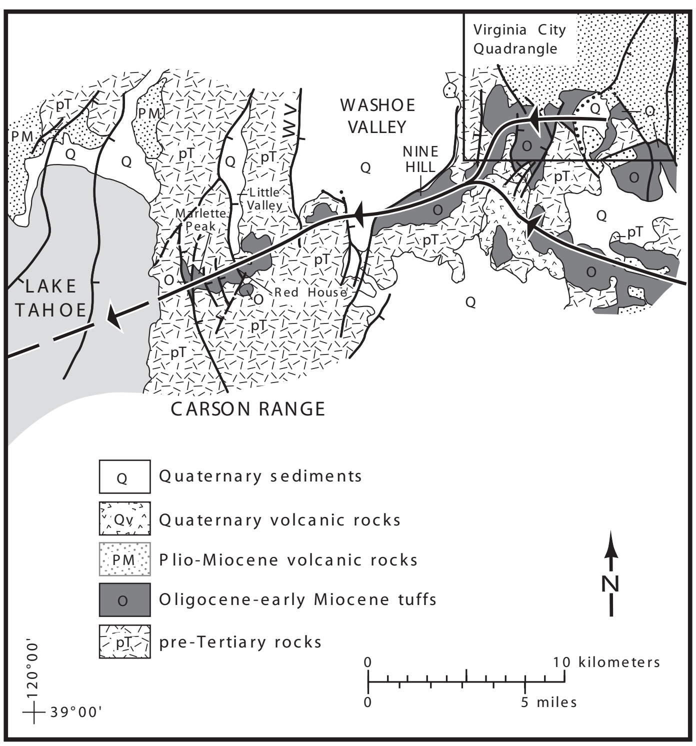

Figure 4. Proposed paleochannel locations and simplified geology in the Virginia City–Lake Tahoe area. Paleochannel centers shown by heavy lines with arrowheads pointing down stream.

American Ravine. A sample from the type area near the south edge of the quadrangle gave a $^{40}Ar/^{39}Ar$ age of 26.77±0.06 Ma (VCL-29, table 4).

As much as 40 m of the Nine Hill Tuff (Tnt) disconformably overlies the Lenihan Canyon Tuff west of American Flat. Pumice in Tnt is strongly compressed, with aspect ratios of 10:1 or more, and stretching, probably formed as the ash flow came to rest in a paleocanyon (fig. 2), locally defines a lineation that is subparallel to the strike of compaction foliation. In the southwest part of the quadrangle, the tuff is more than 200 m thick in a paleocanyon (see Garside et al., 2005) and contains pumice that is highly lineated and stretched in a north-northeast direction, parallel to the axis of the paleocanyon. West of Jumbo, the pre-Nine Hill erosional surface appears to have been of rather low relief. In American Ravine, the Nine Hill Tuff appears to have filled a deep paleocanyon that also contains the Lenihan Canyon Tuff. In a railroad cut southeast of American Flat, white, pumice-poor, weakly welded tuff about 5 meters thick comprises approximately the lower third of the unit. The Nine Hill Tuff pinches out against Mesozoic rocks on the northern edge of American Flat. A $^{40}Ar/^{39}Ar$ age on Nine Hill Tuff at Nine Hill about 2 km south of the quadrangle is 25.32±0.07 Ma (Henry and Faulds, in prep.).

A few scattered exposures of Eureka Canyon Tuff (Tet) disconformably overlie the Nine Hill Tuff or older rocks and underlie the Santiago Canyon Tuff. Eureka Canyon Tuff from the Carson City area yielded a $^{40}Ar/^{39}Ar$ age of 24.90±0.06 Ma on sanidine (Henry and Faulds, in prep.).

The youngest regionally identified ash-flow is the Santiago Canyon Tuff (Tst), which lies disconformably over the Eureka Canyon Tuff, but more commonly lies on the Nine Hill Tuff or Mesozoic units. The tuff is thickest in the paleovalley north of McClellan Peak. The Becker Collection contains no samples of the Santiago Canyon Tuff, and the unit appears to have pinched out against a topographic high of Mesozoic units in the immediate vicinity of Virginia City (see cross sections A–A’’’’’, B–B’’, and C–C’). The Santiago Canyon Tuff is underlain in places by poorly exposed gravel (Tsg) that contains cobbles and boulders of Tnt, Tet, Tlt, and the adularescent sanidine-bearing crystal tuff (Tct) of the Carson City Quadrangle (Trexler, 1977) to the southwest (tuff of Chimney Spring in the Reno area). The age of the Santiago Canyon Tuff is early Miocene, 23.12±0.05 Ma, on the basis of recent $^{40}Ar/^{39}Ar$ dating (Henry and Faulds, in prep.).

An unnamed lithic ash-flow tuff (Tut) overlies the Santiago Canyon Tuff north of American Flat. The tuff is absent in the Overman Pit but present in the subsurface in the Caledonia Mine (on the basis of Becker Collection specimens), and a small amount is on the dump of the Forman Shaft. An Early Miocene age is indicated because this unnamed tuff overlies the Santiago Canyon Tuff and underlies the Silver City andesites.

MIDDLE MIOCENE ANDESITIC TO RHYOLITIC ROCKS

Gianella (1936) proposed several unit names for Miocene rocks in the Silver City area (fig 5). These include the Kate Peak andesite series, the Alta andesite series, the Knickerbocker andesite, and the American Ravine andesite. Calkins (1945) used similar stratigraphic nomenclature, but used the terms “Alta andesite,” and “American Ravine andesite porphyry.” Thompson (1956) applied the terms “Kate Peak formation” and “Alta formation.” Our mapping and $^{40}Ar/^{39}Ar$ age determinations of the middle Miocene rocks have revealed difficulty in the use of these units. Therefore, these old names are used only in a restricted sense on this map, and we mostly use informal names instead. We divide the middle Miocene rocks into four distinct suites on the basis of new $^{40}Ar/^{39}Ar$ dates and field relationships: the 17.4- to 18.3-Ma rocks of the Silver City magmatic suite; the 15.2- to 15.8-Ma rocks of the Virginia City magmatic suite; the 14.2- to 14.9-Ma rocks of the Flowery Peak magmatic suite; and the 12.9-Ma Occidental dacite (Tod). In many cases, it is difficult to assign the intermediate rocks of the Virginia City Quadrangle to a magmatic suite on the basis of mineralogy, texture, or chemistry. This lithologic uncertainty is aggravated by hydrothermal alteration in many places. However, some general lithologic characteristics have been noted. Flow rocks in the Silver City suite are difficult to distinguish from those in the Virginia City suite compositionally or texturally; however, sections of Silver City suite rocks generally include distinctive breccias. The rocks of the Virginia City suite rarely contain biotite, may or may not contain hornblende and orthopyroxene, and commonly contain clinopyroxene. Plagioclase phenocrysts are generally small (<2mm). Although they overlap compositionally with rocks of the Flowery Peak suite, they generally contain less silica (<60%). The rocks of the Flowery Peak suite are generally rich in hornblende, commonly contain biotite, and most contain large, stubby plagioclase phenocrysts. The Occidental dacite contains significant quartz phenocrysts; large, stubby plagioclase phenocrysts; and has the most silicic composition of the extrusive intermediate rock types.

On the basis of our new $^{40}Ar/^{39}Ar$ data, we have abandoned the term “Knickerbocker Andesite.” The unit was considered by previous workers to include the youngest intermediate extrusive rocks in the area (Gianella, 1936; Thompson, 1956; Vikre et al., 1988). Two samples of rock previously considered to be Knickerbocker Andesite gave ages of 17.87±0.15 Ma and 15.80±0.40 Ma (samples C00-51 and VCL-15, table 4). The older age is on pyroxene andesite of the Silver City suite, and the younger is on hornblende andesite of the Virginia City suite collected near the Knickerbocker Shaft.

SILVER CITY MAGMATIC SUITE

The Silver City magmatic suite includes four mapped units, of which the Silver City andesites (Tsa) is the most extensive. Tsa, originally the lower member of the Alta Formation of Thompson (1956) and the lower part of the Alta andesite series of Gianella (1936), unconformably overlies the Santiago Canyon Tuff and older rocks. The rocks give $^{40}Ar/^{39}Ar$ ages of between 17.4 Ma and 18.3 Ma (table 4), about 2 million years older than the 15.2- to 15.8-Ma rocks of the Virginia City suite. The Silver City andesites are relatively alkaline compared with rocks of the Virginia City suite (fig. 6).

Tsa flows are difficult to distinguish from some flows in the Virginia City suite, particularly those in Tva. Both suites include finely porphyritic flows of two-pyroxene andesite, and flows with minor amounts of hornblende. Tsa generally contains interbedded volcanic breccias, which helps to distinguish it from Tva. We include some fine- to coarse-grained sedimentary rocks as the subunit Tss within Tsa. In places, our Tss was previously mapped as Sutro Tuff by Calkins and Thayer (1945).

The basal part of the Silver City suite to the north and northwest of McClellan Peak includes distinctive hornblende-rich andesite (Tsh) with minor amounts of plagioclase phenocrysts that is one of the most mafic intermediate rocks in the quadrangle (appendix 1). Tsh lies directly on, and may have filled local channels cut into, the Miocene-Oligocene ash-flow tuffs. Hornblende $^{40}Ar/^{39}Ar$ dates on Tsh gave distinctly different ages of 17.43±0.16 and 18.32±0.32 Ma (C00-79 and C00-47, table 4), suggesting two episodes of extrusion.

AMERICAN RAVINE ANDESITE

The American Ravine Andesite (Tara), first mapped as “intrusive quartz porphyry” by Becker (1882), was named by Gianella (1936), who considered it to be a highly eroded extrusive unit at the base of the Tertiary section. Calkins (1945) applied the name American Ravine Andesite Porphyry to the unit, a designation followed by Thompson (1956). Calkins described Tara as an intrusive porphyry, and we concur that it is intrusive. Calkins noted that it intruded rhyolitic rock (our Santiago Canyon Tuff) along Gold Creek, and proposed that it likely intruded the lower part of the Alta Formation (our Silver City volcanics) as well. It has relatively low phenocryst content and contains quartz (probably as xenocrysts) and resembles phenocryst-poor andesite in the Jumbo area (Tap). However, the American Ravine Andesite is among the most mafic and alkaline of the intermediate rocks in the quadrangle, which distinguishes it chemically from Tap (fig. alkali-silica). Gianella (1936) believed that the American Ravine Andesite was unconformably overlain by the Hartford

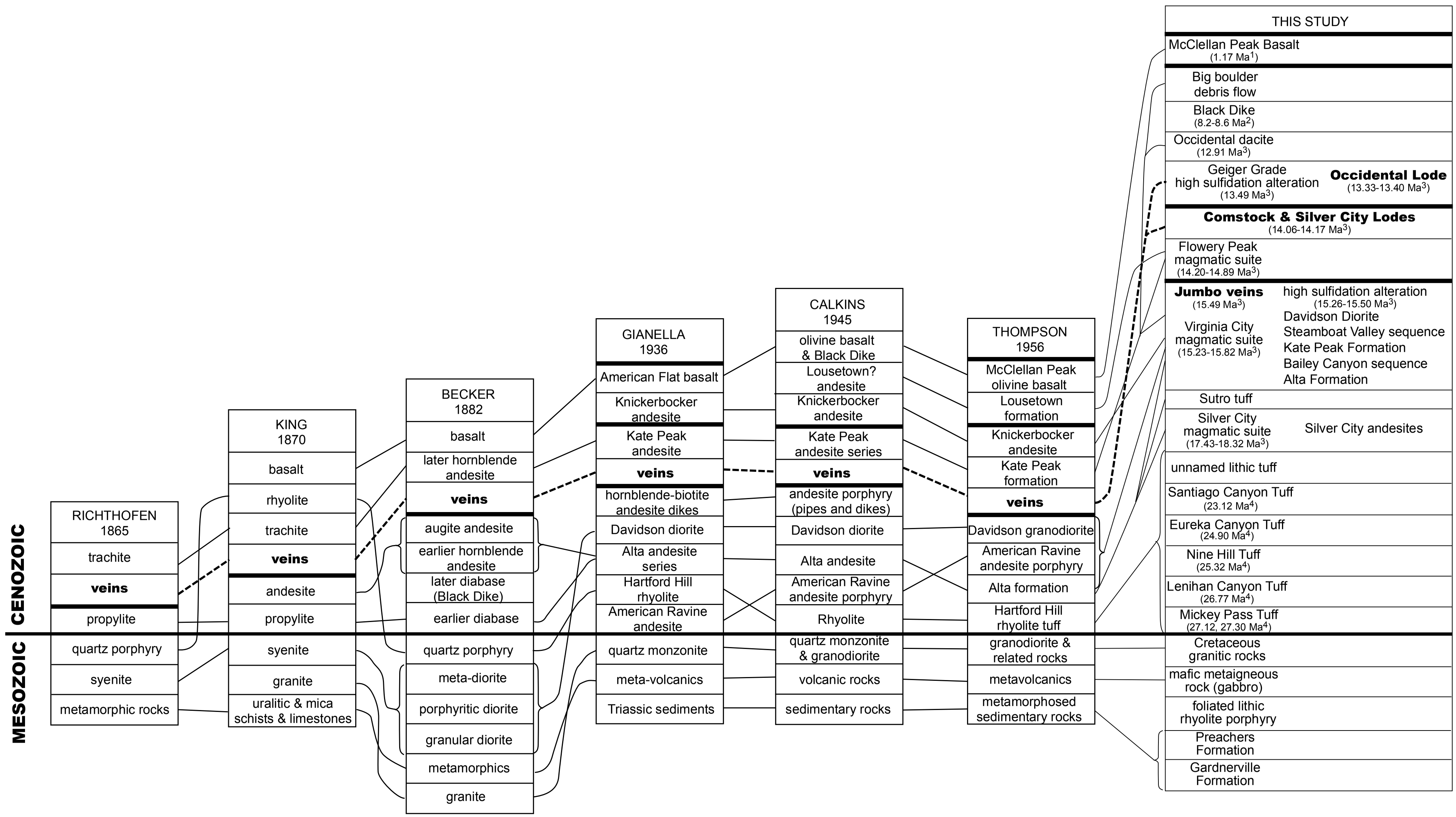

Figure 5. Correlation diagram showing changes in the stratigraphy of the Virginia City Quadrangle by various authors. Ages are from: 1. Doell et al. (1966); 2. Vikre et al. (1988); 3. Table 4; 4. Henry and Faulds (in preparation).

Hill Rhyolite (our Santiago Canyon Tuff); however, in exposures in American Ravine, the andesite crosscuts the ash-flow tuffs (Thompson, 1956). Tara also intrudes the Silver City andesites in a highway cut near Silver City. It may be a late unit of the Silver City suite or part of the Virginia City suite.

SUTRO TUFF

The Sutro Tuff, which generally consists of light colored tuffs with interbedded lacustrine tuffaceous sandstone and conglomerate, is an important marker unit in the eastern part of the Virginia City Quadrangle. It lies above the Silver City andesites and beneath the Virginia City volcanics, and marks a 2-million-year-long hiatus between these two major episodes of local magmatic activity. However, the Sutro Tuff is commonly absent, is variable in thickness, and may be confused with other units in places. Gianella (1936) named the unit the Sutro Tuff for exposures in the Sutro Tunnel and placed it as a member within his Alta andesite series. Later, Calkins (1945) and Thompson (1956) referred to it as the Sutro Member of the Alta andesite and Alta Formation, respectively.

We consider a thin section of bedded rock north of Cedar Hill Canyon to be correlative with the Sutro Tuff. This exposure is underlain by a thick section of Silver City andesite debris flows. It is overlain by hornblende-bearing andesite that gave a $^{40}Ar/^{39}Ar$ age of 15.49±0.41 Ma (C05-226, table 4), consistent with its inclusion in the Virginia City suite.

PHENOCRYST-POOR ANDESITE AND BRECCIA IN THE JUMBO AREA

An isolated mass of andesite flow rock distinguished by relatively low phenocryst content (Tap) forms the host rock for many of the veins in the Jumbo District. The rock has not been dated because the hornblende and plagioclase phenocrysts in it are altered. Similar rock near Steamboat Valley has also been

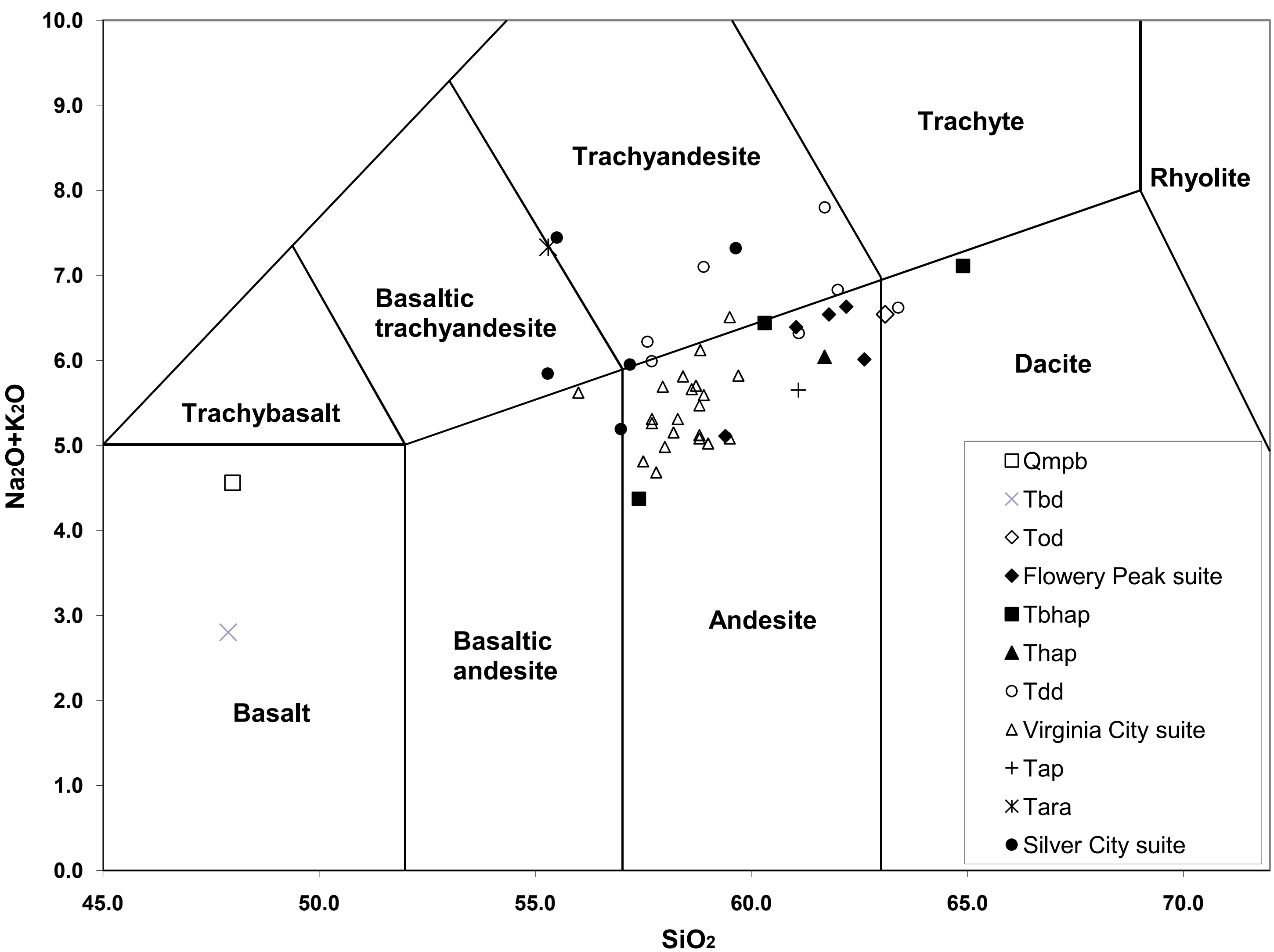

Figure 6. Alkali versus silica diagram for igneous rocks in appendix 1. Fields for volcanic rock compositions are from Le Maitre et al. (2002).

included in Tap. Laharic breccia (Tax) lies below this andesite at Jumbo. Loose pieces of fine-grained sedimentary rock are found below the Tap contact with the underlying breccia, and a small outcrop of sandy to pebbly sedimentary rock occurs with breccia overlying Tap. A thin sequence of breccia that contains sparse granitic clasts occurs between the Silver City andesites and the Virginia City volcanics to the east of the Tap mass. We group Tap and Tax with the Sutro Tuff, stratigraphically between the Silver City andesites and the Virginia City andesites.

VIRGINIA CITY MAGMATIC SUITE

The Virginia City magmatic suite includes 14 extrusive andesitic rock units, six intermediate intrusive units, and two rhyolitic units. The extrusive andesitic rocks comprise the Virginia City volcanics, which form a sequence more than 1 km thick. The Virginia City volcanics are divided into four subunits or sequences on the basis of lithology and geographic distribution; Virginia City suite rocks have relatively tightly grouped $^{40}Ar/^{39}Ar$ ages of 15.3 to 15.8 Ma (table 4).

The Virginia City volcanics are mostly flows, and generally only contain minor amounts of epiclastic rocks (lahars or debris-flow breccia). However, debris-flow breccia is common in parts of the Bailey Canyon and Steamboat Valley sequences in the northwest part of the quadrangle. The sequences are probably, at least in part, laterally correlative, but their equivalence cannot be assured because of extensive faulting and locally strong hydrothermal alteration. The Virginia City volcanics include parts of the Kate Peak and Alta andesite series of Gianella (1936) and the Kate Peak and Alta Formations of Thompson (1956).

Some rock previously mapped as Knickerbocker Andesite by Gianella and Thompson is also included in this suite. We do not consider the Knickerbocker Andesite to be a post-Comstock Lode unit as other authors have (e.g., Vikre et al., 1988), but believe that rocks mapped as Knickerbocker by earlier workers to be relatively dense and impermeable andesite flows that were not altered as strongly as the surrounding rocks. Rock near the Knickerbocker Shaft previously mapped as Knickerbocker Andesite gave a $^{40}Ar/^{39}Ar$ hornblende age of 15.80±0.40 Ma (VCL-15, table 4) and we include this rock in the Alta Formation of the Virginia City suite. K-Ar dates of 13.2±1.3 Ma and 13.6±0.8 Ma on plagioclase from the Knickerbocker Andesite (including a sample from the Knickerbocker Shaft (Vikre et al., 1988) are too young. We also include other two-pyroxene andesite outcrops previously mapped as Knickerbocker Andesite in Tva.

Alta Formation

The Alta Formation is a sequence of hornblende and/or pyroxene andesite flows as much as 1 km thick. Phenocrysts typically do not exceed 2 mm, except hornblende in some flows. Most of the exposed Alta Formation is hydrothermally altered. In many places, the Sutro Tuff defines the base of the Alta Formation, but where the Sutro Tuff is absent, a change in lithology approximates the lower contact. In contrast to the Silver City andesites, the Alta Formation of the Virginia City volcanics has significantly fewer lahars and autobrecciated flows.

The unit name was first used by Gianella (1936) who referred to a thick series of andesitic rocks near the Alta Shaft in the Silver City district as the Alta andesite series, applying the name to rocks he had previously referred to as Forman andesites to distinguish them from a formation in California. Gianella's (1936) map showing the Alta only covered the Silver City-American Flat area, but he applied the unit name to areas as far north as Long Valley. Calkins (1945) and Thompson (1956) extended the use of the term Alta Formation to rocks in the southern half of the Virginia City 15-minute Quadrangle, as far west as Steamboat Valley. Both authors used the term to refer to andesitic rocks lying both above and below the Sutro Tuff. However, this stratigraphy would include andesitic rocks above the Sutro Tuff that have yielded $^{40}Ar/^{39}Ar$ ages of 15.3 to 15.8 Ma with rocks below the Sutro that have yielded significantly older $^{40}Ar/^{39}Ar$ ages of 17.4 to 18.3 Ma. Therefore, we restrict the Alta Formation to rocks lying above the Sutro Tuff, and include a large part of the rocks mapped by Thompson (1956) as Alta Formation. Usage of the formation name outside of the immediate area of Virginia City is discouraged.

Our unit Tva consists of two-pyroxene andesite, including rock previously mapped as Knickerbocker andesite at the Knickerbocker Shaft (Gianella, 1936), near the Haywood Mine (Thompson, 1956), on Basalt Hill, and northeast of American Flat. These two-pyroxene rocks are generally dark gray and rusty weathering, as are relatively unaltered rocks elsewhere in the Alta Formation. We interpret them as relatively pristine parts of the Alta Formation that are weakly altered or unaltered due to their low permeability.

Bailey Canyon sequence

Andesitic rocks of the Bailey Canyon sequence occur in the northwest part of the Virginia City Quadrangle, and apparently underlie the lower andesites of Steamboat Valley. They consist of a lower unit that consists mainly of heterolithic laharic breccias and minor to abundant two-pyroxene andesite flows (Tvbfl), and an upper hornblende andesite unit distinguished in most places by highly vesicular flow rock (Tvbh).

The Bailey Canyon sequence appears to overlie the Alta Formation, but is mostly in fault contact with it, so the two sequences may be equivalent in part. The frothy and glassy nature of the Bailey Canyon sequence hornblende andesites is unlike that of hornblende andesites in the flow member of the Alta Formation, but nearly all exposures of the Alta flow member are hydrothermally altered, possibly obscuring original vesicular textures. The Bailey Canyon sequence was mapped as Kate Peak Formation by Thompson (1956). The unit yielded a hornblende $^{40}Ar/^{39}Ar$ age of 15.79±0.20 Ma (VCH-1037, table 4).

Kate Peak Formation

The Kate Peak Formation contains andesite flows and lesser thicknesses of lahars. Most of the andesites contain hornblende and pyroxene phenocrysts. Plagioclase phenocrysts are usually small (<2 mm). Some flows contain larger stubby, conjoined plagioclase grains and biotite phenocrysts, and resemble rocks in the andesite of Flowery Peak. Olivine-bearing andesite occurs in the formation north of Kate Peak in the Flowery Peak Quadrangle (D.M. Hudson, unpub. data).

The name Kate Peak andesite series was first used by Gianella (1936) to refer to a series of andesitic rocks on the west flank of Kate Peak in the Flowery Peak Quadrangle, but no type section was described. Gianella (1936) broadly included andesitic rocks in the Carson Range and in the Donner Pass area of the Sierra Nevada as being equivalent. Thompson (1956) assigned rocks in the western part of the Virginia City Quadrangle to the Kate Peak Formation; these rocks are mostly in our Bailey Canyon and Steamboat Valley sequences of the Virginia City volcanics. Examination of the section on Kate Peak shows similarities to these units, particularly to the Steamboat Valley sequence, and a single hornblende $^{40}Ar/^{39}Ar$ age of 15.43±0.26 Ma (COM-963, table 4) indicates that the units are coeval. Most of the rocks in the northeast part of the quadrangle that Thompson assigned to the Kate Peak Formation are in our 14.2- to 14.9-Ma Flowery Peak sequence. The Kate Peak Formation is herein restricted to the immediate vicinity of Kate Peak, and usage beyond this area is discouraged.

Steamboat Valley sequence

Rocks of the Steamboat Valley sequence consist of two-pyroxene andesite flows and debris flows, olivine-bearing two-pyroxene andesite flows, and volcaniclastic sediments in the vicinity of Steamboat Valley. At least one of the andesite flows contains minor biotite. These rocks may be coeval with the Kate Peak Formation southeast of Virginia City, because they both include olivine-bearing and biotite-bearing andesite and are texturally similar. An $^{40}Ar/^{39}Ar$ date on plagioclase from a pyroxene andesite flow high in the Steamboat Valley sequence is 15.35±0.22 Ma (C01-19, table 4).

Virginia City suite intrusions

Many bodies of andesite and diorite intrude volcanic rocks of the Virginia City magmatic suite. Those mapped are distinguishable from the enclosing extrusive rocks by texture and/or mineralogy. There are probably many other unmapped intrusions that could not be distinguished from their host rocks.

The most prominent intrusive complex is that of the Davidson Diorite (Tdd). The name "Davidson Diorite" was applied by Gianella (1936), but Thompson (1956) used the name "Davidson Granodiorite." We use the former term for a complex of intrusions that range in composition from diorite to quartz diorite to granodiorite with marginal parts being andesite porphyries. The compositionally variable Davidson Diorite is more alkaline and richer in silica, on average, than extrusive rocks of the Virginia City suite (fig. 6). On the basis of surface exposures and from underground samples and drillholes, the Davidson Diorite seems to be widespread in the subsurface, extending from west of Jumbo to east of the Occidental Lode, and from American Flat on the south to Cedar Hill on the north. On the basis of Becker Collection specimens, equigranular diorite and related andesite porphyry occur in a number of places in the Sutro Tunnel, including just east of the quadrangle boundary. Tdd is also found north of the Sutro Tunnel to the Scorpion Shaft.

The Davidson Diorite (Tdd) appears to be a multi-phased pluton that formed from repeated pulses of intrusion. Only rarely are internal intrusive contacts observable, but some were found in drill core. We did not subdivide Tdd into separate phases; however, Edmondo (1991) mapped quartz dioritic and quartz monzonitic phases in the Mount Davidson area.

We include subsurface rock in the hanging wall of the Comstock Lode in Tdd. It is similar in composition to Tdd in the footwall, but relatively fine grained as shown by many examples in the Becker Collection. A multi-phased plug of fine-grained propylitized diorite west of Jumbo is also considered correlative with Tdd. The intrusive andesitic porphyry Tdap is considered to be equivalent to Tdd on the basis of mineral assemblage similarities and contact relations (see Appendix 3).

The best estimate of the age of the Davidson Diorite comes from a biotite $^{40}Ar/^{39}Ar$ age of 15.32±0.12 Ma (COM-966, table 4) from a sample in the dump of the Savage Shaft. This age overlaps with those of the Virginia City volcanic rocks and thus the Davidson Diorite is considered to be a late phase of the Virginia City magmatic suite. Imprecise zircon fission-track dates of 17.6±2.1 Ma and 16.9±2.1 Ma (Vikre et al., 1988) overlap with our $^{40}Ar/^{39}Ar$ date. K-Ar dates of Davidson Diorite that range from 10.8 to 14.7 (Vikre et al., 1988) may reflect later heating or hydrothermal activity, because some ages are younger than dated post-Davidson rocks, and $\delta^{18}O$ and δD mineral values are too low for magmatic values (Vikre et al., 1988).

INTRUSIONS OF THE FLOWERY PEAK OR VIRGINIA CITY MAGMATIC SUITES

We mapped four types of intrusive rock that may include rocks from either the Flowery Peak or Virginia City magmatic suites. The most abundant of these are Tbhap and Thap, which are differentiated in the field by the occurrence of biotite in the former. The three dated samples of intrusive rock units Tbhap and Thap have $^{40}Ar/^{39}Ar$ ages between 14.53±0.11 and 14.72±0.14 Ma (table 4), which are indistinguishable from ages of Flowery Peak suite extrusive rocks. However, altered dikes mapped as Tbhap and Thap in the north part of the Comstock district could be part of the older (15.2 to 15.8 Ma) Virginia City magmatic suite. Rhyolitic intrusions (Tri) and andesite of Crown Point Ravine (Tac) are undated.

Intrusions of Tbhap are abundant in the northern and eastern part of the quadrangle. Some intrusive rocks in the southern part of the quadrangle are included in this unit as well. Many of these intrusions are hydrothermally altered to varying degrees, and locally intense argillization or alunitization may obscure their textures and primary mineralogy.

Tbhap intruded the Alta Formation of the Virginia City magmatic suite and locally the Davidson Diorite. In texture, Tbhap resembles extrusive rocks in both the Virginia City and Flowery Peak magmatic suites, including biotite hornblende andesite in the Virginia City suite east of the Occidental Lode (in the Flowery Peak Quadrangle) and flows of the andesite of Flowery Peak. Although Tbhap intrusions in the south part of the quadrangle resemble some Virginia City suite rocks, the presence of as much as 10% biotite suggests that they are part of the Flowery Peak suite. The zoning in the plagioclase is suggestive of Flowery Peak andesite, but the general lack of conjoined phenocrysts in Tbhap is not typical of that suite (appendix 3).

Ages of Tbhap intrusions may span those of late Virginia City magmatic suite rocks and rocks of the Flowery Peak magmatic suite. Some Tbhap intrusions are moderately to strongly altered and unconformably overlain by unaltered andesites of the Flowery Peak suite. Alunite from altered Tva near the Union shaft gave a disturbed $^{40}Ar/^{39}Ar$ spectrum with an isochron age of 15.50±0.40, which is similar to other alunite ages in the Virginia City area. Tbhap intrusions in Tva near the VC-14C site are cut by alunitic veins and affected by related alteration and are therefore considered to be part of the Virginia City suite. Tbhap from the Sugar Loaf dome and a dike, 1.5 km and 3 km east of the Virginia City Quadrangle respectively, gave hornblende $^{40}Ar/^{39}Ar$ ages of 14.53±0.11 Ma (C02-14, table 4) and 14.16±0.15 Ma (Castor et al., in press).

Altered biotite andesite northeast of the Cedar Hill Mine gave a biotite $^{40}Ar/^{39}Ar$ age of 14.72±0.14 Ma (H01-1, table 4). This rock has been mapped as Tbhap, but may be Tfp. The alteration mineral assemblage includes cristobalite and clay, but the biotite is unaltered and the age is considered to represent that of magmatic cooling. Unaltered lahars and flows of the Flowery Peak suite that overlie this rock at the H01-1 site gave a hornblende $^{40}Ar/^{39}Ar$ age of 14.75±0.22 Ma (H01-2, table 4). The contact between these rocks is sharp and shows evidence of shearing. The contact may be a fault or landslide contact, but may be partly an unconformity because lahar directly above the contact contains altered rock with cristobalite.

Dikes and other intrusions of Thap appear to cut the Davidson Diorite, and some have illitic and sericitic (fine-grained muscovite) alteration. A $^{40}Ar/^{39}Ar$ age of 14.53±0.42 Ma was obtained on hornblende from propylitized Thap (COM-960C, table 4), indicating that the rock is part of the Flowery Peak magmatic suite. More strongly altered intrusions to the north on Cedar Hill are similar to the dated rock. If illitic and sericitic alteration on Cedar Hill is related to the 15.5-Ma high sulfidation alteration (see the section on hydrothermal alteration below), then some of these intrusions may be part of the Virginia City magmatic suite.

The age of rhyolite intrusions in the Comstock district (unit Tri) is not clear. They intrude the 15.2- to 15.8-Ma Alta Formation (Tva) and are hydrothermally altered. The rhyolite near Cedar Ravine is cut by a Tbhap dike, but other intrusive relationships are lacking. Tri could be coeval with Davidson Diorite, late Virginia City suite, or early Flowery Peak magmatism.

ROCKS OF THE FLOWERY PEAK MAGMATIC SUITE

Rocks of the Flowery Peak magmatic suite are flows and breccias that range in age from about 14.2 to 14.9 Ma (table 4), and typically contain relatively abundant hornblende. In addition, sparse to moderately abundant biotite is common, and plagioclase phenocrysts are commonly stubby, conjoined crystals more than 3 mm long (table 1). All rocks of this suite are IUGS andesites on the basis of $Na_2O + K_2O$ and SiO_2 contents (fig. 6). On the basis of a large number of petrologic examinations of samples from the Virginia City and Flowery Peak Quadrangles, two types of extrusive rock seem to be typical of this suite; hypersthene-hornblende andesite and biotite-hornblende andesite. The latter type commonly contains minor olivine, quartz, and clinopyroxene, and does not contain hypersthene.

Along the north edge of the quadrangle, rocks of the Flowery Peak suite are divided into three major units, Tfba, Tfha, and Tfbha, on the basis of phenocryst assemblages. To the south, all of these rocks may all be present in a single unit (Tfp). Tfha, which contains hornblende and little or no biotite, is generally more highly altered than the biotite-bearing Tfba and Tfbha. The massive nature, rarely preserved steep flow banding, lack of magnetite-rimmed hornblende, and lack of lahars and flow breccias all suggest that at least part of Tfha is intrusive or flow domes. Its poorly defined contact with Tfp north of Long Valley Creek is based mainly on the absence of biotite in Tfha. Tfha is intruded by Tfbha, which is similarly affected by hydrothermal alteration. Tfba is overlain to the northeast of the quadrangle by 7.5 Ma olivine basalt flows of the Lousetown Basalt (Schwartz, 2001).

The andesite of Flowery Peak (Tfp) consists of andesitic flows and interbedded debris flows that are generally unaltered and unconformably overlie altered Virginia City suite andesites and associated intrusions. The unconformity can be clearly seen in road cuts along Nevada Route 341 northeast of the Cedar Hill Mine. The earliest phase in the Comstock district is an extensive debris flow breccia with clasts of Flowery Peak suite andesite and some older lithologic types. This basal laharic breccia is present north of the Sutro Tunnel (east of the quadrangle) to at least Long Valley and northeast of Mt. Abbie. It thins south of the Sutro Tunnel.

Shallowly northwest-dipping debris flow breccias that contain pebble- to boulder-sized clasts of andesite with large hornblende phenocrysts as well as biotite-bearing andesite occur west of the mouth of Bailey Canyon in the northwest part of the quadrangle. They lie atop Virginia City suite andesites that are generally more steeply dipping. Exposures of similar breccia occur in a narrow zone that extends as far to the southeast as Mount Abbie, and may have filled a paleovalley cut into rocks of the Virginia City suite.

A mass of spectacularly columnar-jointed, glassy, biotite hornblende andesite porphyry mapped as Tfp forms a crude semicircle and seems to overlie altered Virginia City suite rocks about 2 km northeast of Jumbo (Sec. 26, T17N, R20E). The columnar joints are mostly sub-vertical suggesting extrusive deposition, but this rock could be intrusive.

Rock that we have mapped as andesite of Flowery Peak was previously included in the Kate Peak Formation by Thompson (1956) and Hudson (2003). However, as noted above, the andesite that underlies the topographic feature Kate Peak is older, and we have included it in the Virginia City suite. Our $^{40}Ar/^{39}Ar$ ages on hornblende from the lower part of Tfp north of Virginia City are 14.89±0.20, 14.75±0.22, and 14.39±0.20 Ma (C00-126A, H01-2, and COM-962, table 4).

LATE MIOCENE AND/OR PLIOCENE ROCKS

Two units of late Miocene and/or Pliocene age occur in the quadrangle. The big boulder debris flow unit (Tbdf), for which no date is available, and the late Miocene Black Dike (Tbd). Tbdf overlies Virginia City suite rocks, and lies on Cretaceous granite near the western quadrangle edge. It is mostly andesitic, but contains granitic boulders locally. The lahar apparently flowed over a surface of low relief because its contacts with underlying andesitic rocks are flat or dip shallowly west. The unit could be as young as Quaternary but is more likely Late Miocene or Pliocene. It is offset by faults having Quaternary displacement. The source of the debris is not known. It includes altered fragments that could have been derived from the altered area north of Jumbo, the main Comstock district, or the Geiger Grade area. There are, however, no known exposures of Cretaceous granitic rocks in those directions except at the base (west end) of the Geiger Grade. The lack of ash-flow tuff clasts would probably preclude a source to the south. A possible source is in the Slide Mountain area >8 km to the west, where andesites, some hydrothermally altered, are exposed on the Mount Rose highway east of Slide Mountain. The debris may have been shed eastward during Pliocene uplift of the Carson Range. Tabor and Ellen (1975) mapped this debris flow unit in the Washoe City Quadrangle east of New Washoe City as part of the Kate Peak Formation, but it is lithologically distinct from any units now included in the Virginia City magmatic suite.

The Black Dike of Becker (1882), an olivine-bearing basalt found only underground in the south part of the Comstock district, has given whole-rock late Miocene K-Ar ages of 8.2 and 8.6 Ma (Vikre et al., 1988). These ages are similar to $^{40}Ar/^{39}Ar$ ages of 7.54±0.08 Ma and 7.57±0.45 Ma on olivine-bearing Lousetown Basalt flows and plugs north and northeast of the Virginia City Quadrangle (Schwartz and Faulds, 2002).

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QUATERNARY BASALT AND SEDIMENTS

The McClellan Peak Basalt is a Quaternary lava flow that lies in a paleovalley that passed through American Flat and down American Ravine toward Silver City. The flow likely erupted from the area of a plug on the east flank of McClellan Peak, and subsequent erosion left only remnants of the flow. This basalt was called the American Flat Basalt by Gianella (1936, p. 76–78) and the olivine basalt of American Ravine by Calkins and Thayer (1945). Thompson (1956) applied the name McClellan Peak Olivine Basalt to these rocks because the name American Flat had been applied to a formation in Colorado. A K-Ar age for this basalt is 1.17±0.04 Ma (new constants) from a flow on Basalt Mesa (Doell et al., 1966). A cinder cone – lava flow complex about 5 km to the southwest of American Flat includes olivine basalt flow rock that gave a K-Ar age of 1.37±0.29 Ma (Bingler, 1977; decay constants not reported), overlapping with the Basalt Mesa date. Thompson (1956) extended the use of the unit name to locally sourced basalt flows about 19 km northeast of Virginia City, and Schwartz (2001) obtained an $^{40}Ar/^{39}Ar$ age of 1.44±0.01 Ma on a flow in this area.

Quaternary sediments include mainly alluvial gravels in stream valleys and small basins. Eolian deposits occur in the western part of the quadrangle, probably derived from Washoe Valley to the west.

STRUCTURE

MESOZOIC

Exposures of the Gardnerville and Preachers Formations, the only bedded pre-Tertiary units, were folded before deposition of the Tertiary rocks in the area. They only make up a few percent of the exposures in the quadrangle, so it is not possible to establish a regional folding pattern.

CENOZOIC

FOLDS

Although the Tertiary volcanic strata dip shallowly to moderately west to northwest in most parts of the quadrangle, in places they dip eastward. The Miocene andesites and the underlying ash-flow tuffs seem to have been folded into an anticline north of American Flat. Near Wakefield Peak, the Sutro Tuff dips 30–60º west, whereas near Suicide Rock, the Sutro Tuff and bedded rocks of Tss dip as much as 83º east. Flow and compaction foliation in the adjacent volcanic rocks, including the Santiago Canyon Tuff also show this feature. The axial trend of such a fold would be northwesterly to northerly, roughly along the township boundary between T20E and T21E. To the east of this apparent fold, on the southwest side of Butler Peak, there may be a broad syncline with a northwesterly axis in the Silver City andesite, breccias, and sedimentary layers.

Folds also may be present in the Ophir Hill area, based on reversals of flow foliation dips in the Virginia City volcanics. Foliations dip east to the west and southwest of Ophir Hill, and dip west to the east of Ophir Hill, suggesting a synform. Extension of this fold north of Ophir Hill is problematic, but a similar reversal may be present west of Middle Hill. To the west of Ophir Hill, flow foliation reversals suggest the presence of a northeast-trending antiform.

There are no observable folds in the hanging wall of the Comstock fault zone. East of the Comstock fault zone, the Sutro Tuff maintains a relatively uniform approximately 35º westerly dip, with about a N30ºE strike. Gianella (1936, and unpublished notes, NBMG and University of Nevada, Reno Library, Special Collections) described similar attitudes of the Sutro Tuff in the South Lateral of the Sutro Tunnel between the East Yellow Jacket and Forman Shafts, as well as in the footwall (west) of the Occidental Lode.

The cause of the folding in the footwall of the Comstock fault zone is uncertain. A possible explanation is doming or warping due to intrusion of the Davidson Diorite. However, this hypothesis does not explain the lack of doming in the hanging wall of the Comstock fault zone where the Davidson Diorite is also present (sections C–C' and D–D").

PRE-COMSTOCK FAULTING

A set of faults associated with the Virginia City magmatic suite is probably the oldest Tertiary set in the quadrangle. Small displacement faults or fractures were conduits for hydrothermal fluids, mostly for fluids that produced quartz-alunitic and related alteration. Alunite from these structures yielded 15.3- to 15.4-Ma ages (C02-69C, H02-142, H02-144, table 4). These form a crudely radial pattern to the east, south, and west of the hydrothermal center about 2 km west of Mount Davidson (Fig. 7). Quartz-alunite alteration east of the Comstock Lode is mostly along approximately north-south fractures south of the Union Shaft. North and east of the Union Shaft, the fracture set is dominantly about N45ºE.

Intrusions of the Davidson Diorite (15.3 Ma, COM-966, table 4) and its andesite porphyry phases locally follow this radial set of faults or fractures. In the vicinity of Crown Point Ravine and Wakefield Peak, several dikes strike about N30ºW but a few strike north-south. Toward Jumbo, the dikes strike about N30ºE, and around Jumbo, about N60ºE. This pattern of dikes is roughly radial, centered approximately on the location of the hydrothermal center noted above. A series of N20ºE to N60ºE, locally vein-filled faults in and west of Jumbo were the focus of quartz-adularia alteration in andesite, granite, and ash-flow tuffs, and appear to be part of this early fault set. Adularia from one of these veins gave a 15.5-Ma age (C02-72C, table 4).

COMSTOCK-AGE FAULTING

A period of normal faulting was apparently synchronous with, or earlier than, mineralization in the Comstock district and intrusion of some Thap and Tbhap dikes. The major faults are curvilinear with N10ºE to N40ºW strikes. The general attitudes of the major pre- and/or syn-mineralization faults are summarized in table 5 and shown in figure structure.

The Comstock fault zone (CFZ, Fig. 7) or Comstock Lode is the major fault in the Comstock district. From its junction with the Silver City fault to about Cedar Hill, this fault zone is as much as 300 meters wide at the present level of erosion, as shown by the presence of quartz veining, but varies considerably in width. Within a few hundred meters down dip, the zone narrows to 5 to 50 meters in width. North of Cedar Hill, the zone narrows to less

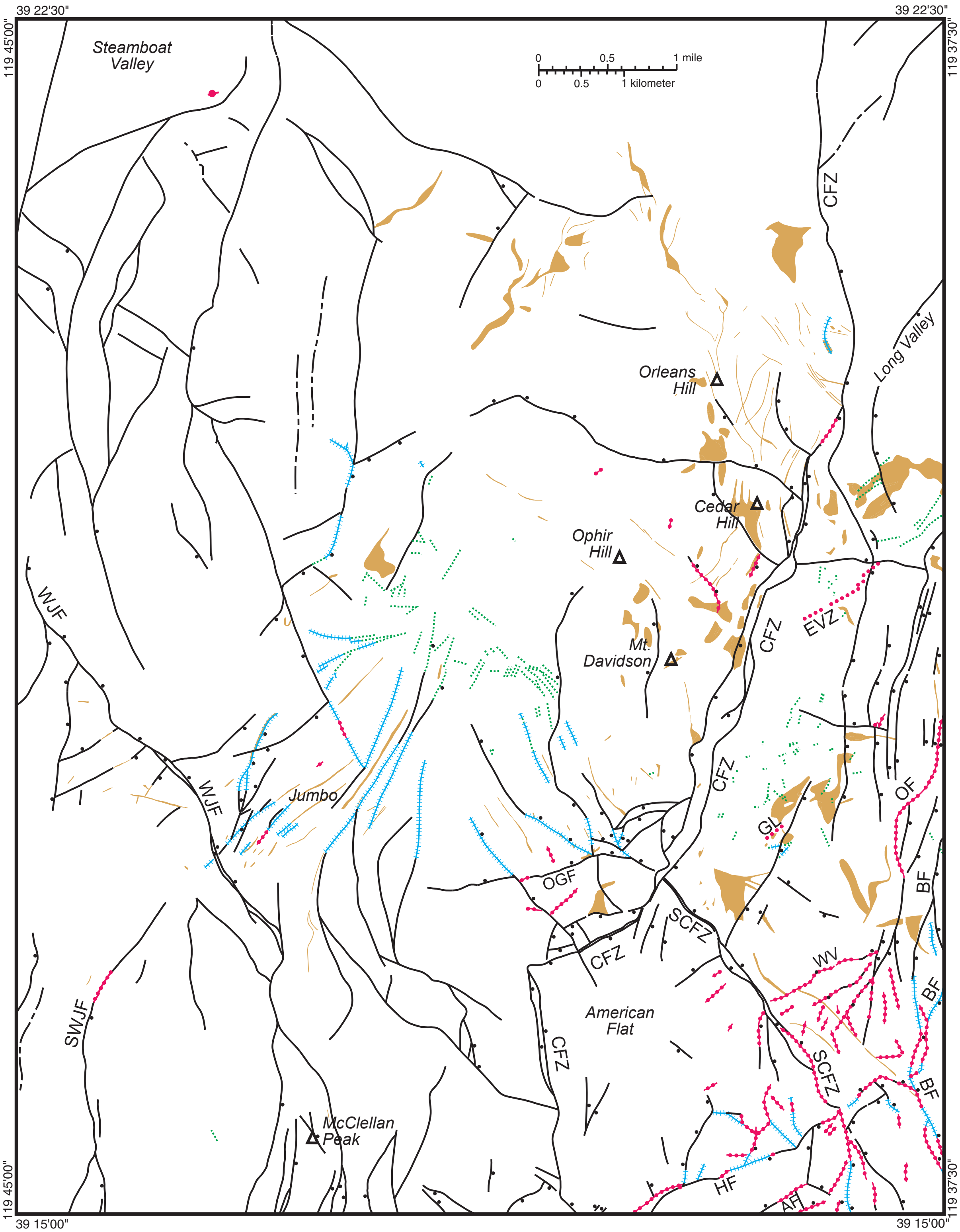

Figure 7. Map showing faults, andesite dikes, quartz±adularia±calcite veins, and hydrothermally altered faults and fractures in the Virginia City Quadrangle.

Fault, ball on downthrown side

Linement

Vein

Concealed vein

Dike

Quartz-alunite or silicified ledge

Clay alteration along fault or fracture

AF	Amazon fault
BF	Buckeye fault
CFZ	Comstock fault zone (Comstock Lode)
EVZ	East Vein zone
GL	Garfield Lode
HF	Haywood fault
OF	Occidental fault (Occidental Lode)
OGF	Ophir Grade fault
SCFZ	Silver City fault zone (Silver City Lode)
SWJF	Southwest Jumbo fault
WJF	West Jumbo fault
WV	Woodville Vein

than a few meters. No veining is known north of Long Valley, where the zone becomes difficult to trace. South of the junction with the Silver City fault, the Comstock fault swings abruptly to about S70°W, then turns abruptly again in the northwest corner of American Flat to a north-northwest strike. A few splays in the footwall from the Comstock fault zone are represented by veins or Tbhap dike-filled faults. Veins formed along a few small structures in the hanging wall. The most prominent is the N45°E striking, southeast dipping East Vein zone (EVZ, Fig. 7), which has several small ore bodies along it at depth. The East Vein zone lacks any recognizable surface manifestation between the Union Shaft and the Comstock Lode. The intersection of the East Vein zone and the Comstock fault zone is the Con Virginia orebody, which has its widest portion at the intersection. The Garfield Lode (GL, Fig. 7), which strikes roughly N45°E and was intersected in the South Lateral of the Sutro Tunnel near the East Yellow Jacket Shaft, also appears to lack surface manifestation. Because they have similar strikes to many of the quartz-alunite ledges in the area, the northeast striking lodes may have formed along reactivated faults that were earlier occupied by high sulfidation alteration.

The Occidental and Buckeye faults, which parallel the Comstock fault, are the only large-displacement faults in the hanging wall of the Comstock fault zone. The Silver City fault and the East Vein zone form a trapezoidal block in the hanging wall of the Comstock fault zone (Fig. 7). The vast majority of the known ore and the bulk of vein material are localized along the Comstock fault zone between the intersections of East Vein zone and the Silver City fault zone.

South of the Woodville Vein (Fig. 7), the Silver City fault has numerous splays, in both its footwall and hanging wall. These are mostly east-side-down north-striking faults that offset, and are offset by, east-northeasterly horsts and grabens. The Haywood and Amazon faults (HF and AF, Fig. 7) bound one of these grabens. This area of relatively complex faulting appears to be bounded by the Comstock fault zone on the west and the Buckeye fault on the east.

Berger et al. (2003) proposed that the N15ºE productive part of the Comstock fault zone developed as an extensional stepover between two parallel and overlapping right-lateral to right-oblique faults. They interpreted the Silver City fault to be the southern right-lateral fault, and postulated a ~15 km long Bain Spring fault zone as the northern right-lateral fault. Berger et al. (2003) showed the Bain Spring fault as extending from northwest of the Virginia City Quadrangle, southeast across the northern part of the quadrangle, past the north end of the Comstock fault, and into the Flowery Peak Quadrangle. However, neither Thompson (1956) nor we recognized such a fault zone. Along this zone, we mapped only a ~1.5 km long, partly queried fault, and found no evidence for a major structure (such as the Silver City fault) in the area. On the basis of our mapping, we interpret the Virginia City area structure as a complex of mostly normal faults, many of which are arcuate or otherwise non-linear, and we suggest that these formed as a series of concave-eastward scoops that stepped eastward during Miocene extension. Displacement along such non-linear faults would have local lateral strike-slip shear sense. Just south of the Occidental Shaft, the north-striking Occidental fault (OF, Fig. 7) exhibits well-developed 65°–85° ESE-raking slickenlines on several parallel surfaces indicating a slight to moderate right lateral component to normal movement. About 700 m northwest of its intersection with the Woodville Vein, the northwest-striking Silver City fault is marked by consistent 60°–75° E-raking slickenlines and parallel fault plane bends with amplitudes of as much as 30 cm. These data also indicate normal movement with only a slight to moderate right lateral component. On other major fault surfaces slickensides are rarely exposed and in the few instances where exposed, they have inconsistent rakes that range from vertical to horizontal.

Table 5. Summary of orientations and displacements of major faults in the Virginia City quadrangle.

FAULT	SYMBOL ON FIGURE 4	GENERAL STRIKE	DIP AT SURFACE	DIP AT DEPTH	DISPLACEMENT	VEIN	AGE OF MOVEMENT
Comstock (Virginia City)	CFZ	N 15° E	50° E to 80° W	35° to 40° E	500 to 900 m	yes	Miocene, Quaternary
Comstock (north American Flat)	CFZ	N 70° E	50° S		300 m	yes	Miocene, Quaternary
Comstock (west American Flat)	CFZ	N 10° W	40°? E		900 m	yes	Miocene, Quaternary
Occidental	OF	N 15° E	45° E	35° E	0 to 300m	yes	Miocene, Quaternary?
Silver City	SCFZ	N 50° W to N-S	60° to 40° E	35° to 40° E	100 to 500 m	yes	Miocene, Quaternary
East Vein	EVZ	N 50° E	?	70° to 55° SE	<50 m?	yes	Miocene
Haywood	HF	N 70° E	70° S		250 m?	yes	Miocene, Quaternary?
Amazon	AF	N 70° E	55° N		< 70 m?	yes	Miocene
Buckeye	BF	N 15° E to N 20° W	50° to 55° E		>300 m	yes	Miocene, Quaternary?
Woodville	WV	N 45° E	80° N		200 m	yes	Miocene
Ophir Grade	OGF	N 75° E	70° N		50 m	no	Miocene, Quaternary
West Jumbo	WJF	N 35° W	70°? NE		50 to 1500 m	no	Miocene, Quaternary
Southwest Jumbo	SWJF	N 35° E to N 10° W	50° E		300? M	yes	Miocene

POST-MINERALIZATION FAULTING

Many pre- and/or syn-mineralization faults were reactivated; however, it is commonly not possible to determine if post-mineralization displacement occurred, although there is commonly some post-veining gouge in most of the minor faults, particularly around Silver City. Sag ponds are located along some poorly exposed north- to north-northwest- and west-northwest-trending faults in the hanging wall of the northern part of the West Jumbo fault, suggesting recent movement.

Reactivation of the Silver City, Comstock, and West Jumbo faults resulted in "double" faults, two bounding faults to the same fault zone. In the Comstock fault zone, the West fault (or "West Clay") had at least some post-mineralization movement. The East fault (or "East Clay") appears to have considerably more displacement, based upon stratigraphic markers. These bounding faults have numerous small-displacement faults between them, but poor exposure makes mapping these small structures difficult. The bounding faults on the Silver City and West Jumbo faults apparently took up most of the post-mineralization motion, with the hanging wall splay appearing to have, by far, the greatest movement. The double fault nature of the Silver City fault seems to end south of Devils Gate.

The West Jumbo fault may have some right-lateral displacement, as indicated by displacement of hydrothermal alteration. Veins and propylitic alteration around Jumbo may have been displaced by as much as 1500 m to the southeast relative to the strong alteration in the ash-flow tuffs and granitic rocks to the west of the fault. However, we consider most of the displacement along this fault to have been normal.

The age of the younger period of faulting is probably post-Miocene. The big boulder debris flow (Tbdf) was deposited on a relatively flat surface and was later displaced by the West Jumbo fault, suggesting late Miocene to Quaternary movement. The northern extent of the West Jumbo fault controls a sag basin that is mostly west of the quadrangle, indicating probable late Quaternary movement, and a north-trending fault in this area had <130 Ka movement (dePolo, 2008). In addition, small sag ponds (containing Ql) within the quadrangle occur along N- and NW-striking faults in the hanging wall of the West Jumbo fault. The Comstock fault and a possible NW-striking extension along Long Valley is thought to have had <1.8 Ma movement, along with other NW-striking faults in this area (dePolo, 2008). The 1.2- to 1.4-Ma McClellan Peak Basalt lies in a canyon carved following reactivation of the southern end of Comstock fault and the Silver City fault. Due to lack of dated post-Miocene units, however, the exact age of fault reactivation is uncertain.

ECONOMIC GEOLOGY

HYDROTHERMAL ALTERATION

Most rocks in the Virginia City Quadrangle have undergone hydrothermal alteration. Several periods and types of Miocene alteration are present in the quadrangle. Becker (1882) noted that the volcanic rock type propylite, first applied by Richtofen (1865) in the Comstock district, was in fact hydrothermally altered andesite. Whitebread (1976) briefly described alteration in the northern part of the quadrangle along the Geiger Grade. For many years, the Virginia City area has been the site of remote sensing alteration studies. Ashley et al. (1979) mapped hydrothermally altered areas using enhanced Landsat images. Hyperspectral remote sensing work in the area was described by Smailbegovic et al. (2000), Bedell (2005) presented alteration maps based on Landsat and ASTER images, and Vaughan and Calvin (2005) mapped specific alteration minerals using hyperspectral remote sensing techniques.

Hudson (2003) described 12 alteration assemblages and subassemblages and showed their distribution in the Comstock district. Of these, four generalized types of alteration are shown on the Virginia City Quadrangle geologic map.

Propylitic alteration (table 6) affects rocks as young as the Flowery Peak magmatic suite. An epidote-bearing, nearly calcite-free sub-assemblage of propylitic alteration forms a belt up to 1 km wide along the Occidental Lode, a belt as much as 1.2 km wide east of the Comstock Lode, an area up to 2.5 km wide west of the Comstock Lode, and several patches in granodiorite west of Jumbo (Hudson, 2003). Elsewhere, a commonly calcite-rich, epidote-free assemblage is present at the surface. Epidote is rarely found in rhyolitic rocks.

Four main alteration assemblages (combined under the term "phyllosilicate alteration" on the map) characterized by clay and mica mineral species (table 6) cover large areas of the quadrangle and have several distinct centers. The illitic assemblage makes up much of the phyllosilicate-type alteration at the surface. The sericitic assemblage is confined to the footwall west of the Comstock Lode, a large area west of Mt. Davidson (most of Sec. 25, T17N, R20E), and some of the ash-flow tuffs and granodiorite west of Jumbo (parts of Sec. 33 and 34, T17N, R20E). The alsic (aluminum silicate) assemblage (table 6) is confined to a few small exposures scattered in larger areas of illitic alteration or bands less than a few meters wide adjacent to alunitic ledges. The kaolinitic assemblage is largely confined to small patches east of the Comstock Lode and east of the Occidental Lode. Phyllosilicate alteration west of Jumbo in the ash-flow tuff units may have formed from fluids moving laterally beneath the Virginia City volcanics from the alteration center northeast of Jumbo. Much of the rock along the north edge of the quadrangle, from just west of the Comstock fault to the vicinity of Five Mile Flat and the mouth of Bailey Canyon, is strongly altered to phyllosilicate minerals, and locally to resistant ribs and irregular bodies of quartz±alunite (e.g., Whitebread, 1976).

The alunitic assemblage (table 6) typically forms resistant ledges along faults and fractures because of the presence of ubiquitous intergrown fine-grained quartz. The ledges vary from less than 1 m to over 200 m wide. The ledges are discontinuous and other alteration assemblages may alternate with the alunitic assemblage along strike. Hydrothermal breccias or silicified fault breccias locally occur in the alunitic ledges. Some broad areas of silicification (±alunite) are also shown on the geologic map.

Black fine-grained tourmaline veinlets and disseminations locally constitute as much as 60% of the rock along with tourmaline breccias about 1.5 km west of Mt. Davidson. The tourmalinized area is surrounded by sericitized or kaolinized andesites. Several areas of tourmaline-magnetite veins occur on the flanks of Mount Davidson within or immediately adjacent to the Davidson Diorite. The tourmaline veins are mostly <2 cm wide, rarely up to 20 cm, and 1 to 3 m in length with gangue K-feldspar and quartz (Edmondo, 1991). These veins commonly have selvages of K-feldspar and sericite replacement several centimeters wide.

Alunite from the two sites west of the Comstock Lode and one site east of the Comstock Lode yielded $^{40}Ar/^{39}Ar$ ages in a narrow range of 15.26±0.14 to 15.40±0.29 Ma (C02-69C, H02-142, H02-144, table 4). The area of alunitization is spatially related to the Davidson Diorite in the footwall of the Comstock Lode, and the ages correspond to the late stages of the Virginia City magmatic suite. However, the alteration appears to be older than at least part of the Davidson Diorite, which is moderately altered to propylitic assemblages in some areas where Virginia City rocks are strongly alunitized. In at least one area alunitized ledges are intruded by propylitized Davidson Diorite. A single sample (VC-14C, table 4) of alunite in the hydrothermal center east of the Comstock Lode yielded an isochron age of 15.50±0.40 and a weighted mean age of 14.72±0.64 Ma. Although the ages are indistinguishable within analytical uncertainty, the isochron age suggests alteration during Virginia City magmatism, whereas the plateau age indicates younger alteration. This alteration affects intrusions of Tbhap but not flows of the overlying Tfp, and may have formed during the early part of Flowery Peak magmatism or the latter stages of Virginia City magmatism. Alunite from the southern part of a large hydrothermal center along Geiger Grade at the north edge of the quadrangle yielded a $^{40}Ar/^{39}Ar$ age of 13.49±0.70 Ma (VH02-1, table 4). Similar $^{40}Ar/^{39}Ar$ ages (13.8±0.4 and 14.1±0.7) were reported by Vikre et al. (1988) on alunite from about 3 km to the east. This area of alteration affects various units of the Flowery peak magmatic suite. Alteration in Tfha includes epidote+chlorite+albite (propylitic); illite, kaolinite, and other clays (phyllosilicate); and local ledges and irregular replacement by silica±alunite. Propylitized rocks commonly appear to be surrounded by or cut by irregular to linear areas of argillized and/or silicified rocks. Mafic minerals are commonly converted to iron oxides in altered rock. This alteration is significantly younger than all Flowery Peak suite rocks with the exception of Tfba (14.20±0.43 Ma). Vikre et al. (1988) reported $^{40}Ar/^{39}Ar$ ages of 9.4 Ma and 16.0 Ma on alunite 4 km to the northwest at the base of Geiger Grade.

Table 6. Mineralogy of alteration assemblages of the Virginia City quadrangle.

Propylitic assemblages:	**Phyllosilicate assemblages:**				**Alunitic assemblage:**
	Illitic:	Sericitic:	Alsic:	Kaolinitic:	
Chlorite	*Illite*	*Muscovite*	*Pyrophyllite*	*Kaolinite*	*Alunite*
Epidote	*Quartz*	*Quartz*	*Quartz*	*Dickite*	*Quartz*
Albite	Pyrite	Pyrite	Diaspore	*Quartz*	Natroalunite
Calcite	Anhydrite		Pyrite	Pyrite	Pyrite
Smectite	illite/smectite			nacrite	hematite
Quartz	smectite				
Zeolites					
actinolite					
anhydrite					
pyrite					
hematite					

Note: *Essential Mineral* , Common Mineral, uncommon mineral.

VEINS

Numerous veins are found in the Virginia City Quadrangle. Many of these have been described in detail (e.g., King, 1870; Church, 1879; Becker, 1882; Vikre, 1989; Hudson, 2003); consequently, they are only briefly described below.

The Comstock Lode is the major silver-gold vein deposit in the quadrangle, having its productive part from the junction with the Silver City Lode to Cedar Hill. Mine dumps or alluvium cover the lode along most of its productive length. The Comstock Lode is a combination of relatively small, lenticular, intermittent ore shoots contained within a much larger mass of sub-ore grade massive veins, breccias, and stockwork veins. It includes massive quartz veins and large volumes of quartz and quartz-adularia stockwork veins. Massive calcite is only noted on the surface at the Cedar Hill Mine. The lode is up to 300 m wide at the surface but in places it narrows rapidly with depth and pinches and swells along dip. The main ore minerals were acanthite, electrum, and stephanite, with other sulfides including sphalerite, chalcopyrite, galena, and pyrite. The southern part of the lode north and west of American Flat had very minor production. Quartz veins locally are exposed in some of the lode splays north of American Flat. Adularia from the Comstock and Silver City Lodes yielded $^{40}Ar/^{39}Ar$ ages of 14.06±0.04 Ma to 14.17±0.06 Ma (samples H00-62, NS-402, H01-4, H00-61, table 4).

The Silver City Lode is similar in character to the Comstock Lode, pinching and swelling along strike and dip to as much as 75 m in width. Massive quartz vein, quartz-adularia stockwork veins, and massive calcite are exposed along the Silver City Lode. Ore minerals were the same as for the Comstock. The Silver City Lode has many splays including the Woodville, Haywood, Oest, Drysdale, and Amazon, all of which had some production.

The Occidental Lode parallels the Comstock Lode about 2 km to the east. It is up to 12 m wide and splays into narrow segments along its southern end. The bulk of the lode at the surface consists of massive calcite locally containing numerous clasts of andesite up to 1 m across. The calcite passes upward to non-banded, quartz-adularia-cemented breccia that is exposed on several hilltops near the Occidental Mine. Ore mineralogy was reported to be the same as for the Comstock Lode (Stoddard and Carpenter, 1950). Adularia from the Occidental Lode has yielded $^{40}Ar/^{39}Ar$ ages of 13.39±0.04 Ma to 13.53±0.03 Ma (samples C02-19, C02-20, H00-51, table 4). The Buckeye Lode lies east of and parallel to the Occidental Lode. It yielded unknown but probably minor production from quartz and calcite veins. The age of the Buckeye Lode is unknown.

The Jumbo District contains numerous discontinuous and narrow veins (fig. 7). On the basis of our mapping, the veins strike N20°E to N60°E, and dip 40°NW to 70 °SE. According to Bonham and Papke (1969) underground mapping by L.H. Beal revealed a second set of veins that strike N20°W to N60°W with a northeast dip. Selvages of illitization up to 10 m wide locally follow the northeast set of veins. In places, wall rock directly adjacent to the veins is strongly adularized. The veins vary from fracture fillings to brecciated zones. Sheeted, braided, and stockwork vein zones are present in places. Gangue minerals include quartz, calcite, zeolites, and minor adularia. Ore mineralogy is unknown but the gold is reportedly free-milling (Bonham and Papke 1969). Vein adularia is rare in the Jumbo District, and we found it at only one prospect along a northeast-striking vein. A sample from this site yielded an $^{40}Ar/^{39}Ar$ age of 15.49±0.04 Ma (sample C02-72C, table 4), about the same age as alunitic alteration 3 km to the northeast along a structure of similar strike.

A quartz vein filling the southwest Jumbo fault (Fig. 7), separating Cretaceous granodiorite and Miocene andesite, was prospected about 3 km southwest of Jumbo (SE¼, Sec. 4, T16N., R20N.). The vein, where exposed, is less than 30 cm wide, strikes about N30°E and dips 50°SE. The vein consists of fine-grained quartz and quartz-cemented breccia with minor sericite. Ore minerals from dumps include acanthite, stephanite, sphalerite, electrum, and pyrite. The age of the vein is unknown; $^{40}Ar/^{39}Ar$ analysis of sericitized biotite from altered granodiorite gave a disturbed spectrum that climbed from a low age of 31 Ma to a maximum of 85 Ma. These data probably indicate that the granodiorite is at least 85 Ma, and reheating related to either magmatism or hydrothermal alteration occurred after 31 Ma. Whether sericite formed during this reheating is uncertain.

Quartz-tourmaline veins cut the Gardnerville Formation west of Jumbo and Jurassic gabbro east of the Volcano Mine near Silver City (Gianella, 1936, p. 39). Scattered float of quartz-tourmaline veins in Jurassic gabbro west and south of the Florida Shaft consists of massive white quartz containing 10 to 50% black tourmaline as laths less than 1 mm long. Traces of limonite also occur in the veins. The veins are probably Cretaceous, based on their similarity to other quartz-tourmaline veins of western Nevada (see Doebrich et al., 1996).

GEOLOGIC HISTORY

Geologic history recorded by rocks in the Virginia City Quadrangle began with the deposition of the Gardnerville and Preachers Formations in an arc-related, marine basin during the Late Triassic and Early Jurassic. The rocks are part of a volcanic and sedimentary section that is more than 4,000 m thick in the Pine Nut Range about 50 km south of the Virginia City Quadrangle (Noble, 1962). The thickness of this section, and of equivalent rocks in the Yerington area to the east, requires rapid subsidence, possibly due to extension (Saleeby and Busby-Spera, 1992). The deposition of Mesozoic sedimentary rocks in the area ended with the onset of the Middle to Late Jurassic Nevadan orogeny, which was accompanied by the development of ubiquitous cleavage, local folding, and possibly regional greenschist metamorphism.

Metamorphosed mafic igneous rocks of probable Jurassic age appear to overlie the Mesozoic sedimentary rocks in the Virginia City Quadrangle. These rocks are thought to include both intrusive and extrusive types and may be similar in age and form to the Jurassic (~170 Ma) Humboldt gabbro-basalt complex about 150 km to the northeast, as described by Johnson (2000).

Granitic rocks intruded during the Cretaceous, producing local thermal metamorphism in the Triassic-Jurassic rocks. These rocks comprise the eastern edge of the Sierra Nevada batholith, the deeper remnant of a Jurassic-Cretaceous magmatic arc related to subduction of the Pacific Plate beneath the North American Plate.

No rocks seem to have been deposited or emplaced in the Virginia City Quadrangle between late Cretaceous and Oligocene times (about 85 Ma to 27 Ma). During this period the area was deeply eroded, producing an irregular erosional surface on the Mesozoic basement rocks. This surface was later covered by Oligocene ash-flow tuffs and younger volcanic rocks. The pattern of ash-flow tuff outcrops and the paleorelief on the basement beneath indicates deposition in a southwest-trending paleovalley through American Flat and north of McClellan Peak (fig. 4). A southern branch of the paleovalley that drains from the Yerington area joins the Virginia City paleovalley just southwest of the quadrangle. An outcrop pattern of strips of older tuffs cut off by masses of younger tuffs suggests that the paleovalley was filled and eroded several times in nearly the same position. The Virginia City paleovalley connects westward across Lake Tahoe to the famed, auriferous gravel paleochannels in the Sierra Nevada (fig. 8; Lindgren, 1911; Garside et al., 2005).

Petrographic data and $^{40}Ar/^{39}Ar$ ages show that the upper, quartz-rich part of the Guild Mine Member of the Mickey Pass Tuff correlates with the lower tuff of Mount Jefferson, which erupted from a large caldera in the Toquima Range in central Nevada (fig. 8; Boden, 1992; Garside et al., 2002; Henry and Faulds, in prep.). The Lenihan Canyon Tuff correlates with the upper tuff of Mount Jefferson, which erupted from a caldera inset into the older caldera in the Toquima Range. The Santiago Canyon Tuff correlates with the tuff of Toiyabe, which erupted from a caldera in the Toiyabe Range (Brem et al., 1991; John, 1992). The source of the widespread Nine Hill Tuff is uncertain, but Deino (1989) postulated a source beneath the Carson Sink (fig. 8). The source of the Eureka Canyon Tuff is also unknown.

A depositional gap of as much as 5 million years followed deposition of the regional ash-flow sequence in the Virginia City Quadrangle. Intermediate volcanic rocks of the Silver City magmatic suite were deposited during a ~1-million-year episode (18.3-17.4 Ma). The surface on which the Silver City andesites were deposited appears to have been an erosional surface of some relief, and may have included large paleochannels similar to those underlying the ash-flow tuffs. The source of the Silver City suite rocks, which occur widely in both the Virginia City Quadrangle and Flowery Peak Quadrangle to the east, is not known. The thickest exposed sections are in the southeast part of the Virginia City Quadrangle and the southwest part of the Flowery Peak Quadrangle (Castor et al., 2006), so the source may have been a volcanic center to the south. No dated Silver City suite intrusive rocks are known, but the American Ravine Andesite, which forms several masses intruding Silver City andesites and older rocks in the southeast part of the Virginia City Quadrangle, may be part of the suite. Sericitic alteration west of Jumbo yielded an 18.1 Ma age and may be related to the Silver City magmatic episode.

The Sutro Tuff was deposited during a ~2-million-year period of little or no local volcanic deposition between Silver City suite rocks and the overlying rocks of the Virginia City magmatic suite. The Sutro Tuff consists of bedded sedimentary and volcaniclastic rocks that were laid down in a local basin in the Silver City area. It has not been identified outside the Virginia City Quadrangle. Undated flows of distinctive phenocryst-poor andesite and associated breccias near Jumbo may have been deposited during the time gap between the Silver City and Virginia City magmatic episodes.

The 15.2-Ma to 15.8-Ma rocks of the Virginia City suite are mostly andesitic flows and represent a composite volcano that was centered at or near Virginia City. Vikre (1989) suggested a volcanic crest in the Cedar Hill area, just north of Virginia City. The dominance of flow rock and a general lack of pyroclastic deposits in this rock suite indicate that it does not represent a typical andesitic stratovolcano (Cas and Wright, 1987). However, rocks of the Alta Formation may represent the flow rock-dominated core of this volcano, whereas mixed flow and fragmental rocks of the Kate Peak Formation and the Bailey Canyon and Steamboat Valley sequences may have been deposited more distally. The 15.3-Ma Davidson Diorite pluton and associated dikes, also centered near Virginia City, represent related, but relatively late intrusions into the volcano core. Other intrusions were arguably emplaced during Virginia City magmatism or a later episode. Widespread 15.3–15.5 Ma high-sulfidation (quartz-alunite) alteration in the Virginia City-Jumbo area was associated with this magmatic activity, and quartz-adularia veins west of Jumbo are chronologically indistinguishable. Much of this alteration and mineralization occurs along faults that appear to radiate from a strongly altered area that coincides with the western extent of the main complex of Davidson Diorite intrusions. Quartz-alunite and associated phyllosilicate alteration centered at the north end of Virginia City probably was formed at about the same time.

The Flowery Peak magmatic suite, which includes mostly unaltered flows and breccias deposited between 14.2 Ma and

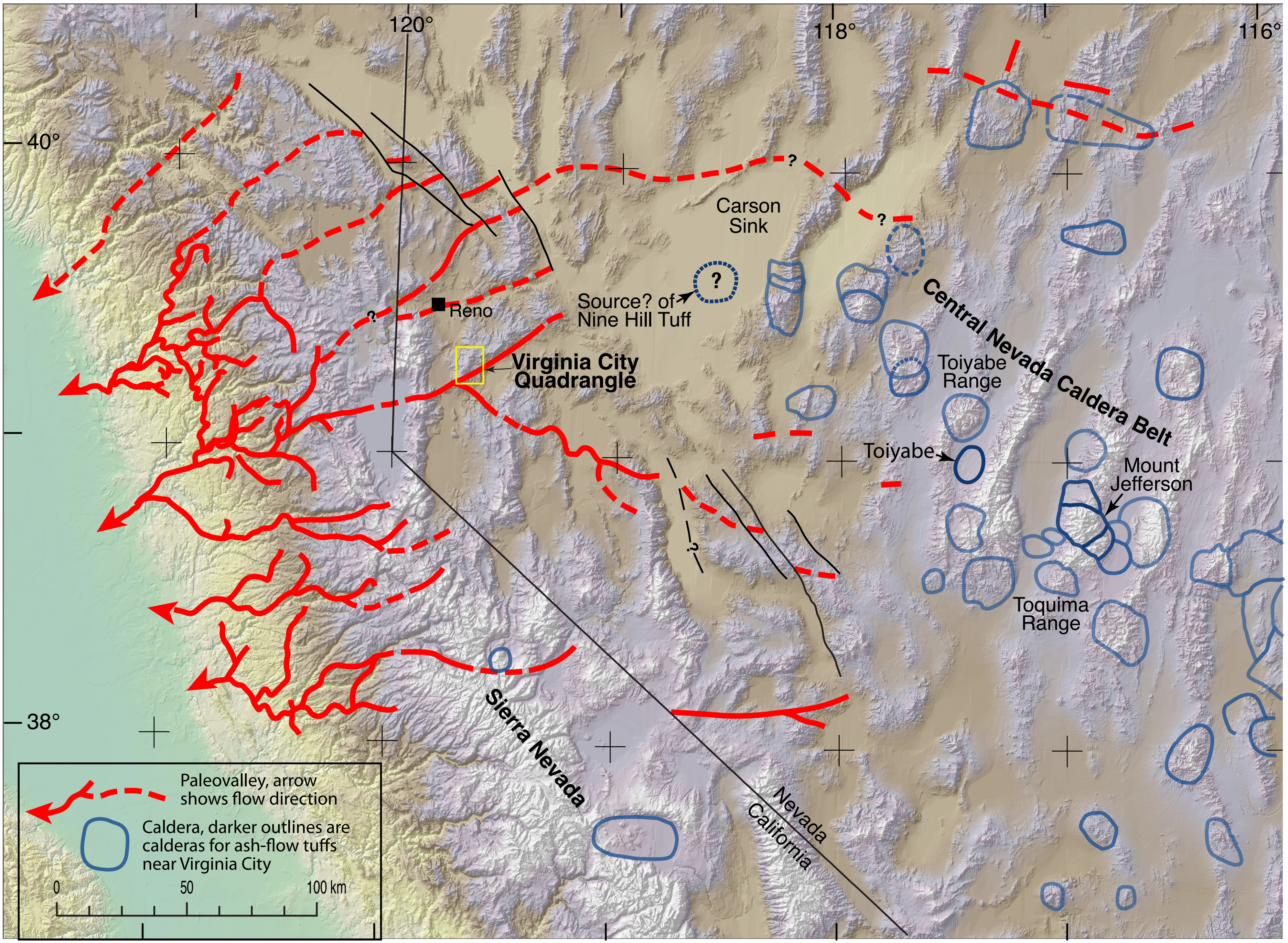

Figure 8. Shaded relief map of central western Nevada and eastern California showing calderas and Eocene-early Miocene paleovalleys.

14.9 Ma in the north part of the Virginia City Quadrangle, lies upon quartz-alunite altered rocks of the Virginia City suite. On the basis of our mapping, this volcanic episode may represent a widespread dome and flow field, rather than a composite volcano. Scattered small intrusive masses and abundant dikes of andesite emplaced between 14.5 and 14.9 Ma are most abundant in the north part of the quadrangle, and form a north-northwesterly swarm through the Virginia City area. The larger intrusive masses lack a structurally preferred orientation and may represent an earlier phase of intrusion. However, numerous dikes intruded along the Comstock, Silver City, and Occidental Lodes or nearby, subparallel structures. These structures were probably early faults, some of which became the focus of mineralization. Such structural control is well displayed around Cedar Hill Canyon and in the hanging wall of the Silver City Lode.

The period of mineralization that formed the highly productive ores of the Comstock and Silver City Lodes occurred at 14.06–14.17 Ma shortly after Flowery Peak suite volcanism. A second period of less productive 13.33–13.53 Ma quartz-adularia mineralization took place along the Occidental and Flowery Lodes to the east. Both mineralization episodes were controlled by east-southeast- to northeast-dipping normal faults which are part of a regional set of similarly oriented down-to-the-east faults that were likely active following the Virginia City magmatic episode. Well developed, post-vein kinematic indicators along the Occidental Lode suggest that primarily dip-slip movement continued after mineralization. A large area of high-sulfidation alteration in the Geiger Grade area in the north part of the Virginia City Quadrangle and the Steamboat Quadrangle to the north yielded an age of 13.49 Ma from alunite along Geiger Grade, which suggests that it took place at about the same time as Occidental and Flowery Lode mineralization.

A dacite dome emplaced along the east edge of the Virginia City Quadrangle at 12.9 Ma does not match other volcanic ages in the quadrangle. However, it may be part of a volcanic episode represented by other domes in the Flowery Peak Quadrangle (Castor et al., in prep.), along with 12.6–12.1 Ma andesitic and dacitic rocks in the Chalk Hills about 5 km north-northeast of the Virginia City Quadrangle (Schwartz and Faulds, 2004).

Little volcanic activity took place in the Virginia City Quadrangle during the late Miocene and Pliocene. At ~8 Ma, black basalt, possibly related to the 7 Ma Lousetown Basalt to the northeast of the quadrangle, was intruded along the Comstock Lode. The big boulder debris flow most likely flowed over a surface of relatively low relief in the late Miocene or Pliocene. The source of the debris is not known, but may have been the Carson Range to the west. Renewed faulting, probably initiated in the Pliocene, reactivated older faults as well as produced new faults. The escarpment along the Comstock fault zone is a result of renewed faulting.

Quaternary deposition in the Virginia City Quadrangle included the McClellan Peak Basalt, a 1.2 Ma lava flow that likely erupted from the area of a plug on the east flank of McClellan Peak and flowed down a paleovalley that passed through American Flat and down American Ravine toward Silver City. Quaternary sediments are mainly alluvial gravels deposited in stream valleys and small basins. Eolian deposits in the western part of the quadrangle were probably sourced from Washoe Valley to the west. Large amounts of mine waste that conceal important aspects of the geology were mainly deposited during the latter part of the 19th Century, particularly in Virginia City. Quaternary fault movement took place along several faults (Table 5) with probable late Quaternary displacement (<130 Ka) along faults in the northwest part of the quadrangle (dePolo, 2008).

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Appendix 1. Chemical analyses of rocks from the Virginia City area. Major oxides reported in weight percent, trace elements in parts per million.

Sample	COM-517	BD	COM-908	C00-161	COM-701	H02-136	COM-902	COM-929	COM-239A
Unit symbol	Qmpb	Tbd	Tod	Tfha	Tfbi	Tfbha	Tfp	Tfp	Tbhap
Laboratory	NBMG	NBMG	NASI	Acme	NASI	WSU	NASI	NBMG	NBMG
SiO_2	48.0	47.9	63.1	61.04	62.2	62.62	61.8	59.4	64.9
TiO_2	2.06	0.95	0.59	0.60	0.58	0.516	0.66	0.64	0.46
Al_2O_3	14.4	17.2	15.8	17.11	16.6	15.77	17.2	17.5	16.4
Fe_2O_3	2.62	3.63	2.68	5.79	2.80	4.699	4.13	3.85	0.08
FeO	7.63	4.40	2.02		2.27		1.56	2.55	5.40
MnO	0.14	0.15	0.09	0.10	0.11	0.069	0.11	0.12	0.10
MgO	9.99	5.74	2.14	2.12	1.99	1.86	1.19	2.62	1.74
CaO	9.93	8.66	4.66	5.68	5.06	3.92	4.71	5.48	3.95
Na_2O	2.74	1.77	4.04	4.13	4.21	3.42	4.04	3.34	4.21
K_2O	1.82	1.03	2.50	2.26	2.42	2.591	2.5	1.77	2.9
P_2O_5	0.79	0.22	0.15	0.20	0.17	0.17	0.21	0.21	0.23
L.O.I.	0.30	6.38	0.96	0.80	0.70	2.5	1.52	2.29	1.02
Sum	100.42	98.03	98.73	99.84	99.11	98.32	99.63	99.77	101.39
Density (g/cc)	2.94	2.92	2.54		2.70		2.50	2.66	2.65

Laboratory			NASI	Acme	NASI	WSU	NASI		NASI
Be			3	1	3		2		3
B			40		40		40		30
Sc			11.1	13.0	10.9	10.2	12.1		7.3
V			94	130	86	110	92		76
Cr			50	27.4	20	29.3	30		30
Co			13	15.2	12	10.3	15		12
Ni			16	5.00	9	9.5	13		16
Cu			25	13.9	33	108.3	28		50
Zn			84	33	79	62.8	89		62
Ge			10		<10		<10		<10
As			3	1.4	2		3		3
Br			3.9		1.5		3.0		2.2
Rb			50	48.0	70	65.6	60		70
Sr			770	652	650	482	780		700
Y			10	14.0	20	12.4	10		20
Zr			60	102		77	80		80
Nb			20	4.0	<10	4.9	20		<10
Mo			<5	0.2	<5	0.9	<5		6
Ag			<0.5	0.3	<0.5		<0.5		<0.5
Cd			1	<.1	<1	0.04	<1		<1
Sb			0.9	0.1	0.3	0.4	0.5		0.7
Cs			2.1	1.9	1.9	1.5	1.5		1.0
Ba			1000	957	1000	1006	1100		1100
La			25.2	18.4	19.6	20.9	21.6		20.6
Ce			43	36.2	32	38.9	39		37
Nd			17	16.8	17	16.7	16		12
Sm			2.97	3.6	2.78	3.09	3.00		2.27
Eu			1.02	0.93	1.18	0.87	0.72		0.73
Tb			<0.5	0.43	<0.5	0.38	<0.5		<0.5
Yb			1.19	1.18	1.31	1.31	0.97		1.08
Lu			0.24	0.19	0.24	0.21	0.20		0.21
Hf			2.9	3.3	3.2	2.4	3.2		4.0
Ta			<1.0	0.3	<1.0	0.4	<1.0		<1.0
W			<3	0.6	<3	0.7	<3		<3
Pb			14	1.4	8	16.9	10		6
Th			7.5	4.4	4.5	7.7	5.7		6.7
U			3.2	2.1	1.9	3.2	2.5		2.9

Appendix 1. (cont.).

Sample	COM-921	C00-169	COM-727A	COM-661	COM-920	COM-925	COM-924	Peak	Tunnel
Unit symbol	Tbhap	Tbhap	Thap	Tdd	Tdd	Tdd	Tdap	Tdd	Tdd
Laboratory	NASI	Acme	NASI	NASI	NASI	NBMG	NASI	USGS	USGS
SiO_2	57.4	60.31	61.7	57.6	61.7	58.9	57.7	61.1	63.4
TiO_2	0.67	0.59	0.58	0.72	0.61	0.71	0.78	0.33	0.27
Al_2O_3	16.4	17.52	16.6	17.0	16.4	17.2	17.5	17.6	16.5
Fe_2O_3	1.99	5.24	1.86	0.78	0.64	1.88	1.49	2.8	2.4
FeO	4.01		3.60	7.11	4.91	4.26	4.54	3.0	2.3
MnO	0.10	0.05	0.11	0.15	0.07	0.17	0.13	0.71	0.07
MgO	2.92	1.90	2.41	2.95	2.25	2.94	3.31	3.3	2.5
CaO	6.49	5.30	5.23	5.66	3.55	4.99	5.92	4.6	4.8
Na_2O	2.72	3.93	3.72	3.93	4.61	3.71	3.54	3.69	4.11
K_2O	1.65	2.51	2.32	2.29	3.19	3.39	2.45	2.63	2.51
P_2O_5	0.18	0.19	0.17	0.22	0.18	0.22	0.21	0.27	0.22
L.O.I.	3.46	2.30		0.41	1.02	1.00	1.84	1.67	1.05
Sum	97.99	99.84	98.30	98.82	99.13	99.37	99.41	101.70	100.13
Density (g/cc)	2.58		2.66	2.73	2.69	2.69	2.71		

Laboratory	NASI	Acme	NASI	NASI	NASI		NASI	USGS	USGS
Be	4	<1	3	3	2		4		
B	20		30	30	90		30		
Sc	15.5	11.0	11.2	13.8	9.6		17.8	15.0	10.0
V	160	120	92	120	92		160	100	70
Cr	20	6.8	30	60	50		50		
Co	16	11.9	14	19	13		18	15	10
Ni	11	5	12	32	20		21	20	15
Cu	42	21.5	47	76	61		59	30	70
Zn	90	58	83	86	29		90		
Ge	<10		<10	<10	<10		<10		
As	2	<.5	2	10	12		5		
Br	2.5		1.1	3.1	2.7		2.5		
Rb	20	51.2	70	60	100		60	62	61
Sr	950	630	780	710	630		850	620	580
Y	10	15.5	20	10	10		20	20	15
Zr	80	106	100	100	120		100	150	100
Nb	<10	4.2	<10	10	10		<10		
Mo	6	0.4	<5	6	9		<5		
Ag	<0.5	<.1	<0.5	<0.5	<0.5		<0.5		
Cd	<1	0.1	<1	<1	<1		<1		
Sb	0.7	0.1	0.5	1.7	2.2		1.0		
Cs	1.1	1.3	1.1	1.0	1.6		0.8		
Ba	1400	943	1100	900	1200		1200	1000	1000
La	18.0	18.0	18.1	22.2	21.1		19.6		
Ce	36	34.0	36	43	45		40		
Nd	16	15.8	12	18	20		18		
Sm	2.71	3.1	2.49	3.16	2.86		3.18		
Eu	1.01	0.89	1.01	1.16	0.81		0.99		
Tb	<0.5	0.47	<0.5	<0.5	<0.5		<0.5		
Yb	1.26	1.41	1.13	1.40	1.18		1.46	2	1.5
Lu	0.21	0.26	0.22	0.24	0.24		0.26		
Hf	3.6	3.7	3.2	3.9	4.4		4.3		
Ta	<1.0	0.3	<1.0	<1.0	<1.0		<1.0		
W	<3	0.4	<3	<3	<3		<3		
Pb	12	4.3	8	8	4		10		
Th	4.3	4.1	4.4	5.5	6.6		4.8	5.4	7.6
U	2.2	2.1	2.5	2.2	2.7		2.4	1.4	2.5

Appendix 1. (cont.).

Sample	C7	C00-136	COM-285A	COM-928	C01-8	COM-147A	COM-148	COM-202	COM-222A
Unit symbol	Tdd	Tvsu	Tvka	Tvka	Tvbh	Tva	Tva	Tva	Tva
Laboratory	USGS	Acme	NBMG	NBMG	Acme	NBMG	NBMG	NBMG	NBMG
SiO_2	62.0	58.62	59.5	59.5	57.95	58.0	58.8	59.7	58.9
TiO_2	0.62	0.69	0.74	0.65	0.64	0.70	0.66	0.73	0.81
Al_2O_3	16.6	16.50	16.7	16.6	17.99	17.1	17.6	16.8	17.8
Fe_2O_3	2.9	6.61	3.37	1.49	6.12	1.21	2.31	2.07	0.92
FeO	2.5		3.05	4.26		5.25	4.04	3.97	6.40
MnO	0.04	0.14	0.15	0.10	0.10	0.14	0.14	0.11	0.18
MgO	2.2	3.06	2.72	2.83	2.91	2.42	2.69	3.20	3.02
CaO	4.0	6.83	5.69	6.00	6.32	6.92	6.07	5.72	5.74
Na_2O	3.90	3.68	3.86	2.34	3.97	3.22	3.27	3.51	3.82
K_2O	2.93	1.98	2.65	2.74	1.72	1.76	1.81	2.31	1.77
P_2O_5	0.19	0.18	0.26	0.22	0.19	0.25	0.23	0.29	0.26
L.O.I.	2.58	1.40	1.21	2.39	1.90	2.78	1.79	2.75	1.45
Sum	100.46	99.71	99.90	99.12	99.82	99.75	99.41	101.16	101.07
Density (g/cc)	2.66		2.66	2.66		2.72	2.66	2.68	2.72

Laboratory	USGS	Acme			Acme	NBMG	NBMG	NBMG	NBMG
Be		1			1				
B									
Sc	10.0	18.0			12.0				
V		174			134				
Cr		41.0			34.2	49	26	48	57
Co	10	20.3			15.5				
Ni	3	5			25				
Cu	8	40.1			20.6				
Zn	17	47			35				
Ge									
As		1.0			<.5				
Br									
Rb	67	43.1			31.4	46			
Sr	515	696			681	624	624	1016	662
Y	15	19.1			16.0	25	22	25	24
Zr	150	98			114	153	128	170	142
Nb		3.3			4.5	8	4	11	5
Mo		0.9			0.6				
Ag		<.1			<.1				
Cd		0.1			0.1				
Sb		0.1			0.1				
Cs		1.4			1.4				
Ba	700	1865			893	754	978	1324	921
La		19.5			18.1				
Ce		35.7			32.8				
Nd		19.8			16.2				
Sm		4.9			3.3				
Eu		1.22			0.89				
Tb		0.64			0.46				
Yb	2	1.92			1.46				
Lu		0.29			0.21				
Hf		3.6			3.8				
Ta		0.4			0.3				
W		0.5			0.6				
Pb	37	2.0			2.6				
Th	18.0	4.0			5.1	19	10	26	14
U	2.6	4.4			1.6				

Appendix 1. (cont.).

Sample	COM-247A	COM-252A	COM-440	COM-548A	COM-679	COM-898	COM-911	COM-922	COM-923
Unit symbol	Tva	Tva	Tva	Tva	Tva	Tva	Tva	Tva	Tva
Laboratory	NBMG	NBMG	NBMG	NBMG	NBMG	NASI	NBMG	NBMG	NASI
SiO_2	57.8	59.0	58.3	58.8	57.7	56.0	58.2	57.5	57.7
TiO_2	0.83	0.74	0.82	0.74	0.73	0.83	0.65	0.74	0.64
Al_2O_3	17.9	17.3	17.6	17.8	17.0	17.8	16.5	16.9	17.5
Fe_2O_3	3.00	1.93	2.39	2.78	1.10	2.85	1.12	2.76	1.12
FeO	3.97	4.58	4.61	3.55	5.96	4.53	5.37	4.36	5.97
MnO	0.14	0.17	0.13	0.01	0.14	0.14	0.12	0.22	0.13
MgO	3.38	3.25	3.13	2.88	3.25	3.21	2.20	2.85	2.80
CaO	6.97	6.14	6.44	6.36	5.73	6.65	6.26	6.63	6.27
Na_2O	3.30	3.59	3.42	3.83	3.18	3.75	3.13	2.75	3.65
K_2O	1.38	1.43	1.89	1.64	2.13	1.87	2.02	2.06	1.61
P_2O_5	0.25	0.24	0.25	0.28	0.14	0.23	0.21	0.22	0.22
L.O.I.	1.81	1.55	1.75	1.21	1.04	0.63	3.21	3.03	1.81
Sum	100.73	99.92	100.73	99.88	98.10	98.49	98.99	100.02	99.42
Density (g/cc)	2.69	2.68	2.93	2.69	2.68	2.73	2.69	2.66	2.72

Laboratory	NASI	NASI	NBMG	NBMG		NASI			NASI
Be	3	4				4			5
B	30	30				30			30
Sc	14.7	13.0				17.6			11.5
V	150	130				150			120
Cr	20	40	46	49		20			30
Co	19	17				19			18
Ni	12	20				15			18
Cu	53	55				52			59
Zn	94	120				91			91
Ge	10	20				<10			20
As	3	3				2			2
Br	1.4	2.2				2.4			1.9
Rb	30	30				50			30
Sr	800	760	642	969		650			760
Y	20	20	25	23		<10			10
Zr	160	170	164	125		80			70
Nb	20	<10	9	5		10			20
Mo	<5	<5				<5			7
Ag	<0.5	<0.5				<0.5			<0.5
Cd	<1	<1				<1			<1
Sb	0.9	0.8				0.3			0.6
Cs	0.9	0.9				1.0			1.5
Ba	860	970	854	697		740			980
La	16.6	18.3				17.0			17.0
Ce	34	34				32			33
Nd	17	17				16			20
Sm	2.95	2.84				3.03			2.70
Eu	1.17	0.99				1.22			0.88
Tb	0.5	<0.5				0.6			<0.5
Yb	1.49	1.44				1.48			1.41
Lu	0.23	0.24				0.25			0.24
Hf	3.1	4.2				3.6			3.1
Ta	<1.0	<1.0				<1.0			<1.0
W	<3	<3				<3			<3
Pb	8	10				6			10
Th	3.1	4.7	19	17		3.4			3.2
U	1.8	2.2				1.6			1.6

Appendix 1. (cont.).

Sample	COM-926	C05-219	C05-226	C01-20	COM-953	C02-26	C00-51	H01-6	C00-112
Unit symbol	Tva	Tva	Tva	Tvah	Tara	Tap	Tsa	Tsa	Tsa
Laboratory	NBMG	Acme	Acme	WSU	NBMG	Acme	Acme	WSU	WSU
SiO_2	58.8	58.82	58.42	58.72	55.3	61.09	56.98	57.19	55.5
TiO_2	0.67	0.68	0.67	0.652	0.93	0.48	0.63	0.789	0.78
Al_2O_3	17.4	17.48	17.71	17.57	18.2	16.22	17.59	17.45	17.39
Fe_2O_3	1.48	6.20	6.37	5.857	7.12	4.63	6.78	5.85	6.977
FeO	5.43				n.d.				
MnO	0.13	0.11	0.11	0.1	0.11	0.10	0.12	0.094	0.114
MgO	3.24	3.03	2.95	2.87	2.80	1.92	3.05	3.27	4.68
CaO	6.49	5.73	5.96	5.89	5.36	5.22	7.08	6.32	5.15
Na_2O	3.39	3.90	3.63	4.05	4.93	2.96	3.74	4.21	5.25
K_2O	1.73	2.22	2.18	1.652	2.40	2.69	1.45	1.739	2.195
P_2O_5	0.26	0.25	0.23	0.24	0.44	0.16	0.23	0.3	0.27
L.O.I.	1.08	1.40	1.60	1.9	1.67	4.40	2.00	2.5	1.8
Sum	100.10	99.83	99.83	97.81	99.26	99.87	99.65	99.94	100.33
Density (g/cc)	2.70								

Laboratory		Acme	Acme	WSU		Acme	Acme	WSU	WSU
Be		1	1			1	2		
B									
Sc		13.0	12.0	10.9		7.0	11.0	11.8	16.8
V		139	131	130		79	123	155	171
Cr		34.2	27.4	37.9		6.8	13.7	42.7	109.2
Co		15.5	15.9	15.4		10.7	15.9	16.4	22.8
Ni		25.0	21.0	19.1		5.0	9.0	16.9	47.0
Cu		25.0	36.2	42.8		14.9	39.0	21.2	92.5
Zn		48	39	67.6		49	39	75.3	71.1
Ge									
As		1.9	0.7			0.6	3.4		
Br									
Rb		43.7	33.3	34.7		74.9	49.3	31.3	52.3
Sr		739	705	808		419	1067	993	717
Y		15.7	16.0	12.2		14.9	14.9	13.4	14.0
Zr		128	112	115		119	100	122	119
Nb		4.9	4.2	4.6		31.0	3.9	4.2	4.4
Mo		1.0	0.4	0.8		0.3	0.7	0.6	0.8
Ag		<.1	<.1			<.1	<.1		
Cd		<.1	0.1	0.06		0.1	0.1	0.07	0.06
Sb		0.2	0.1	0.8		0.4	0.1	0.6	0.3
Cs		0.9	<0.1	1.0		15.0	121	1.2	1.4
Ba		1055	1098	840		851	811	816	1023
La		19.5	17.3	19.4		19.3	16.5	20.1	17.8
Ce		40.1	35.1	39.1		38.5	32.6	42.0	38.4
Nd		20.6	15.8	19.25		16.2	15.5	21.84	20.02
Sm		4.3	3.4	3.7		3.1	3.3	4.27	3.96
Eu		1.09	0.99	1.05		0.86	1.00	1.17	1.14
Tb		0.48	0.44	0.41		0.38	0.43	0.46	0.48
Yb		1.26	1.53	1.17		1.39	1.35	1.25	1.37
Lu		0.23	0.23	0.18		0.23	0.22	0.19	0.20
Hf		3.7	3.6	3		3.5	3.2	3.3	3.2
Ta		0.4	0.3	0.3		0.5	0.3	0.2	0.3
W		0.8	0.8	0.4		0.8	0.6	0.3	0.3
Pb		3.9	2.4	10.8		3.5	1.0	11.9	9.7
Th		4.4	3.8	4.1		4.6	3.2	4.9	3.7
U		2.0	1.8	1.7		2.3	1.4	2.1	1.3

Appendix 1. (cont.).

Sample	C00-84	C00-47	COM-912	G-1	G-2	G-3
Unit symbol	Tshp	Tsh	Kg	Jm	Jm	Jm
Laboratory	WSU	WSU	NBMG	NBMG	NBMG	NBMG
SiO_2	59.64	55.29	69.4	50.8	50.1	47.2
TiO_2	0.673	0.893	0.42	0.85	0.84	0.92
Al_2O_3	18.12	17.17	15.1	18.4	19.1	16.9
Fe_2O_3	5.328	7.401	0.10	3.42	2.18	2.82
FeO			3.32	6.82	5.89	8.10
MnO	0.152	0.128	0.06	0.18	0.19	0.24
MgO	2.31	3.76	0.92	5.27	5.47	6.26
CaO	4.18	6.07	2.84	8.92	5.13	13.36
Na_2O	5.23	4.42	3.96	3.65	5.59	1.27
K_2O	2.089	1.424	3.11	0.82	0.19	0.77
P_2O_5	0.28	0.31	0.13	0.45	0.48	0.40
L.O.I.	1.6	3.2	0.46	0.88	2.22	0.88
Sum	99.86	100.28	99.82	100.46	97.38	99.12
Density (g/cc)			2.67	2.91	2.83	3.07

Laboratory	WSU	WSU		NASI		NASI
Be						
B						
Sc	10.2	15.7		23.7		38.0
V	134	188				
Cr	26.3	44.3		10		60
Co	11.5	20.2		25		32
Ni	5.9	19.9		<50		<50
Cu	12.9	19.3				
Zn	73.9	76.3		71		100
Ge						
As				2		2
Br				1.8		3.9
Rb	44.6	25.1		30		<10
Sr	873	899		1400		1800
Y	17.0	16.4				
Zr	137	115				
Nb	4.8	4.8				
Mo	0.6	0.7		<2		4
Ag				<2		<2
Cd	0.08	0.06				
Sb	0.2	0.8		2.2		1.2
Cs	1.6	1.7		2.1		0.9
Ba	1038	749		390		540
La	25.6	18.8		22.2		23.9
Ce	52.2	40.9		42		44
Nd	26.15	22.39		22		22
Sm	4.84	4.57		4.93		4.53
Eu	1.28	1.30		1.76		1.84
Tb	0.54	0.54		0.6		0.5
Yb	1.59	1.62		1.90		1.54
Lu	0.25	0.24		0.28		0.22
Hf	3.6	3.1		1.9		1.3
Ta	0.3	0.3		<0.5		<0.5
W	0.3	0.5				
Pb	11.7	7				
Th	4.8	2.8		3.3		2.3
U	1.6	1.1		1.7		1.1

Appendix 2. Location data (NAD27) and descriptions of analyzed rocks in Table 5 from the Virginia City area that are not given in Table 4.

Appendix 2							
Sample Number	Lat. Deg.	Lat. Minutes	Long. Deg.	Long. Minutes	Map Symbol	Description	Comment
COM-517	39	16.108	119	39.912	Qmpb	weakly vesicular olivine basalt lava	
BD	39	18.220	119	39.110	Tbd	weakly clay altered basalt dike	400 level, New Savage Mine
COM-908	39	17.963	119	37.500	Tod	biotite-hornblende dacite intrusion or lava dome	
C00-161	39	21.54	119	42.13	Tfha	pyroxene-hornblende andesite lava	
COM-701	39	19.962	119	40.166	Tfbi	biotite-hornblende andesite lava dome	
H02-136	39	21.405	119	39.670	Tfbha	biotite-hornblende andesite lava dome	
COM-902	39	20.228	119	38.277	Tfp	biotite-hornblende andesite lava	
COM-929	39	19.272	119	38.561	Tfp	biotite-hornblende andesite lava	
COM-239A	39	16.976	119	38.194	Tbhap	very weakly propyltized dike	
COM-921	39	20.223	119	39.527	Tbhap	very weakly propyltized plug	
C00-169	39	21.37	119	41.71	Tbhap	hornblende andesite dike with biotite	
COM-727A	39	20.118	119	39.141	Thap	very weakly propyltized dike	
COM-661	39	18.492	119	39.746	Tdd	weakly actinolized pyroxene quartz diorite	
COM-920	39	18.095	119	39.534	Tdd	weakly actinolized pyroxene diorite	
COM-925	39	18.775	119	40.750	Tdd	very weakly altered pyroxene quartz diorite	
COM-924	39	19.061	119	40.371	Tdap	weakly propyltized pyroxene andesite dike	
C00-136	39	20.84	119	44.46	Tvsu	pyroxene-hornblende andesite lava with biotite and olivine	
COM-285A	39	17.016	119	37.361	Tvka	hornblende andesite lava	not on quad
COM-928	39	17.300	119	37.810	Tvka	weakly propylitized biotite-hornblende andesite lava	
C01-8	39	19.85	119	43.26	Tvbh	hornblende andesite lava	
COM-147A	39	16.889	119	38.444	Tva	weakly propylitized pyroxene andesite lava	Tk, Hudson (2003)
COM-148	39	16.732	119	38.337	Tva	weakly propylitized pyroxene andesite lava	
COM-202	39	17.281	119	39.484	Tva	weakly propylitized hornblende pyroxene andesite lava	
COM-222A	39	17.935	119	40.220	Tva	weakly propylitized hornblende pyroxene andesite lava	
COM-247A	39	18.015	119	38.175	Tva	weakly propylitized pyroxene hornblende andesite lava	
COM-252A	39	18.775	119	38.110	Tva	weakly propylitized pyroxene andesite lava	
COM-440	39	18.386	119	37.764	Tva	weakly propylitized pyroxene hornblende andesite lava	
COM-548A	39	17.006	119	41.236	Tva	weakly propylitized hornblende andesite lava	
COM-679	39	19.065	119	40.539	Tva	weakly propylitized hornblende andesite lava	
COM-898	39	20.246	119	40.978	Tva	two pyroxene andesite lava	
COM-911	39	16.843	119	39.802	Tva	weakly propylitized pyroxene andesite lava	Tk, Gianella (1936)
COM-922	39	19.820	119	39.962	Tva	weakly propylitized pyroxene andesite lava	
COM-923	39	19.411	119	40.257	Tva	weakly propylitized pyroxene andesite lava	
COM-926	39	16.526	119	40.822	Tva	pyroxene andesite lava	Tk, Hudson (2003)
C05-219	39	20.12	119	39.83	Tva	pyroxene-hornblende andesite lava	
C05-226	39	19.93	119	39.07	Tva	hornblende-pyroxene andesite lava	
C01-20	39	18.20	119	42.56	Tvah	hornblende andesite lava	
COM-953	39	15.195	119	37.768	Tara	hornblende andesite plug	
C02-26	39	17.47	119	42.81	Tap	phenocryst-poor andesite lava	
C00-51	39	16.68	119	42.01	Tsa	two pyroxene andesite lava	
H01-6	39	16.37	119	38.88	Tsa	hornblende andesite lava	
C00-112	39	16.64	119	41.59	Tsa	hornblende andesite breccia clast	
C00-84	39	16.83	119	42.61	Tshp	hornblende andesite lava	
C00-47	39	16.68	119	42.80	Tsh	hornblende andesite lava	
COM-912	39	16.273	119	40.624	Kg	hornblende biotite granite	Rock Island dump
G-1	39	15.103	119	40.722	Jm	actinolite and biotite altered pyroxene gabbro	
G-2	39	15.033	119	40.641	Jm	actinolite altered pyroxene gabbro	
G-3	39	15.000	119	40.732	Jm	actinolite and biotite altered pyroxene gabbro porphyry	

APPENDIX 3. Detailed petrographic information on selected rock units

Tbdf Big boulder debris flow

Tbdf contains clasts of many lithologic types, but the most common type is finely porphyritic pyroxene andesite. Although there are a number of textural variations, in general this andesite contains 20 to 45% phenocrysts to 3 mm (generally <2 mm) across of plagioclase, augite, and lesser orthopyroxene (table 1). Equant plagioclase to 3 mm occurs in some of the andesite boulders, while other andesite boulders are scarcely phenocrystic but have well-developed platy jointing that helps differentiate this laharic unit from others. Plagioclase phenocrysts tend to have 1:3 elongation, but some are more stubby. They are commonly somewhat castellated, having oscillatory-normal zoning averaging about An65. Some have glassy cellular zones. The rock also contains small stubby, euhedral dark hypersthene and pale-green augite, and magnetite phenocrysts. The matrix consists of variable amounts of plagioclase and pyroxene microlites in black glass.

Tfp Flowery Peak andesites

Plagioclase phenocryst size and shape is characteristic of Flowery Peak suite andesites, although in some flows it is not obvious. The plagioclase phenocrysts are generally stubby, anhedral, equant grains. Typically more than half of the plagioclase grains are complex aggregates of 2 to 10 fragments that are 3 to 10 mm across and tend to form irregular equant clusters or have a castellated appearance in hand sample. The aggregates commonly show several periods of construction with common zones growing around each stage of aggregation. Individual component grains generally have crystallographic axes at random orientations. Zoning in the plagioclase phenocrysts is typically highly complex and variable from phenocryst to phenocryst in the same rock. Cellular sieve texture, often glassy, is common in crystal growth zones, along with resorbed zones and fluting of zones.

Tbhap Biotite hornblende andesite dikes

Plagioclase phenocrysts in Tbhap are relatively large in comparison to those in host flow rocks. They are typically poorly formed, equant grains 3–10 mm across. Even in strongly altered rock, these large plagioclase grains are diagnostic. Microscopically, they are resolved as conjoined aggregates of 2 to 10 fragments. The plagioclase phenocrysts average An40-47 where determined (in many specimens plagioclase is too altered). Zoning tends to be highly complex and variable from phenocryst to phenocryst in the same rock. Cellular zones, often glassy, are common throughout crystal growth, along with resorbed zones and fluting of zones. Plagioclase aggregates often show several periods of aggregation with common zones growing around each stage of aggregation. Aggregates tend to have crystallographic axes at random orientations. Hornblende phenocrysts generally contain plagioclase inclusions and some are corroded and partially replaced by biotite and/or pyroxene. Some have magnetite rims. The presence of biotite distinguishes Tbhap from other intrusive types. An elongate intrusive body that crops out about 0.5 km east of Geiger Summit contains only a trace of biotite, but is otherwise similar to other Tbhap dikes and intrusive masses in the area. Sparse, round quartz phenocrysts to 1 mm, but generally less than 0.5 mm across, occur in a few of the intrusions. Minor magnetite is present as grains to 0.7 mm. In some specimens, traces of apatite as clear prisms to 0.1 mm long, and zircon as tiny grains, are present. The matrix consists of variable proportions of plagioclase microlites, biotite microlites, brown devitrified glass or black glass. Typically there is a clear distinction in size between the plagioclase phenocrysts and the groundmass microlites.

A swarm of propylitized hornblende biotite andesite porphyry dikes near the Mahoney Mine at Jumbo is included in Tbhap. It is typified by abundant subhedral to euhedral green hornblende phenocrysts generally less than 4 mm long but with a few up to 1 cm long (elongation 1:3 to 1:5). The hornblende contains many inclusions of plagioclase and some of augite. Abundant andesine phenocrysts include some conjoined grains, but they are not as common as in the rocks in the northern and eastern part of the quadrangle. About 25% of the plagioclase phenocrysts have cellular zones (commonly several zones) while the rest have non-cellular oscillatory-normal zoning. The rock contains minor magnetite, biotite, and quartz phenocrysts. The phenocrysts grade in size nearly to matrix plagioclase and hornblende microlites that average about 0.05 mm long.

On the east flank of Basalt Hill, an intrusion crops out that is similar to the Mahoney Mine dikes except that it contains large xenoliths (or pendants) of Santiago Canyon Tuff and Virginia City volcanics. This variably altered intrusion contains phenocrysts that are similar to those in the Mahoney Mine dikes, but there is no quartz and a trace of apatite. There is a fairly sharp break in size between the phenocrysts and squarish plagioclase microlites in the matrix, which also contains about 20% glass.

Thpap Hollow hornblende-pyroxene andesite porphyry

Andesite porphyry with abundant distinctive "hollow" hornblende phenocrysts to 3 cm long crops out northeast of Silver City. The "hollow" hornblendes, brownish-green in thin section, have discontinuous matrix-filled central cavities along the c-axis. Formation of the cavities took place during primary growth, because compositional zones in the hornblende are parallel to the cavity walls and cut off by them. The hornblende is partly replaced by magnetite, and may have corroded rims replaced by microscopic intergrowths of plagioclase, augite, and brown hornblende. Andesine phenocrysts, some with spongy outer zones, are as much as 2 mm long. The plagioclase and augite phenocrysts grade in size to a matrix of microlites, magnetite, and about 20–30% brown devitrified glass.

Tdd Davidson Diorite

Fine-grained diorite that is similar in composition to the Davidson Diorite is found mostly in the hanging wall of the Comstock Lode. It is subequigranular with average crystal size of about 0.5 mm and some crystals up to 1 mm. The hanging-wall diorite contains major plagioclase, altered pyroxene, and small amounts of quartz and orthoclase (table 1), and is included with the Davidson Diorite due to similarities in composition. However, it is distinctively finer grained. This diorite does not crop out, but the Becker Collection contains numerous samples from underground localities in the Sierra Nevada, Union, Mexican, and Ophir Mines along with a few samples from the footwall in the Yellow Jacket and Crown Point Mines.

A multi-phased plug of fine-grained propylitized diorite west of Jumbo is probably correlative with Tdd; however, the Jumbo area rock is relatively fine-grained (grain sizes of 0.2 to 0.7 mm in different textural types). Plagioclase, varying from subhedral to anhedral in different types, makes up most of the rock. Anhedral brown biotite is minor. Other mafic minerals are completely altered but appear to have included minor augite; one diorite type contains thin prisms to 4 mm of what may have been orthopyroxene. The rock contains minor interstitial anhedral quartz and orthoclase, minor magnetite, and a trace of apatite.

Tdap andesite porphyry

Intrusive andesitic porphyry Tdap is considered to be equivalent to Tdd. In places north of the Scorpion Shaft, phaneritic Tdd was found to grade into Tdap over about 3 m. north of Crown Point Ravine, a dike of phaneritic Tdd grades into Tdap over a vertical extent of about 6 m. In the vicinity of the Scorpion Shaft and the East Yellow Jacket Shaft, Tdap grades in texture to a rock that resembles andesite of the Virginia City volcanics.

Tva Alta Formation

Tva contains variable amounts of stubby plagioclase phenocrysts (elongation about 1:2) that rarely exceed 2 mm in length. The plagioclase is weakly to moderately oscillatory-normal zoned andesine-labradorite (table 1). Commonly 10 to 40% of the plagioclase phenocrysts have spongy cellular zones, generally near the outer rim. Augite and less abundant orthopyroxene phenocrysts rarely exceed 1 mm in length and commonly form clumps with each other or with plagioclase and magnetite; in some cases the clump interstices are filled with brown glass. Some flows contain sparse to abundant brown hornblende phenocrysts commonly less than 2 mm long, but in some flows as much as 7 mm long. The hornblende generally has thin rims of, or is partially to completely replaced by, magnetite or hematite. "Hollow" hornblende phenocrysts similar to those in Thpap (see above) occur in some flows. Magnetite crystals to 0.5 mm are present. Phenocrysts generally grade in size to a locally pilotaxitic matrix that makes up 20–40% of the rock and consists mainly of plagioclase microlites in brown glass. However, in most rocks the glass is devitrified, probably in large part due to hydrothermal alteration.

Biotite, normally absent from Alta Formation rocks, occurs in flows between Mt. Abbie and Orleans Hill, and north of the Scorpion Shaft. Here, medium reddish brown weathering, dark brown biotite-bearing flows, commonly with indistinct flow foliation, contain 40-60% phenocrysts that rarely exceed 3 mm. Plagioclase phenocrysts are typically stubby and weakly zoned andesine, some with spongy cellular zones. Pyroxene phenocrysts, about equal amounts of augite and orthopyroxene, comprise 5 to 10% of the rock. Shreddy brown biotite makes up less than 1% of the rock, generally as grains <1 mm. These flows are interbedded with hornblende-pyroxene andesite flows, probably about 900 m or more above the base of Tva. They are not mapped separately because of poor exposure, locally intense alteration, and general lithologic similarity to other Alta Formation rocks.

Tva is mostly composed of flows, but breccias occur locally. Breccias a few meters thick occur rarely at the base of Tva flows near Jumbo. A relatively thick section of lahars crops out northeast of Orleans Hill and volcanic breccia is present just to the north, about 1 km east of Geiger Summit. A thin lahar also occurs near Ophir Hill.

Tvah Hornblende andesite

Tvah is distinctive hornblende-rich andesite. Euhedral black hornblende phenocrysts, pale-brown to pale-olive in thin section, are abundant. The hornblende phenocrysts are nearly all less than 5 mm long, but larger crystals as much as 3 cm long generally comprise less than 1% but in some cases as much as 10% of the rock. Hornblende elongation averages about 8:1. The hornblende has been partially to almost totally replaced by magnetite and other minerals. The rock also contains abundant plagioclase crystals to 5 mm long that grade in size to the matrix.

Tvbl Bailey Canyon sequence debris flows

Tvbl is at least 70 m thick in the north part of Bailey Canyon. There it consists of matrix- to clast-supported breccias with clasts of vesicular to dense glassy medium- to dark-gray two-pyroxene andesite, dark olive-green glassy to light greenish-gray devitrified hornblende andesite, and dense dark-gray finely porphyritic andesite, along with minor amounts of reddish-brown scoria in pinkish-gray to pale brownish gray matrix. At least 70 m of heterolithic andesitic lahars are exposed about 3 km northwest of Jumbo. The lahars contain andesite clasts similar in texture to andesites in the Alta Formation of the Virginia City volcanics. There are also up to 15% clasts of black basaltic (?) andesite. The clasts are up to 1 m in diameter but most are less than 50 cm, and commonly somewhat rounded and spherical. The matrix is sand and mud, and the unit forms subdued outcrops here or does not crop out.

Ts Sutro Tuff

The Sutro Tuff is as much as 60 m thick in Negro Ravine in the hanging wall of the Comstock Lode, but it pinches out to the southwest near the Woodville Shaft. Gianella (1936) found it in several locations in the Sutro Tunnel in both the footwall and hanging wall of the Occidental Lode, and a thick section that he estimated to be 960 ft (ca. 290 m) thick was intercepted in the south lateral of the Sutro Tunnel near the East Yellow Jacket Shaft (V.P. Gianella, unpublished notes, NBMG mining district files). The Sutro consists of about 65 m of lapilli tuff with some silt- to coarse-sand-size water-lain tuff or sedimentary beds in Long Canyon south of the Occidental Shaft. This bedded section is overlain by about 5 m of pebble breccia with clasts of fine tuff or sedimentary rock. Sparse clasts of granitic rock occur in the basal part of the Sutro at this locality.

In the footwall of the Comstock Lode, a thick section of moderately to steeply east dipping Sutro Tuff is exposed in the Suicide Rock area between Ophir Grade and Crown Point Ravine. Calkins (1945) estimated Sutro thickness to be between 300 and 500 feet (90 and 150 m) here, but noted that structural complexity made this estimate uncertain. In this area, the Sutro includes fine-grained sedimentary rock or bedded tuff, sandy to conglomeritic beds, and some ash-flow tuff. A section of Sutro Tuff about 80 m thick is exposed along the Ophir Grade to the west of Suicide Rock. The upper half of this section is well exposed and consists of sandstone, pebble conglomerate, pumiceous non-welded ash-flow tuff, and minor siltstone. The lower half, which is poorly exposed, appears to consist mostly of ash-flow tuff, heterolithic breccia, and minor pyroxene andesite. The northernmost extent of the Sutro Tuff is a section of laminated, fine-grained, white sandstone, and andesitic conglomerate as much as 4 m thick north of Cedar Hill Canyon.

Calkins (1945) reported “a small collection of leaves from the Sutro member obtained in a cut on the new highway in the lower part of Long Canyon, southwest of the 5,229-foot hill, is judged by Roland W. Brown to be middle or upper Miocene.” A small area of Sutro was mapped by Calkins and Thayer (1945) at this locality, and this outcrop area was transferred to the later map of Thompson (1956). The locality plots directly on State Route 341, on the south part of a loop in the highway, less than 0.5 km southeast of Silver City (NW¼ SE¼ SW¼ Sec. 9, T16N, R21E). Axelrod (1949, 1966) reported additional material was collected in 1946 and 1953. He originally suggested an Oligocene age for the Sutro, but later indicated it was probably Miocene. We were unable to locate any fossil leaves at the locality shown on the Calkins and Thayer (1945) map. The cited locality is along a fault contact between Tsa and Tst, is likely low in the Tsa section, and thus does not represent Sutro Tuff.

Tsa Silver City andesite

Tsa flows typically have small stubby plagioclase phenocrysts (elongation about 1:2) that are weakly to strongly zoned from about An70 to An35. The largest phenocrysts locally have amoeboid shapes. Plagioclase phenocrysts are predominantly isolated grains but a few glomeroporphyritic phenocrysts in a thin section are not unusual. Hornblende occurs in some of the flows, generally in minor amounts as prisms to 2 mm long, but in some flows it is the dominant mafic mineral, occurring as prisms to 4 mm long. A number of flows contain distinctly “hollow” hornblende phenocrysts with matrix filling a central hole in the crystal along the c-axis. In some flows, there is strong embayment of hornblende with partial replacement by augite. Magnetite rims and complete replacement of hornblende by magnetite are common.

Tss sedimentary rocks

The Tss subunit in Tsa includes some fine- to coarse-grained sedimentary rocks in the Crown Point Ravine area that were mapped as Sutro Tuff by Calkins and Thayer (1945). The Suicide Rock Sutro Tuff exposure in this area is similar to nearby outcrops of rock that we mapped as Tss, but the Sutro appears to be more felsic. Tss here includes water-lain tuff, pebble breccia, and sandstone that contains isolated rounded andesite pebbles and cobbles. Ripple-marked surfaces occur in some exposures of fine-grained sandstone in this area. These bedded rocks seem to interfinger with andesitic flows and breccia in Crown Point Ravine and to thin to the north near Mount Bullion.

JTRg Gardnerville Formation

The Gardnerville Formation, mostly siltstone and sandstone (JTRgs), contains other rock types including limey beds (JTRgm). Similar rocks are exposed east of Little Washoe Lake and on Rocky Hill, just west of the quadrangle, where they are reported to be tightly folded, with the sequence tops mostly to the west (Tabor and others, 1983). In addition to exposed rocks in the Virginia City Quadrangle, thick sections of Gardnerville Formation siltstone lie in the footwall of the Comstock fault in the Crown Point, Yellow Jacket, and Belcher Mines.

The Gardnerville Formation is thermally metamorphosed near intrusive contacts with Mesozoic plutonic rocks. On the east flank of McClellan Peak, the discernable metamorphic aureole does not appear to be related to the gabbro (unit Jm), as relatively unmetamorphosed siltstones locally underlie the gabbro. Thus, we presume other granitic rocks intrude the Gardnerville Formation under McClellan Peak. This is partly confirmed by the presence of granodiorite on a dump located in a canyon 500 m southwest of the Delaware Mine. Specimens from the Becker Collection in the footwall of the Yellow Jacket, Crown Point, and Belcher

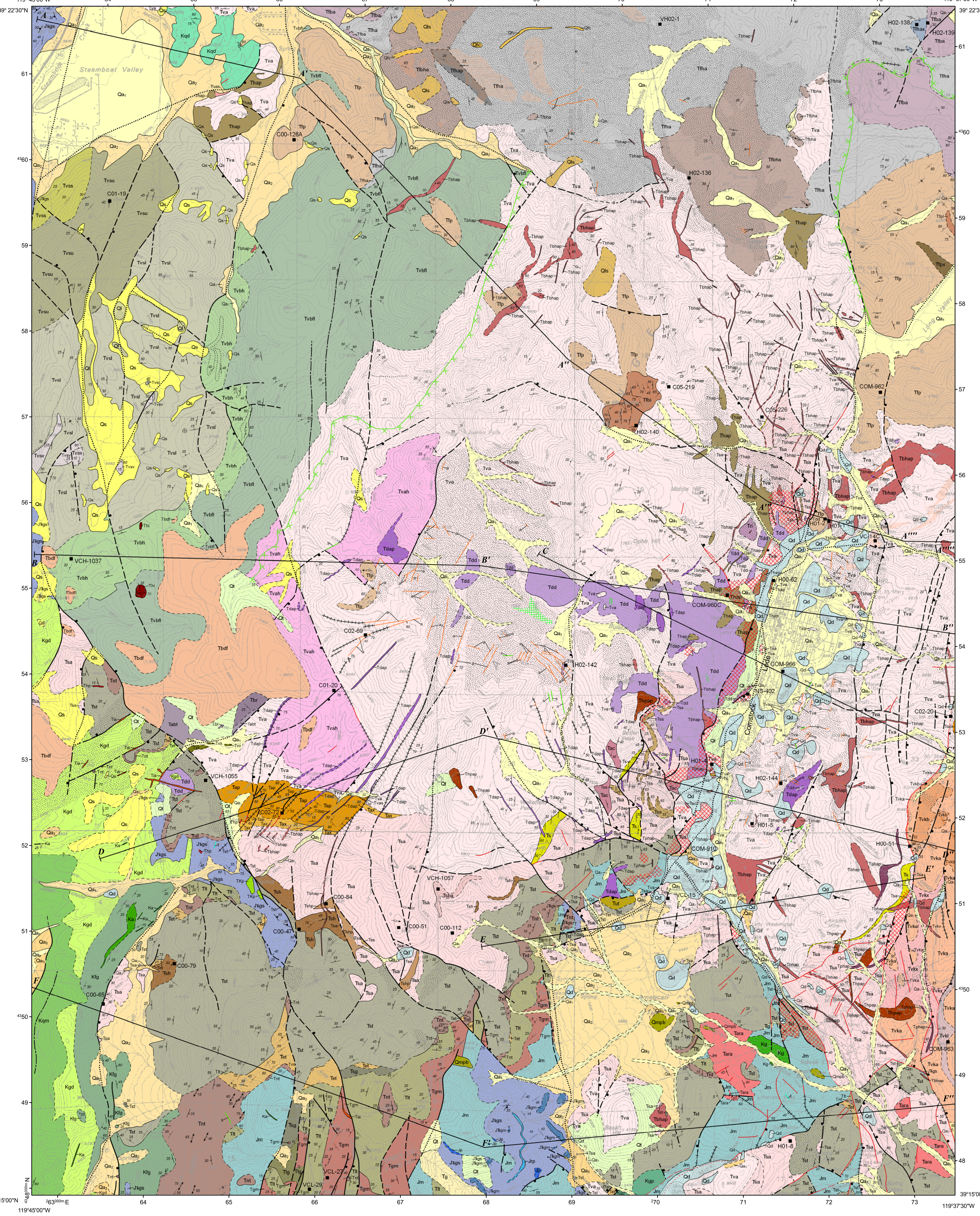
Mines are weakly hornfelsed, with some epidote-bearing marble below the 2000 level. Specimens from the carbonate rocks in the footwall of the Comstock fault on the 1200 level and in the vicinity of the 2300 level of the Sierra Nevada Mine adjacent to Mesozoic granitic rocks consist of white marble, wollastonite-bearing marble, and epidote-pyroxene-garnet skarn with no siltstone. The skarn-altered carbonate rocks in the Rock Island and Sierra Nevada Mines might represent the Oreana Peak Formation of Noble (1962), which underlies the Gardnerville, alternatively they may be metamorphosed Gardnerville Formation limestone.

Jm Metagabbro and metabasalt

The texture and composition of the metagabbro and metabasalt unit vary subtly from outcrop to outcrop but not systematically across the exposures. Rarely, amygdaloidal, fragmental (welded tuff?), or breccia textures are observed, particularly in the area west of McClellan Peak. Similar volcanic textured material is exposed on a ridge about 700 m south of the Delaware Mine on the east flank of McClellan Peak; there it appears to underlie gabbro. Dikes and small irregular masses of intrusive gabbro porphyry are scattered throughout the exposed mass of gabbro in the Silver City area; the best exposure is in the railroad cut just west of the Vulcano Mine.

The gabbro intrusion, which may be a sill or a lopolith, forms a nearly horizontal contact with the underlying Preachers and Gardnerville Formations on McClellan Peak, near the Tyler Mine, and probably south of the Florida Shaft. Toward Silver City, no sedimentary rocks are exposed under the gabbro and the deepest shafts in the area apparently bottomed in gabbro, based on dump material. The intrusive center and source of the gabbroic mass are unknown.

Gabbro from the footwall of the Comstock Lode is common on the dump of the Sutro Mine adit west of the Utah Shaft. This gabbro is hornblende bearing and is therefore probably a different unit from Jm, but it may be similar in age.



GEOLOGIC MAP OF THE VIRGINIA CITY QUADRANGLE, WASHOE, STOREY, AND LYON COUNTIES AND CARSON CITY, NEVADA

Donald M. Hudson, Stephen B. Castor, Larry J. Garside, and Christopher D. Henry

2009

Scale 1:24,000

CONTOUR INTERVAL 40 FEET

Projection: Universal Transverse Mercator, Zone 11, North American Datum 1927 (m)

Base map: U.S. Geological Survey Virginia City 7.5' Quadrangle (1994)

Symbology (per FGDC-STD-013-2006)

QUATERNARY DEPOSITS

LATE MIOCENE AND/OR PLIOCENE DEPOSITS

MIDDLE MIOCENE ANDESITIC TO RHYOLITIC ROCKS

FLOWERY PEAK MAGMATIC SUITE

INTRUSIONS OF THE FLOWERY PEAK OR VIRGINIA CITY MAGMATIC SUITES

VIRGINIA CITY MAGMATIC SUITE

Virginia City intrusions and rhyolites

Virginia City volcanics

Steamboat Valley sequence

Kate Peak Formation

Bailey Canyon sequence

Alta Formation

UNITS IN THE VIRGINIA CITY OR SILVER CITY SUITES

INTRUSIVE ROCK IN THE VIRGINIA CITY OR SILVER CITY MAGMATIC SUITES

SILVER CITY MAGMATIC SUITE

MIOCENE-OLIGOCENE TUFFS AND SEDIMENTS

TERTIARY OR MESOZOIC ROCKS

MESOZOIC ROCKS

CRETACEOUS PLUTONIC ROCKS

METAIGNEOUS AND METASEDIMENTARY ROCKS

See accompanying text for full unit descriptions, notes, and references for this map. All tables, figures, and references cited above are also found in this text.

Nevada Bureau of Mines and Geology
Mackay School of Earth Sciences and Engineering
College of Science
University of Nevada, Reno

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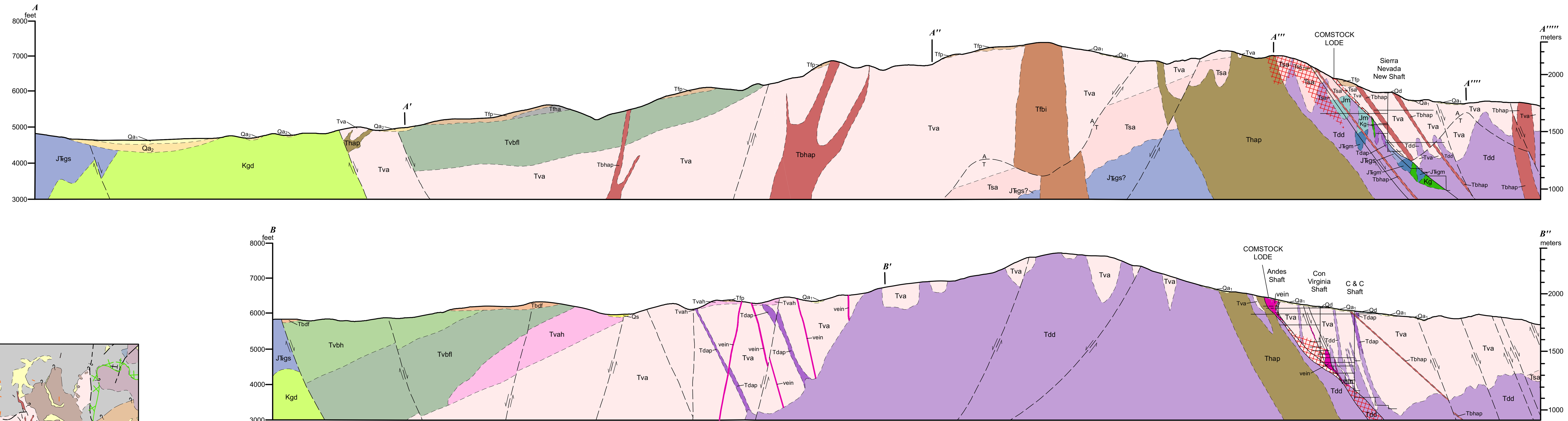
Supported by the U.S. Geological Survey

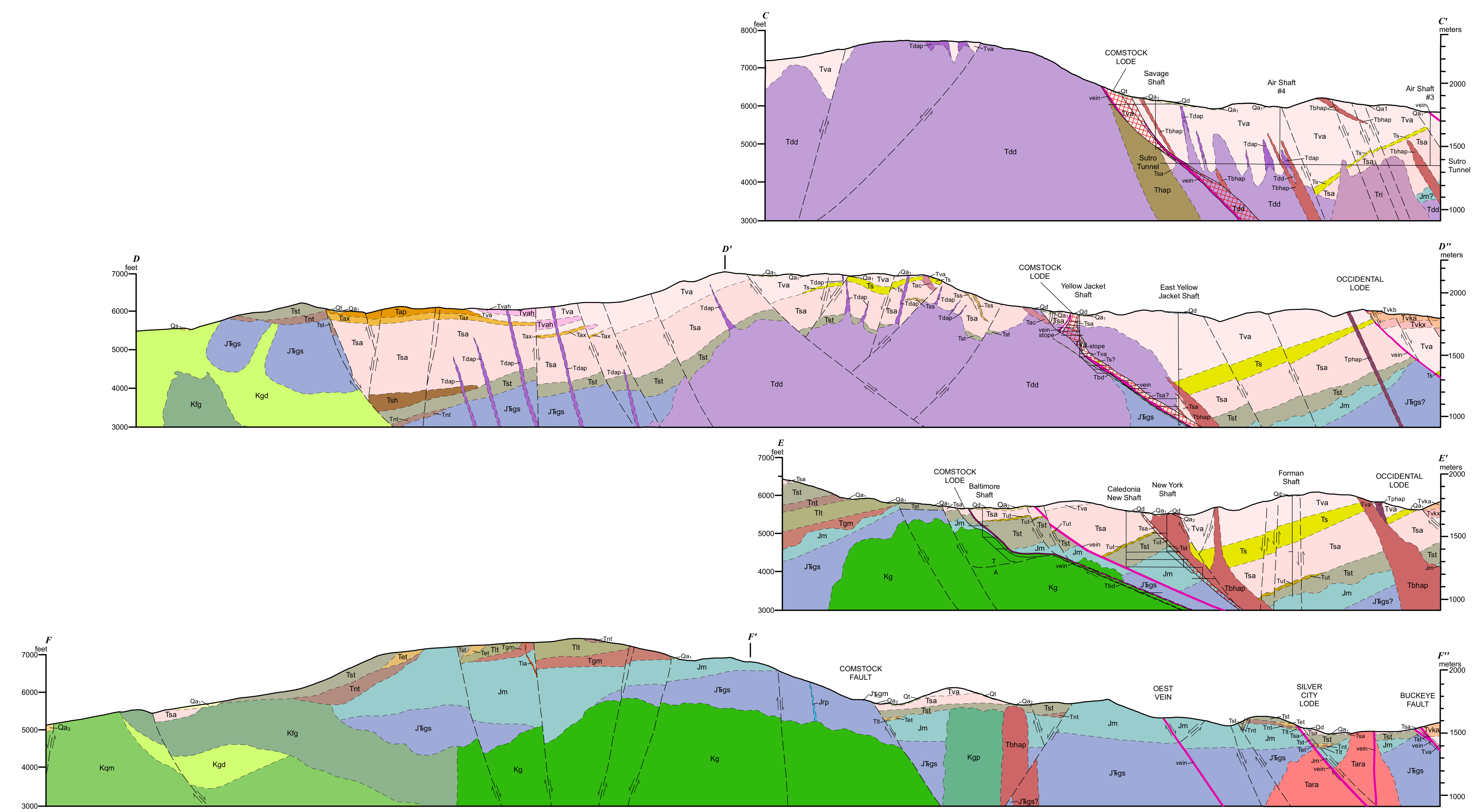
PEER-REVIEWED MAP
Office review by David Boden, David John, Joseph Tingley, and Susan Tingley
Field review by David Boden, David John, John Muntean, and Daphne LaPointe

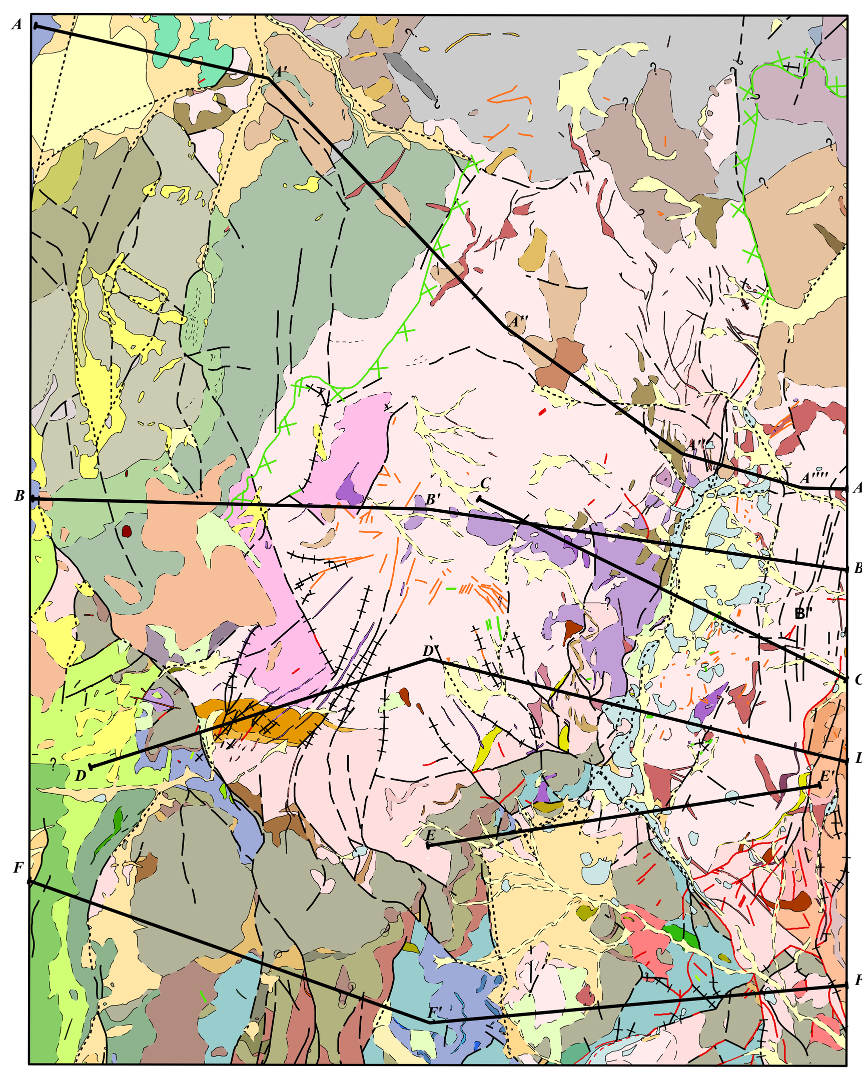
Edited by Jonathan Price
Compilation by Donald Hudson, Stephen Castor, and Larry Garside
Cartography and map production in ESRI ArcGIS v9.2 (ArcGeology v1.2) by Heather Armeno and Christine Arritt
First Edition, 2009
Printed by Nevada Bureau of Mines and Geology

1958

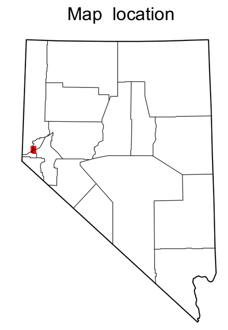
PREPARED AS PART OF THE STATEMAP COMPONENT OF THE NATIONAL COOPERATIVE GEOLOGIC MAPPING PROGRAM IN COOPERATION WITH THE U.S. GEOLOGICAL SURVEY

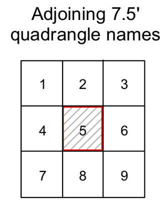






GEOLOGIC MAP (SIMPLIFIED FROM PLATE 1), SHOWING LOCATIONS OF CROSS SECTIONS





1 Mount Rose NE
2 Steamboat
3 Chalk Hills
4 Washoe City
5 Virginia City
6 Flowery Peak
7 Carson City
8 New Empire
9 Dayton

QUATERNARY DEPOSITS

- Qd Mine waste
- Qs Sand
- Qt Talus
- Qa_1 Young alluvium
- Qa_2 Intermediate-age alluvium
- Qa_3 Old alluvium

LATE MIOCENE AND/OR PLIOCENE DEPOSITS

- Tbdf Big boulder debris flow
- Tbd Black dike

MIDDLE MIOCENE ANDESITIC TO RHYOLITIC ROCKS

- Tia Andesite porphyry dikes

FLOWERY PEAK MAGMATIC SUITE

- Tfha Hornblende andesite
- Tfbi Biotite hornblende andesite intrusion
- Tfp Andesite of Flowery Peak

INTRUSIONS OF THE FLOWERY PEAK OR VIRGINIA CITY MAGMATIC SUITE

- Tbhap Biotite hornblende andesite dikes and intrusions
- Thap Hornblende andesite porphyry intrusions
- Tri Rhyolite intrusions
- Tac Andesite of Crown Point Ravine

VIRGINIA CITY MAGMATIC SUITE

Virginia City intrusions and rhyolites

- Tdd Davidson Diorite
  - Tdap Andesite porphyry phase of the Davidson Diorite
- Tphap Pyroxene hornblende andesite porphyry

Kate Peak Formation

- Tvka Hornblende and pyroxene andesite flows
  - Tvkb Biotite-hornblende andesite flows
  - Tvkx Autobreccia

Bailey Canyon sequence

- Tvbh Hornblende andesite flows
- Tvbfl Andesite flows and lahars

Alta Formation

- Tva Alta Formation undivided
  - Tvah Hornblende andesite porphyry flow rock

VIRGINIA CITY OR SILVER CITY SUITES

- Ts Sutro Tuff
- Tap Phenocryst-poor andesite
- Tax Lahar unit

INTRUSIVE ROCK IN THE VIRGINIA CITY OR SILVER CITY MAGMATIC SUITES

- Tara American Ravine Andesite

SILVER CITY MAGMATIC SUITE

- Tsa Silver City andesites
  - Tss Sedimentary rocks
- Tsh Hornblende andesite

MIOCENE-OLIGOCENE TUFFS AND SEDIMENTS

- Tut Unnamed lithic tuff
- Tst Santiago Canyon Tuff
- Tet Eureka Canyon Tuff
- Tnt Nine Hill Tuff
- Tlt Lenihan Canyon Tuff
- Tgm Guild Mine Member, Mickey Pass Tuff

MESOZOIC ROCKS

CRETACEOUS PLUTONIC ROCKS

- Kgd Granodiorite
- Kqm Leuco quartz monzonite
- Kfg Foliated granite
- Kgp Granodiorite porphyry
- Kg Undivided granitic rocks

METAIGNEOUS AND METASEDIMENTARY ROCKS

- Jm Mafic metaigneous rock
- Jrp Foliated lithic rhyolite porphyry
- JTRgs Gardnerville Formation siltstone and sandstone
  - JTRgm Gardnerville Formation marble

Contact

A / T

Fault Solid where certain and location accurate; long-dashed where location uncertain. Double arrows indicate offset; A indicates movement away from profile, T indicates movement toward profile.

Massive quartz

Stockwork veining

Underground workings

Nevada Bureau of Mines and Geology
Mackay School of Earth Sciences and Engineering
College of Science
University of Nevada, Reno

Field work done in 1999-2008
Supported by the U.S. Geological Survey

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1958

Scale 1:24,000

0 0.5 1 kilometer

0 0.5 1 mile

0 1000 2000 3000 4000 5000 feet

Projection: Universal Transverse Mercator, Zone 11, North American Datum 1927 (m)

GEOLOGIC CROSS SECTIONS, VIRGINIA CITY QUADRANGLE, NEVADA

Donald M. Hudson, Stephen B. Castor, Larry J. Garside, and Christopher D. Henry

2009