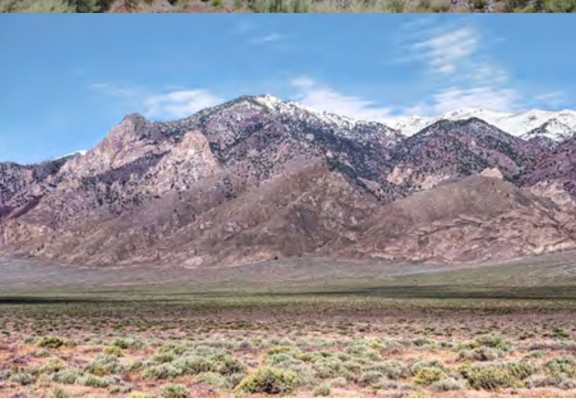
National Cooperative Geologic Mapping Program

Prepared in cooperation with the Nevada Bureau of Mines and Geology

Geologic Map of the Southern Stillwater Range, Nevada

By David A. John, Joseph P. Colgan, Margaret E. Berry, Christopher D. Henry, and Norman J. Silberling



pamphlet to accompany

Scientific Investigations Map 3521

U.S. Department of the Interior
U.S. Geological Survey

Cover. Top left: View looking east down the mouth of Coyote Canyon to Dixie Valley and the snow-covered Clan Alpine Mountains in the background. The Freeman Creek pluton forms the outcrop on left side and intrudes the rhyolite of Pirouette Mountain, which crops out on the right side of the canyon.

Bottom left: View looking southwest of the east side of the Stillwater Range and Dixie Valley. Vertical relief is about 1500 m. Job Peak forms the high point on left side of the snow-covered crest of the range. The prominent white stripe along the base of the range is an approximately 2-m-high scarp from the 1954 Dixie Valley earthquake along the Dixie Valley Fault. The lower, light-colored outcrops are the Freeman Creek pluton. The pluton intrudes and hornfelses the darker-colored rhyolite of Pirouette Mountain, which extends to the skyline. Sloping, dark outcrops along left side of the photo are a Miocene diabase dike that intrudes the pluton.

Right: View looking south of the crest of the southern Stillwater Range. Job Peak is the high point covered by snow and enveloped by clouds. The tuff of Job Peak forms the ridgeline between Job Peak and bold outcrops near left side of photo, which are granite porphyry and rhyolite porphyry dikes emplaced along north structural margin of the Poco Canyon caldera. The sun-draped, orange-colored slopes are poorly exposed tuff and breccia of Government Trail Canyon, which fills the lower part of the Poco Canyon caldera. The orange color is due to iron oxides that replace pyrite in blocks of altered rhyolite. The roadbed and outcrop in the foreground are intracaldera tuff of Job Canyon, which form slopes and ridgeline between the road and the porphyry dikes.

Photographs by David John, U.S. Geological Survey.

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Colgan, J.P., John, D.A., Henry, C.D., and Watts, K.E., 2017, Geochemical and geochronologic data from the Stillwater Range, Clan Alpine, and Desatoya Mountains, Nevada (ver. 3.0, December 2023): U.S. Geological Survey data release, https://doi.org/10.5066/F7P26X2V.

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Volume	
cubic kilometer (km^3)	0.2399	cubic mile (mi^3)

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Geologic Map of the Southern Stillwater Range, Nevada

By David A. John,[1] Joseph P. Colgan,[1] Margaret E. Berry,[1] Christopher D. Henry,[2] and Norman J. Silberling[1]

Introduction

The southern Stillwater Range in west-central Nevada contains the western part of the Oligocene Stillwater-Clan Alpine caldera complex, which extends about 55 kilometers (km) east from the west side of the Stillwater Range to the northwestern Desatoya Mountains (figs. 1, 2; John, 1995b; Colgan and others, 2018). The complex consists of at least seven nested ignimbrite calderas and subjacent plutonic rocks emplaced into a complex basement composed of Mesozoic metasedimentary and metavolcanic rocks and Cretaceous granitic plutons (fig. 2). The calderas formed during large-volume (100s to greater than (>) 2,500 cubic kilometers [km^3]) eruptions of silicic ignimbrites between about 30.4 and 25.1 million years before present (Ma) (Colgan and others, 2018). The Job Canyon and Poco Canyon calderas and the western part of the much larger Elevenmile Canyon caldera, and their plutonic roots, are exposed in the southern Stillwater Range. There, the caldera complex was steeply tilted during large-magnitude crustal extension in the middle Miocene, and further exhumed during the late Miocene to Holocene Basin and Range extension that formed the modern Stillwater Range (Colgan and others, 2020). This tilted crustal section affords an exceptional opportunity to view structural cross sections of ignimbrite calderas and their plutonic roots to paleodepths as much as 9–10 km (John, 1995b; Hudson and others, 2000; Colgan and others, 2018).

Methods

This geologic map of the southern Stillwater Range is based mostly on published geologic mapping and mapping done by D.A. John and N.J. Silberling from 1986 to 1994 (John, 1992a, 1993, 1995a, b; John and Silberling, 1994) with additional mapping by D.A. John, J.P. Colgan, M.E. Berry, and C.D. Henry from 2011 to 2021, and mapping modified from Bell and Katzer (1987) and Calvin and others (2012) (fig. 3). New mapping was accompanied by extensive new geochemical analyses (Colgan and others, 2017), and comprehensive new $^{40}Ar/^{39}Ar$ and sensitive high-resolution ion microprobe (SHRIMP) U-Pb dating (table 1; Colgan and others, 2017, 2018), which supplements previous K-Ar dating (table 1; Stewart and others, 1994). This work is part of a larger study of the entire Stillwater-Clan Alpine caldera complex (Colgan and others, 2018).

[1]U.S. Geological Survey.

[2]Nevada Bureau of Mines and Geology.

Stratigraphy

The southern Stillwater Range is underlain by Mesozoic metasedimentary and metavolcanic rocks intruded by felsic Cretaceous plutons. The Mesozoic rocks are unconformably overlain by Oligocene and Miocene volcanic and sedimentary rocks. These Mesozoic and Tertiary rocks are locally overlain by latest Tertiary and Quaternary surficial deposits.

Mesozoic Metasedimentary and Metavolcanic Rocks

The oldest rocks exposed in the southern Stillwater Range are Triassic, Jurassic, and Cretaceous metasedimentary and metavolcanic rocks and Cretaceous plutons that crop out on the north and south sides of the caldera complex and form the walls and floors of the calderas. The Mesozoic rocks are exposed in at least four discrete tectonic blocks that were juxtaposed by the Late Jurassic–Early Cretaceous Luning-Fencemaker thrust system (Oldow, 1984; Oldow and others, 1993; John and Silberling, 1994; Satterfield, 2002). Metamorphic rocks were multiply deformed prior to emplacement of the Cretaceous intrusions.

In the southern part of the map area near La Plata Canyon, the metasedimentary and metavolcanic rocks form three lithologically and structurally diverse tectonic blocks (John and Silberling, 1994). One block consists entirely of phyllite (unit Ᵽzp) and is predominantly composed of stratigraphically disrupted, metamorphosed lower Mesozoic(?) mudstone containing rare interbeds of limestone and volcanic sandstone. The phyllite unit is more strongly deformed than rocks in the other tectonic blocks and is lithologically similar to rocks of the Sand Springs terrane in the Sand Springs Range about 15 km south of the map area (Oldow, 1984; Satterfield, 2002). The age of the phyllites in the La Plata Canyon area is unknown, but the Sand Springs terrane in the Sand Springs Range contain sparse Late Triassic and Early Jurassic fossils (Satterfield, 2002).

The La Plata Fault separates the phyllite unit from an overlying tectonic block composed of Upper Triassic nonvolcanic siliciclastic argillite (unit ŦRca) and Upper Triassic

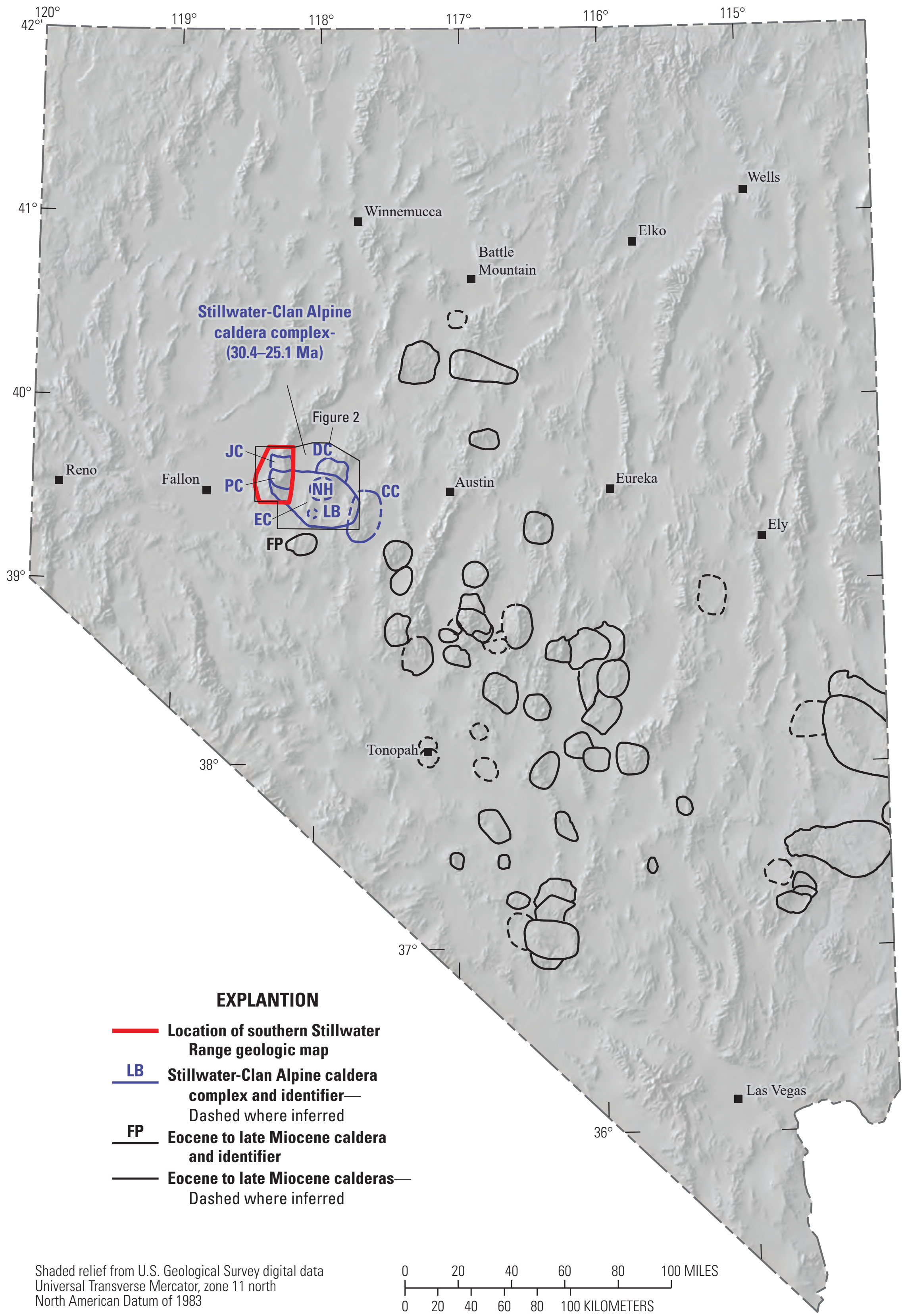


Figure 1. Map showing Eocene to late Miocene calderas in Nevada (black outlines; dashed where caldera location is inferred). Calderas in the Stillwater-Clan Alpine caldera complex outlined in blue (dashed where inferred). Red outline shows location of southern Stillwater Range geologic map shown in more detail in figure 2. Calderas: CC, Campbell Creek; DC, Deep Canyon; EC, Elevenmile Canyon; FP, Fairview Peak; JC, Job Canyon; LB, Louderback Mountains; NH, Nine Hill; PC, Poco Canyon.

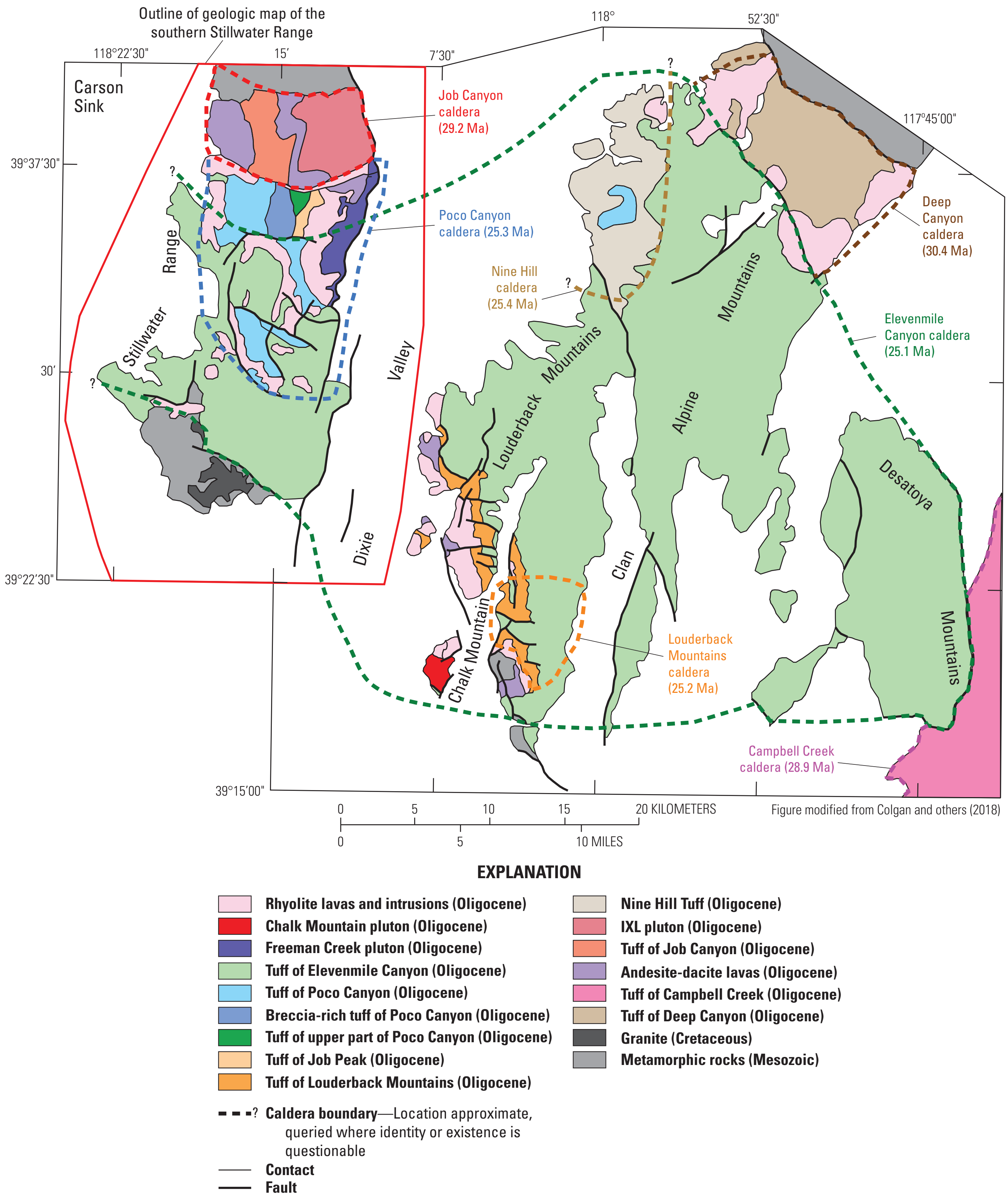


Figure 2. Generalized geologic map of Oligocene calderas in the Stillwater-Clan Alpine caldera complex and basement rocks. Heavy red outline shows location of geologic map of the southern Stillwater Range. Figure modified from Colgan and others (2018).

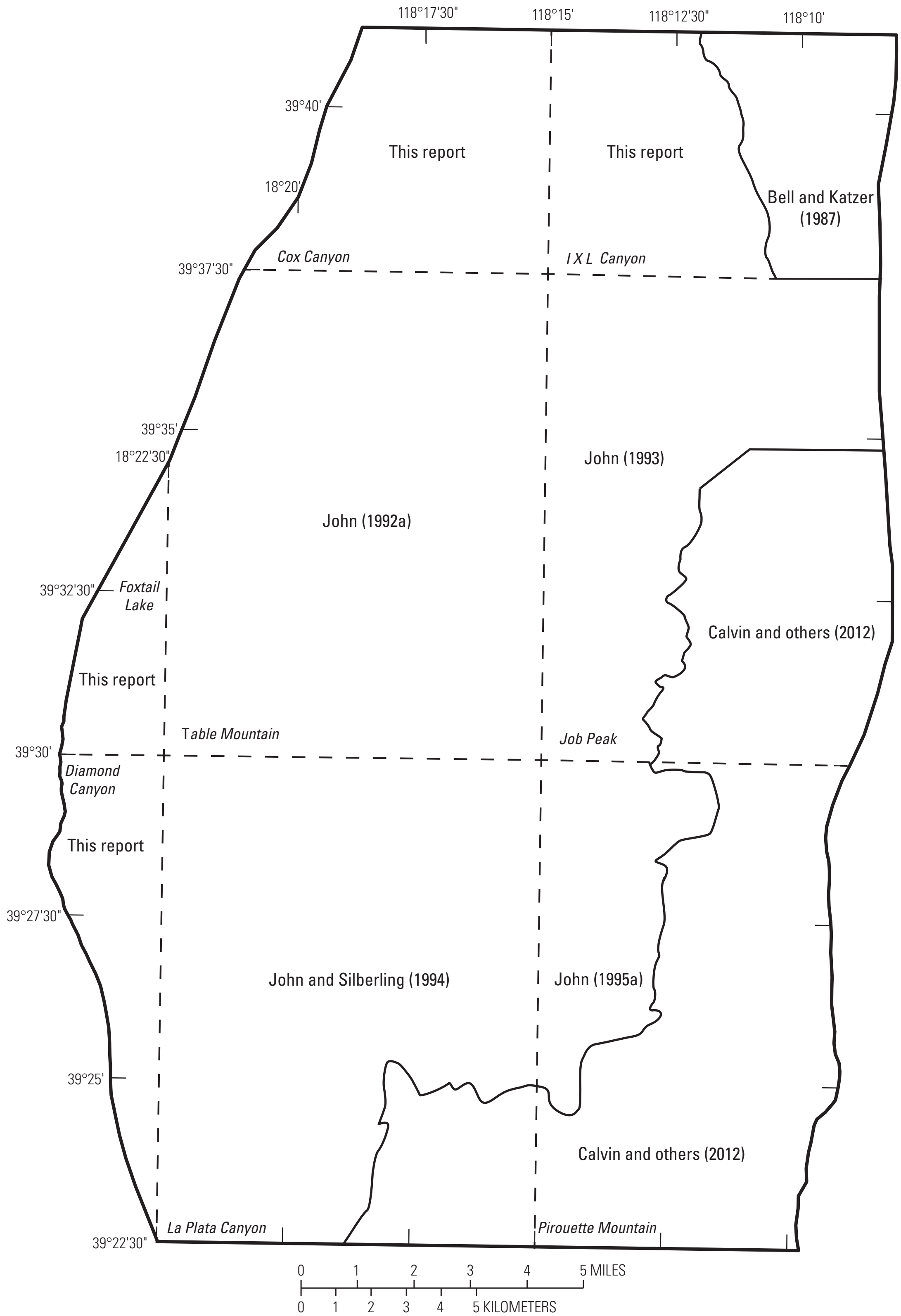


Figure 3. Index map showing principal sources of previous geologic mapping used as a basis for the new geologic map that is demarcated by heavy black line. Names of 7-1/2-minute quadrangles shown in italics. Mapping for the Cox Canyon, I X L Canyon, Foxtail Lake, and Diamond Canyon quadrangles was done by D.A. John and N.J. Silberling from 1986–94. Figure 3 is also on sheet 2.

and Lower Jurassic(?) limestones (units J₸cl and ₸cl) that form a partly coherent stratigraphic sequence. These rocks are representative of the Clan Alpine sequence (Speed, 1978), typified by correlative rocks in the Clan Alpine Mountains about 30 km northeast of the map area.

The third major tectonic block in the La Plata Canyon area is composed of weakly metamorphosed, stratigraphically coherent, volcanic, volcaniclastic, orthoquartzitic, and pelitic rocks, informally designated the Mountain Well sequence (units Kmd, Kms, and Kmv; John and Silberling, 1994). This sequence is faulted against the Clan Alpine sequence. The lithologically distinctive Mountain Well sequence was provisionally assigned an age of Middle and (or) Lower Jurassic, the general age of other volcanic-rock and quartzite associations elsewhere in western Nevada (John and Silberling, 1994; Crafford, 2007, 2008). However, a SHRIMP U-Pb zircon age of 103.9±1.5 Ma on an andesite lava flow in unit Kmv indicates that the sequence is late Early Cretaceous and part of a volcanic-intrusive center that includes felsite intrusions (unit Kf) that were emplaced into units Kmd and Kms.

Mesozoic rocks on the north side of the Stillwater caldera complex consist predominantly of weakly metamorphosed Triassic siltstone, sandstone, argillite, and minor limestone and gritstone (units ₸cl and ₸ca). Some beds have Bouma layering, and flute casts are locally well developed. These rocks are characteristic of the basinal part of Auld Lang Syne Group or Clan Alpine sequence of Speed (1978) (also called the Lovelock assemblage, Oldow, 1984, or Jungo terrane, Crafford, 2007, 2008) and are thought to be Upper Triassic on the basis of poorly preserved fossils. White quartzite locally interbedded with limestone and intermediate composition metavolcanic and metavolcaniclastic rocks (Jurassic?) form coarse blocks and elongate lenses of blocks in megabreccia along the northwestern wall of the Job Canyon caldera. These rocks apparently were shed into the Job Canyon caldera during eruption of the tuff of Job Canyon, caldera collapse, and subsequent eruption of the younger dacite and andesite sequence. Similar white quartzite also forms an elongate outcrop along the northeast wall of the IXL pluton.

Jurassic Rhyolite

A large mass of aphyric to very sparsely porphyritic rhyolite (unit Jrmb) intrudes Jurassic(?) quartzite, limestone, and metavolcanic rocks at the top (northwestern edge) of the Job Canyon caldera. The rhyolite is commonly strongly argillically altered (kaolinite and [or] illite). John (1995b) interpreted the rhyolite as a dome intruding the Job Canyon caldera, but SHRIMP U-Pb zircon ages of 156.33±0.37 and 155.2±2.4 Ma (Colgan and others, 2017) indicate it is a Late Jurassic intrusion that is a megabreccia block in the upper part of the Job Canyon caldera (fig. 4).

Cretaceous Felsite

Several bodies of altered, sparsely porphyritic felsite (unit Kf) intrude rocks of the Clan Alpine and Mountain Well sequences between La Plata Canyon and Ripley Spring. The felsites are structureless and lack tectonically flattened conglomerates that are present in similar appearing rocks in the Mountain Well sequence (unit Kmd). Most contacts with Tertiary rocks are faults, although the andesite of Sheep Canyon (unit Tasc) unconformably overlies the felsite unit about 3 km east of Ripley Spring. The felsite unit has a SHRIMP U-Pb zircon age of 104.8±1.4 Ma.

Cretaceous Granitic Rocks

The La Plata Canyon pluton (unit Klp) intrudes Mesozoic metamorphic rocks in the La Plata Canyon area. The pluton is a composite intrusion consisting of relatively leucocratic, fine- to medium-grained biotite granite and quartz monzonite with numerous irregular bodies of aplite, alaskite, and pegmatite (Butler, 1979; John and Silberling, 1994). It crops out in two major exposures: a small northern body that lies on the ridge separating Elevenmile and La Plata Canyons forms part of the floor of the Elevenmile Canyon caldera, and a larger exposure forms part of the south wall of this caldera. The pluton intrudes rocks of the Clan Alpine sequence and the phyllite unit (unit Pzp), crosscutting folds in these rocks and the folded trace of the La Plata Fault (see section A–A', John and Silberling, 1994). The pluton has a SHRIMP U-Pb zircon age of 87.3±1.0 Ma (Colgan and others, 2017). Coarse-grained muscovite from a selvage on a fluorite vein in Mesozoic wall rocks near the southern margin of the pluton yielded a K-Ar age of 85.2±1.0 Ma (Garside and others, 1981). The age of the La Plata Canyon pluton is similar to U-Pb zircon ages of 88.6±3.1 Ma of the Sand Springs pluton about 20 km south of the map area, and 84.4±0.8 Ma for a small biotite granodiorite pluton in Alameda Canyon about 3 km north (Page, 1965; Colgan and others, 2017; Watts and others, 2019).

Middle Cenozoic, Pre-Stillwater-Clan Alpine Caldera Complex Igneous Rocks

Cenozoic magmatism in the southern Stillwater Range began with deposition of a thick sequence of intermediate to silicic lava flows, breccias, and welded tuffs locally interbedded with conglomerates and sandstones that form the floor of the Job Canyon caldera (older dacite and andesite sequence, units Tobr, Tolf, and Todt). Both the conglomerates and tuffs commonly contain clasts of Mesozoic basement rocks (mostly granite and quartzite). This sequence is as much as 1,000 m thick. Most of the rocks in this sequence are strongly hydrothermally altered and thermally metamorphosed by the IXL pluton; they contain abundant epidote, illite, calcite, and chlorite with local specular hematite and adularia on fractures. Four zircon U-Pb ages range from 29.71±0.39 Ma for a densely welded tuff near the base of the sequence to 29.32±0.97 Ma for a biotite dacite tuff at the top of the sequence. The dacite tuff also has a biotite $^{40}Ar/^{39}Ar$ age of 29.17±0.09 Ma.

Table 1. U-Pb, $^{40}Ar/^{39}Ar$, and K-Ar ages from the southern Stillwater Range.

[Latitude and longitude are in North American Datum of 1983 (NAD 83). Ma, mega-annum; --, not applicable; Tb, basalt; Tbi, basalt intrusions; Tddc, dacite of Diamond Canyon; Tha, hornblende andesite; Ts, sedimentary rocks; Tsi, silicic intrusive rocks; Tsd, silicic dikes; Tyr, younger rhyolite; Tfcgr, granite of the Freeman Creek pluton; Tfcgd, granodiorite porphyry of the Freeman Creek pluton; Tgp, granite porphyry; Trp, rhyolite porphyry; Tst, sedimentary tuff unit of the Elevenmile Canyon caldera; Tec, tuff of Elevenmile Canyon; Tasc, andesite of Sheep Canyon; Tpcu, upper cooling unit of the tuff of Poco Canyon; Tpbr, tuff and breccia of Government Trail Canyon; Tpcl, lower cooling unit of the tuff of Poco Canyon; Tupc, tuff of upper Poco Canyon; Tjp, tuff of Job Peak; Tap, andesite porphyry; Tot, older tuffs; Trpm, rhyolite of Pirouette Mountain; Tobr, breccia, conglomerate, and tuffs of the older dacite and andesite sequence; Tixl, IXL pluton; Tyda, younger dacite and andesite sequence, undivided; Tjc, tuff of Job Canyon; Todt, dacite tuff of the older dacite and andesite sequence; Tolf, lava flows of the older dacite and andesite sequence; Klp, La Plata Canyon pluton; Kf, felsite; Kmv, andesite metavolcanic rocks of the Mountain Well sequence; Jrmb, Jurassic rhyolite megabreccia in the Job Canyon caldera]

Sample number	Latitude	Longitude	Map unit	Material dated	U-Pb age (Ma)	± (Ma, 2 σ)	$^{40}Ar/^{39}Ar$ age (Ma)	± (Ma, 2 σ)	K-Ar age (Ma)	± (Ma)	Source
91-DJ-124	39.54044	−118.3946	Tb	Whole rock	--	--	--	--	13.0	0.4	Stewart and others, 1994
89-DJ-1	39.59222	−118.32256	Tb	Whole rock	--	--	--	--	14.4	0.6	Stewart and others, 1994
87-DJ-145	39.51034	−118.3201	Tb	Whole rock	--	--	--	--	13.3	0.4	Stewart and others, 1994
87-DJ-83	39.4562	−118.37269	Tbi	Whole rock	--	--	--	--	13.9	0.5	Stewart and others, 1994
JC11-LC22	39.4478	−118.3792	Tddc	Plagioclase	--	--	14.51	0.04	--	--	Colgan and others, 2017
88-DJ-81	39.44435	−118.35616	Tha	Hornblende	--	--	--	--	15.3	0.5	Stewart and others, 1994
91-DJ-28	39.4778	−118.40803	Ts	Biotite	--	--	--	--	13.5	0.4	Stewart and others, 1994
91-DJ-127	39.44416	−118.39342	Ts	Biotite	--	--	--	--	13.9	0.4	Stewart and others, 1994
91-DJ-125	39.44714	−118.39208	Ts	Hornblende	--	--	--	--	12.6	0.5	Stewart and others, 1994
16-DJ-32	39.41103	−118.28731	Ts	Sanidine	--	--	12.278	0.035	--	--	Colgan and others, 2017
17-DJ-50	39.43888	−118.27969	Tsd	Zircon	23.36	0.39	--	--	--	--	Colgan and others, 2017
19-DJ-35	39.48197	−118.31169	Tsd	Zircon	22.19	0.26	--	--	--	--	Colgan and others, 2017
JC11-24	39.43550	−118.24942	Tsd	Zircon	24.7	0.3	--	--	--	--	Colgan and others, 2017
89-DJ-34	39.61938	−118.30736	Tyr	Sanidine	--	--	24.834	0.14	--	--	Hudson and others, 2000
H00-108	39.61938	−118.30736	Tsi	Sanidine	--	--	25.17	0.03	--	--	Henry and John, 2013
86-DJ-105	39.6213	−118.2964	Tsi	Biotite	--	--	24.568	0.32	--	--	Hudson and others, 2000
H00-107	39.6213	−118.2964	Tsi	Sanidine	--	--	25.18	0.03	--	--	Henry and John, 2013
88-DJ-62	39.61302	−118.26987	Tsi	Hornblende	--	--	23.068	0.40	--	--	Hudson and others, 2000
89-DJ-30	39.5839	−118.3090	Tsi	Biotite	--	--	--	--	24.8	0.6	Stewart and others, 1994
JC08-IXL8	39.58922	−118.18767	Tfcgr	Zircon	24.93	0.37	--	--	--	--	Colgan and others, 2018
18-DJ-8	39.6236	−118.18004	Tfcgd	Zircon	25.71	0.38	--	--	--	--	Colgan and others, 2017
12-DJ-35	39.58952	−118.18847	Tfcgd	Zircon	25.16	0.23	--	--	--	--	Colgan and others, 2018
14-DJ-74	39.61242	−118.22017	Tgp	Zircon	25.50	0.46	--	--	--	--	Colgan and others, 2018
14-DJ-41	39.61092	−118.24087	Trp	Zircon	25.63	0.44	--	--	--	--	Colgan and others, 2017
14-DJ-76	39.43634	−118.21703	Tst	Zircon	25.05	0.67	--	--	--	--	Colgan and others, 2018
12-DJ-37	39.51292	−118.22157	Tec	Zircon	25.12	0.31	--	--	--	--	Colgan and others, 2018
12-DJ-36	39.51582	−118.21107	Tec	Zircon	25.57	0.26	--	--	--	--	Colgan and others, 2018
12-DJ-36	39.51582	−118.21107	Tec	Sanidine	--	--	25.12	0.012	--	--	Colgan and others, 2018
H00-106	39.61932	−118.30017	Tec	Sanidine	--	--	25.00	0.06	--	--	Henry and John, 2013
H19-ST143	39.57704	−118.28638	Tec	Sanidine	--	--	25.08	0.008	--	--	Colgan and others, 2017
19-DJ-28	39.43877	−118.34559	Tasc	Zircon	25.07	0.41	--	--	--	--	Colgan and others, 2017
10-DJ-4	39.61152	−118.26087	Tpcu	Zircon	25.60	0.25	--	--	--	--	Colgan and others, 2018
17-DJ-40	39.61622	−118.27912	Tpcu	Zircon	25.49	0.4	--	--	--	--	Colgan and others, 2017

Table 1. U-Pb, $^{40}Ar/^{39}Ar$, and K-Ar ages from the southern Stillwater Range.—Continued

[Latitude and longitude are in North American Datum of 1983 (NAD 83). Ma, mega-annum; --, not applicable; Tb, basalt; Tbi, basalt intrusions; Tddc, dacite of Diamond Canyon; Tha, hornblende andesite; Ts, sedimentary rocks; Tsi, silicic intrusive rocks; Tsd, silicic dikes; Tyr, younger rhyolite; Tfcgr, granite of the Freeman Creek pluton; Tfcgd, granodiorite porphyry of the Freeman Creek pluton; Tgp, granite porphyry; Trp, rhyolite porphyry; Tst, sedimentary tuff unit of the Elevenmile Canyon caldera; Tec, tuff of Elevenmile Canyon; Tasc, andesite of Sheep Canyon; Tpcu, upper cooling unit of the tuff of Poco Canyon; Tpbr, tuff and breccia of Government Trail Canyon; Tpcl, lower cooling unit of the tuff of Poco Canyon; Tupc, tuff of upper Poco Canyon; Tjp, tuff of Job Peak; Tap, andesite porphyry; Tot, older tuffs; Trpm, rhyolite of Pirouette Mountain; Tobr, breccia, conglomerate, and tuffs of the older dacite and andesite sequence; Tixl, IXL pluton; Tyda, younger dacite and andesite sequence, undivided; Tjc, tuff of Job Canyon; Todt, dacite tuff of the older dacite and andesite sequence; Tolf, lava flows of the older dacite and andesite sequence; Klp, La Plata Canyon pluton; Kf, felsite; Kmv, andesite metavolcanic rocks of the Mountain Well sequence; Jrmb, Jurassic rhyolite megabreccia in the Job Canyon caldera]

Sample number	Latitude	Longitude	Map unit	Material dated	U-Pb age (Ma)	± (Ma, 2 σ)	$^{40}Ar/^{39}Ar$ age (Ma)	± (Ma, 2 σ)	K-Ar age (Ma)	± (Ma)	Source
87-DJ-194	39.59912	−118.28337	Tpcu	Sanidine	--	--	25.16	0.08	--	--	Henry and John, 2013
86-DJ-107	39.61152	−118.26087	Tpcu	Sanidine	--	--	25.26	0.07	--	--	Henry and John, 2013
86-DJ-107	39.61152	−118.26087	Tpcu	Sanidine	--	--	25.232	0.06	--	--	Hudson and others, 2000
10-DJ-6	39.60822	−118.24707	Tpbr	Zircon	25.99	0.20	--	--	--	--	Colgan and others, 2018
12-DJ-38	39.51862	−118.24257	Tpcl	Zircon	25.74	0.19	--	--	--	--	Colgan and others, 2018
19-DJ-40	39.52990	−118.24550	Tpcl	Sanidine	--	--	25.257	0.008	--	--	Colgan and others, 2017
14-DJ-40	39.60856	−118.2398	Tupc	Zircon	25.90	0.49	--	--	--	--	Colgan and others, 2018
15-DJ-27	39.59830	−118.23050	Tjp	Zircon	25.78	0.49	--	--	--	--	Colgan and others, 2018
18-DJ-2	39.61662	−118.18602	Tap	Zircon	26.36	0.43	--	--	--	--	Colgan and others, 2017
18-DJ-1	39.61451	−118.1846	Tot	Zircon	26.1	0.54	--	--	--	--	Colgan and others, 2017
JC13-9	39.54242	−118.21537	Trpm	Zircon	25.24	0.25	--	--	--	--	Colgan and others, 2018
14-DJ-73	39.61092	−118.21967	Trpm	Zircon	24.97	0.66	--	--	--	--	Colgan and others, 2017
18-DJ-14	39.63918	−118.23487	Tobrì (alteration)	Adularia	--	--	27.628	0.079	--	--	Colgan and others, 2017
JC08-IXL4	39.65532	−118.21817	Tixl	Zircon	28.45	0.35	--	--	--	--	Colgan and others, 2018
JC08-IXL2	39.65202	−118.19917	Tixl	Zircon	28.07	0.33	--	--	--	--	Colgan and others, 2018
10-DJ-3	39.63572	−118.29787	Tyda	Zircon	28.54	0.51	--	--	--	--	Colgan and others, 2018
13-DJ-46	39.65172	−118.30587	Tyda	Biotite	--	--	28.807	0.013	--	--	Colgan and others, 2018
91-DJ-121	39.65102	−118.30517	Tyda	Plagioclase	--	--	28.886	0.4	--	--	Hudson and others, 2000
14-DJ-33	39.62212	−118.2701	Tjcì (alteration)	Illite	--	--	28.767	0.053	--	--	Colgan and others, 2017
14-DJ-103B	39.63639	−118.26217	Tjcì (alteration)	Illite	--	--	28.786	0.178	--	--	Colgan and others, 2017
10-DJ-2	39.64322	−118.27177	Tjc	Zircon	29.25	0.47	--	--	--	--	Colgan and others, 2018
17-DJ-1	39.62538	−118.24576	Tjc	Zircon	29.30	0.45	--	--	--	--	Colgan and others, 2017
10-DJ-5	39.62452	−118.24257	Todt	Zircon	29.32	0.97	--	--	--	--	Colgan and others, 2018
H06-33	39.62452	−118.24247	Todt	Biotite	--	--	29.17	0.094	--	--	Colgan and others, 2018
13-DJ-11	39.64525	−118.25209	Tolf	Zircon	29.38	0.38	--	--	--	--	Colgan and others, 2018
18-DJ-13	39.63918	−118.23487	Tobr	Zircon	29.27	0.49	--	--	--	--	Colgan and others, 2017
18-DJ-55	39.62046	−118.21767	Tobr	Zircon	29.65	0.27	--	--	--	--	Colgan and others, 2017
JC09-LC4	39.43972	−118.30416	Klp	Zircon	87.3	1.0	--	--	--	--	Colgan and others, 2017
18-DJ-10	39.45767	−118.34192	Kf	Zircon	104.8	1.38	--	--	--	--	Colgan and others, 2017
19-DJ-36	39.48288	−118.31197	Kmv	Zircon	103.9	1.5	--	--	--	--	Colgan and others, 2017
15-DJ-6	39.66790	−118.29730	Jrmb	Zircon	156.33	0.37	--	--	--	--	Colgan and others, 2017
14-DJ-75	39.67732	−118.30367	Jrmb	Zircon	155.2	2.4	--	--	--	--	Colgan and others, 2017

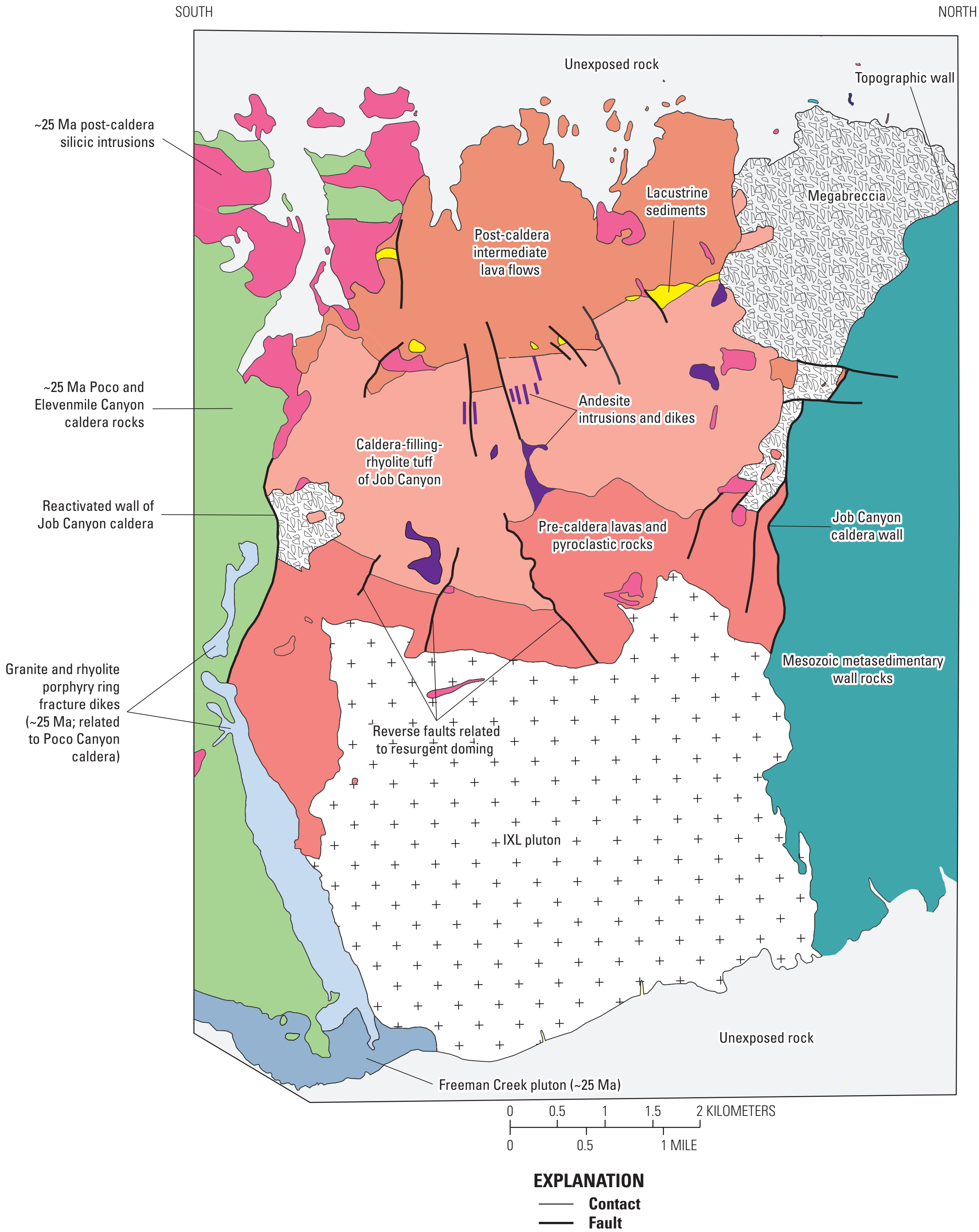


Figure 4. Pre-tilt, north-south cross section of the approximately 29 Ma Job Canyon caldera showing major features of the Job Canyon caldera and northern margins of the Poco Canyon and Elevenmile Canyon calderas.

Job Canyon Caldera

The small Job Canyon caldera is the oldest but least structurally disrupted of the three calderas exposed in the southern Stillwater Range. The caldera is steeply west-tilted, exposing Oligocene pre- and post-caldera rocks to paleodepths of 9–10 km (fig. 4). The caldera-filling tuff of Job Canyon and overlying intermediate lava flows and interbedded tuffs and volcaniclastic deposits (younger dacite and andesite sequence) are as much as 4.5 km thick. The upper approximately 5 km of the IXL pluton is exposed directly under the caldera and intrudes the pre-caldera older dacite and andesite sequence.

The tuff of Job Canyon (unit Tjc) consists of as much as 2,000 m of moderately to densely welded, crystal-poor to moderately crystal-rich (less than or equal to [≤] 15 volume percent phenocrysts) rhyolite ash-flow tuff. Phenocrysts consist of K-feldspar and plagioclase, minor quartz, and trace amounts of biotite. Multiple ash flows are evident by abrupt changes in crystal and lithic contents, but cooling breaks are not apparent in the strongly altered tuff. The tuff was locally deposited on a few tens of meters of poorly exposed fine-grained sandstone and siltstone that overlie biotite dacite tuff (unit Todt) at the top of the older dacite and andesite sequence. The tuff of Job Canyon has zircon U-Pb ages of 29.30±0.45 and 29.25±0.47 Ma, suggesting that it is just slightly younger than the underlying older dacite and andesite sequence.

Lenses of megabreccia and lithic-rich tuff are common along Job Canyon caldera walls. Along the north wall, megabreccia consists of unsorted blocks of Mesozoic rocks and the older dacite and andesite sequence as much as tens of meters in diameter in a poorly exposed, moderately welded tuff matrix. The breccia is zoned with decreasing amounts of tuff matrix outward and upward, and the north-south width of breccia deposits increases upward with outward (northward) flaring of the topographic margin of the caldera (fig. 4). Megabreccia deposits commonly form east-west elongate bands or lenses that are dominantly composed of one rock type (for example, mostly quartzite, limestone, or metavolcanic rocks). The larger blocks are commonly shattered into cm-sized fragments. Late Jurassic rhyolite (unit Jrmb) that intrudes Jurassic(?) quartzite, marble, and metavolcanic rocks north of Dry Canyon is interpreted as a giant (about 1.5 by 2.75 km) megabreccia block at the top of the caldera. Poorly exposed megabreccia along the south edge of the caldera consists of coarse blocks (as much as 200 m in diameter) of the older dacite and andesite sequence in a tuffaceous matrix.

The tuff of Job Canyon is overlain by as much as 2,500 m of intermediate lava flows, flow breccias, shallow intrusive rocks, and minor pyroclastic and sedimentary rocks (younger dacite and andesite sequence). Fine-grained lacustrine sedimentary rocks containing minor water-laid silicic tuff as thick as 200 m are present locally at or near the base of this sequence, and thin zones of epiclastic sandstone and siltstone are locally interbedded throughout the sequence. Numerous andesite dikes and small intrusions (unit Tydai) that likely fed the lava flows intrude the tuff of Job Canyon (unit Tjc). The lava flows are identical petrographically to rocks in the older dacite and andesite sequence. Lava flows sampled near the top of this sequence have $^{40}Ar/^{39}Ar$ ages of 28.81±0.01 and 28.89±0.40 Ma and a zircon U-Pb age of 28.54±0.51 Ma.

The IXL pluton directly underlies the Job Canyon caldera and intrudes the older dacite and andesite sequence. The pluton is composed mostly of medium-grained, equigranular to weakly porphyritic biotite-hornblende granodiorite and quartz monzodiorite (Page, 1965; Nelson, 1975; John, 1995b). The western (upper) part and locally the northern margin of the pluton is granodiorite that has a conspicuous porphyritic texture consisting of subhedral, medium-grained phenocrysts surrounded by small amounts of fine-grained groundmass. The central and eastern parts of the pluton are generally coarser grained and more equigranular than the western part of the pluton. The pluton has considerable compositional variation, with silica contents varying from about 59 to 69 weight percent (John, 1995b; Colgan and others, 2017). The compositional variation is reflected by more abundant hornblende, biotite, and plagioclase in deeper, more mafic parts of the pluton, with the color index increasing from about 10–12 at the top of the pluton to about 25–30 in the deepest exposures. Hornblende crystals commonly contain clinopyroxene and (or) orthopyroxene cores in deeper parts of the pluton. Spongy, hornblende-rich mafic enclaves are locally common near the roof (west margin) of the pluton, and denser, more mafic enclaves are scattered throughout the pluton. Zircon U-Pb ages on two samples are 28.07±0.33 and 28.45±0.35 Ma.

Rocks Erupted Between Formation of the Job Canyon and Poco Canyon Calderas

A 2–3 million-year hiatus of igneous activity in the southern Stillwater Range followed emplacement of the IXL pluton; this hiatus was a regional phenomenon characteristic of the larger Stillwater–Clan Alpine caldera complex (Colgan and others, 2018). Igneous activity resumed south of the Job Canyon caldera about 26–25.5 Ma with eruption of thick sequences of silicic (rhyolite of Pirouette Mountain, unit Trpm) and intermediate (andesite porphyry, unit Tap) lava flows that are locally interbedded with distally sourced ash-flow tuffs (older tuff, unit Tot). The lava sequences are overlain by two small volume, locally sourced(?) ignimbrites (the tuff of Job Peak and the tuff of upper Poco Canyon, units Tjp and Tupc, respectively), which are overlain in turn by rocks of the approximately 25.3 Ma Poco Canyon and 25.1 Ma Elevenmile Canyon calderas.

The older tuff unit (unit Tot) consists of at least three distally sourced ash-flow tuffs. The oldest tuff, which underlies and is intruded by the rhyolite of Pirouette Mountain, is a biotite-rich, low-silica rhyolite that has a zircon U-Pb age of 26.1±0.54 Ma.

The rhyolite of Pirouette Mountain (unit Trpm), previously called the older rhyolite unit (John, 1995b), is a lava dome complex composed mostly of sparsely porphyritic rhyolite that is as much 1,600 m thick and is exposed for about 8 km along the east side of the Stillwater Range. Samples from near the top of the unit at its south and north ends yielded zircon U-Pb ages of 25.24±0.25 Ma and 24.97±0.66 Ma, respectively. The rhyolite of Pirouette Mountain is extensively exposed in the Louderback and southwestern Clan Alpine Mountains (John, 1995a, 1997; Henry and others, 2013; Colgan and others, 2018).

The andesite porphyry unit (unit Tap) consists of coarsely porphyritic lava flows and hypabyssal intrusions that overlie and intrude the rhyolite of Pirouette Mountain and older tuff units. The lavas commonly contain conspicuous 3–10 mm, blocky, altered white plagioclase phenocrysts. An intrusion(?) near the base of the unit has U-Pb zircon age of 26.36±0.43 Ma.

The tuff of Job Peak (unit Tjp) is a strongly altered, moderately crystal-rich, densely welded rhyolite ignimbrite that forms the crest of the Stillwater Range. It closely resembles the tuff of Job Canyon but has a much younger zircon U-Pb age of 25.78±0.49 Ma. It is extremely lithic-rich (as much as 50 percent lithic fragments) and contains numerous blocks of intermediate lavas as much as 200 m in diameter. The tuff is approximately 750–1,000 m thick. This tuff was previously correlated with the tuff of Job Canyon (John, 1993, 1995b) or the tuff of the Louderback Mountains (Colgan and others, 2018), but its age, thickness, and the abundance and coarse size of lithic blocks within it indicate that it was erupted locally.

The tuff of upper Poco Canyon (unit Tupc) overlies the north end of the tuff of Job Peak and underlies rocks of the Poco Canyon caldera at the head of Poco Canyon. The tuff contains coarse andesite blocks and appears to fill a paleochannel cut into the tuff of Job Peak. The tuff has a zircon U-Pb age of 25.90±0.49 Ma. It is petrographically similar to, and was previously correlated with, the tuff of Elevenmile Canyon (John, 1993, 1995b). However, mapping in the Clan Alpine Mountains and new $^{40}Ar/^{39}Ar$ dating indicate that the tuff of Elevenmile Canyon is younger than the Poco Canyon caldera, and zircon trace element geochemistry of the tuff of upper Poco Canyon is distinct from zircons in the tuff of Elevenmile Canyon (Colgan and others, 2018).

Poco Canyon Caldera

The Poco Canyon caldera lies south of the Job Canyon caldera, with Poco Canyon caldera-related rocks exposed in three major structural blocks (labeled A, B, C in fig. 5). The northern block (C) is on the west side of the range and extends from Poco Canyon south through Government Trail Canyon to Long Canyon. A well-defined caldera wall is preserved on the north side of Poco Canyon, and the caldera is filled by as much as 4.5 km of densely welded tuff and coarse breccia deposits. The middle block (B) lies along the east side and crest of the range between Job Peak and Coyote Canyon and the southern block (A) is on the east side of the range surrounding East Lee Canyon.

Rocks related to the Poco Canyon caldera consist of upper and lower cooling units of the crystal-rich tuff of Poco Canyon (units Tpcu and Tpcl), the tuff and breccia of Government Trail Canyon (unit Tpbr), which is crystal-poor tuff containing coarse breccia erupted between the two units of tuff of Poco Canyon, and granite and rhyolite porphyry dikes (units Tgp and Trp) that were intruded along the north caldera wall (figs. 5 and 6). Whole rock geochemical analyses and zircon trace element and oxygen isotope data indicate that all these units are genetically related (Colgan and others, 2018; Watts and others, 2019).

The two units of the tuff of Poco Canyon are mostly high-silica rhyolites that generally contain 35–45 volume percent phenocrysts consisting of medium-grained, locally iridescent sanidine, smoky quartz, generally minor plagioclase, and trace amounts of biotite; the lower cooling unit (Tpcl) locally contains minor hornblende. The lower unit crops out south of Job Peak in the middle and southern blocks and is as much as 1,500 m thick. In the middle block, the tuff unconformably overlies the rhyolite of Pirouette Mountain, and these units are locally separated by a few meters of fine-grained sedimentary rocks. Here, the lower tuff unit is locally overlain by as much as 200 m of sandstone and sedimentary breccia (unit Tpsb) that contain abundant clasts of the rhyolite of Pirouette Mountain and the lower cooling unit of the tuff of Poco Canyon. The sandstones contain abundant smoky quartz crystals. In the southern block, the lower cooling unit of the tuff of Poco Canyon is the oldest exposed rock. It is pervasively altered and has a zircon U-Pb age of 25.74±0.19 Ma, and weakly altered sanidine yielded $^{40}Ar/^{39}Ar$ age of 25.257±0.008 Ma. The upper cooling unit only crops out in the northern block, where it is as much as 2,500 m thick. The upper cooling unit has sanidine $^{40}Ar/^{39}Ar$ ages of 25.16±0.08 and 25.26±0.07 Ma and zircon U-Pb ages of 25.6±0.25 and 25.49±0.4 Ma. Outflow tuffs correlated with the intracaldera tuff of Poco Canyon extend to Mt. Airy about 75 km to the east (the New Pass Tuff) and to the Nevada-California border about 150 km west (fig. 7; tuff of Chimney Spring, John, 1995b; Henry and John, 2013).

In the northern part of the Poco Canyon caldera, the upper cooling unit of the tuff of Poco Canyon overlies the tuff and breccia of Government Trail Canyon (unit Tpbr). The tuff and breccia of Government Trail Canyon consists of unsorted blocks (as much as several hundred meters in maximum dimension) of the lower cooling unit of the tuff of Poco Canyon, the tuff of Job Peak, and the rhyolite of Pirouette Mountain, enclosed in a matrix of moderately welded, crystal-poor (2–5 percent phenocrysts) high-silica rhyolite. Thin beds of sandstone and accretionary lapilli are locally interbedded in the unit. The breccia ranges from matrix supported to clast supported. The Government Trail Canyon unit is as thick as 1,800 m in Poco Canyon and is deposited directly on the tuff of Job Peak and the tuff of upper Poco Canyon (fig. 6). The tuff matrix has whole rock geochemistry and zircon trace element and oxygen isotope compositions similar to the tuff of Poco Canyon (John, 1995b; Colgan and others, 2018; Watts and others, 2019). The tuff matrix has a zircon U-Pb age of 25.99±0.20 Ma.

On the north side of the Poco Canyon caldera, a 4.5-km-long, east-northeast-striking (N. 70° E.), steeply dipping composite dike of granite and granite porphyry (unit Tgp) intrudes rocks beneath the Poco Canyon caldera and truncates the IXL pluton and older dacite and andesite sequence. A 1.5-km-long, approximately N. 75° W.-striking

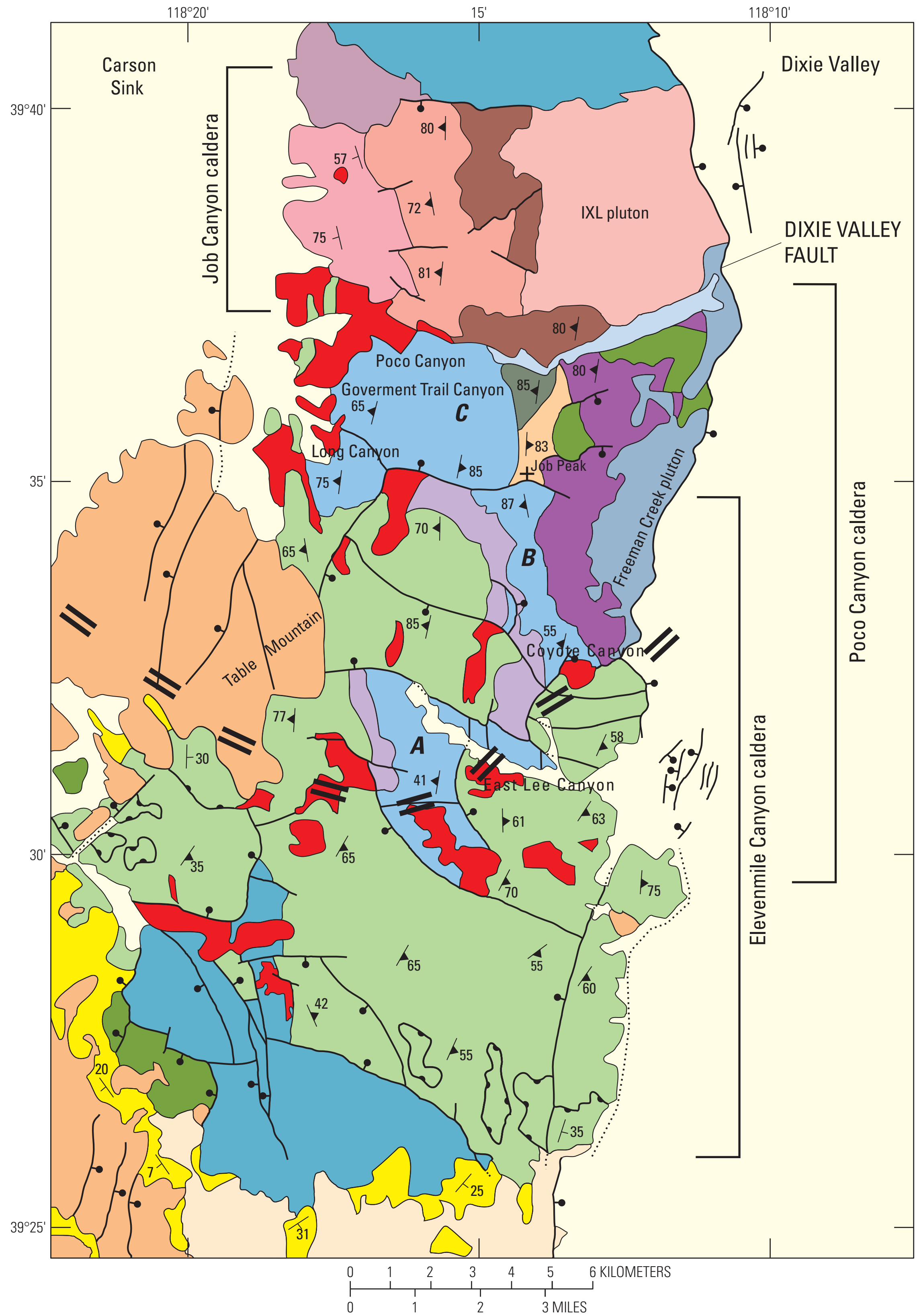


Figure 5. Generalized geologic map of the southern Stillwater Range showing principal structural features of the calderas and Cenozoic extension.

EXPLANATION

Surficial deposits (Quaternary)	Post-caldera collapse rocks and deposits
Older gravel deposits (Pleistocene and Pliocene?)	Post-caldera collapse rocks and deposits
Intermediate and mafic lava flows (Miocene)	Post-caldera collapse rocks and deposits
Sedimentary rocks (Miocene)	Post-caldera collapse rocks and deposits
Silicic intrusive rocks (Miocene and Oligocene)	Post-caldera dikes and domes
Freeman Creek pluton (Oligocene)	Rocks of the Stillwater-Clan Alpine caldera complex
Granite porphyry (Oligocene)	Rocks of the Stillwater-Clan Alpine caldera complex
Rocks of the Elevenmile Canyon caldera, undivided (Oligocene)	Rocks of the Stillwater-Clan Alpine caldera complex
Rhyolite of East Lee Canyon (Oligocene)	Rocks of the Stillwater-Clan Alpine caldera complex
Rocks of the Poco Canyon caldera, undivided (Oligocene)	Rocks of the Stillwater-Clan Alpine caldera complex
Tuff of upper Poco Canyon (Oligocene)	Rocks of the Stillwater-Clan Alpine caldera complex
Tuff of Job Peak (Oligocene)	Rocks of the Stillwater-Clan Alpine caldera complex
Andesite (Oligocene)	Rocks of the Stillwater-Clan Alpine caldera complex
Rhyolite of Pirouette Mountain (Oligocene)	Rocks of the Stillwater-Clan Alpine caldera complex
IXL pluton (Oligocene)	Rocks of the Stillwater-Clan Alpine caldera complex
Job Canyon caldera megabreccia (Oligocene)	Rocks of the Stillwater-Clan Alpine caldera complex
Younger dacite and andesite sequence (Oligocene)	Rocks of the Stillwater-Clan Alpine caldera complex
Tuff of Job Canyon (Oligocene)	Rocks of the Stillwater-Clan Alpine caldera complex
Older dacite and andesite sequence (Oligocene)	Pre-caldera rocks
Metamorphic and granitic rocks (Mesozoic)	Pre-caldera rocks

Contact

Normal fault—Dotted where concealed. Bar and ball on downthrown side

Low-angle normal fault—Half circle on downthrown side

Zone of structural accommodation

65 **Strike and dip of compaction foliation**

25 **Strike and dip of bedding**

B **Poco Canyon caldera stratigraphic-structural blocks (Figure 6)**

Figure 5. Generalized geologic map of the southern Stillwater Range showing principal structural features of the calderas and Cenozoic extension.—Continued

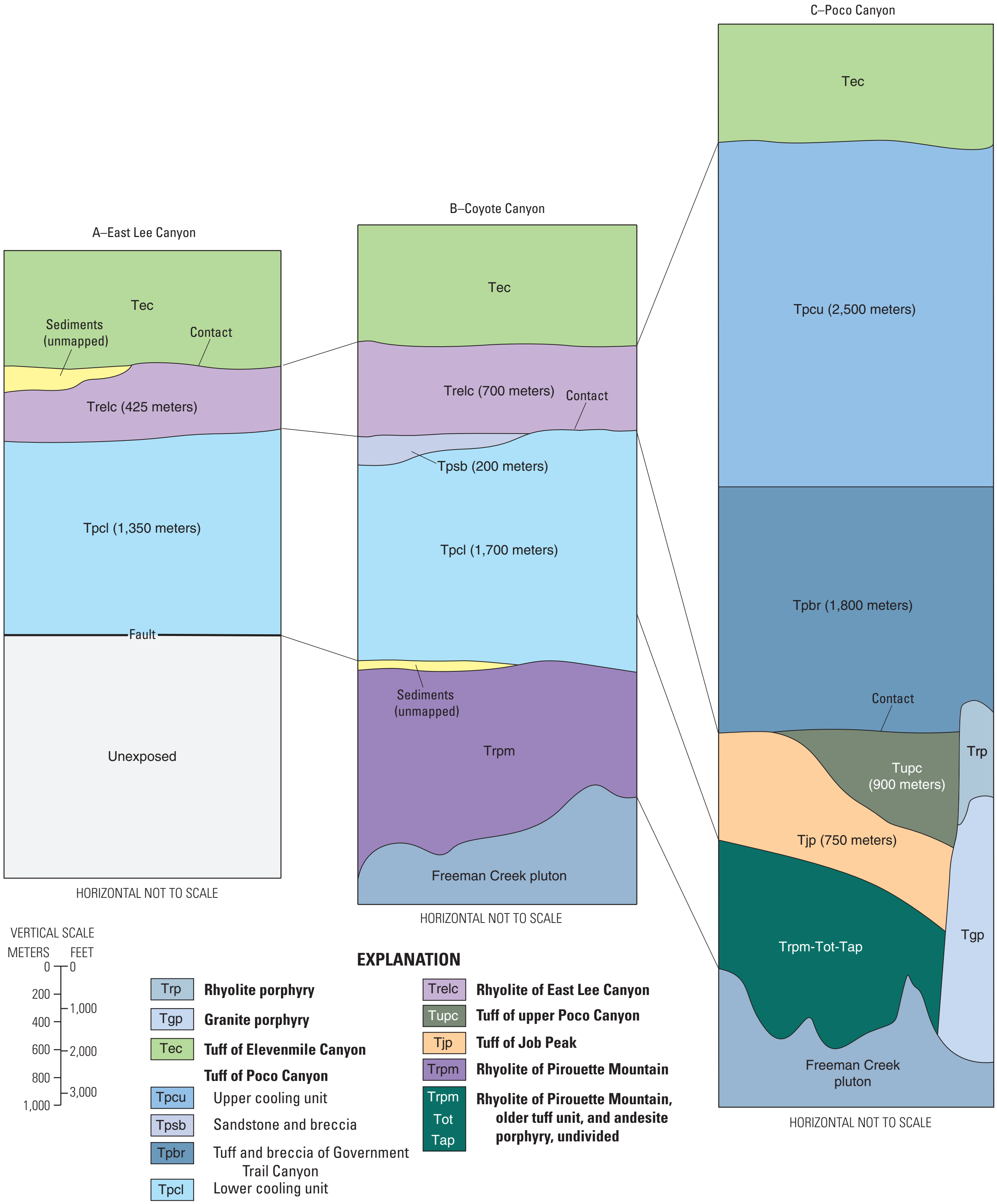
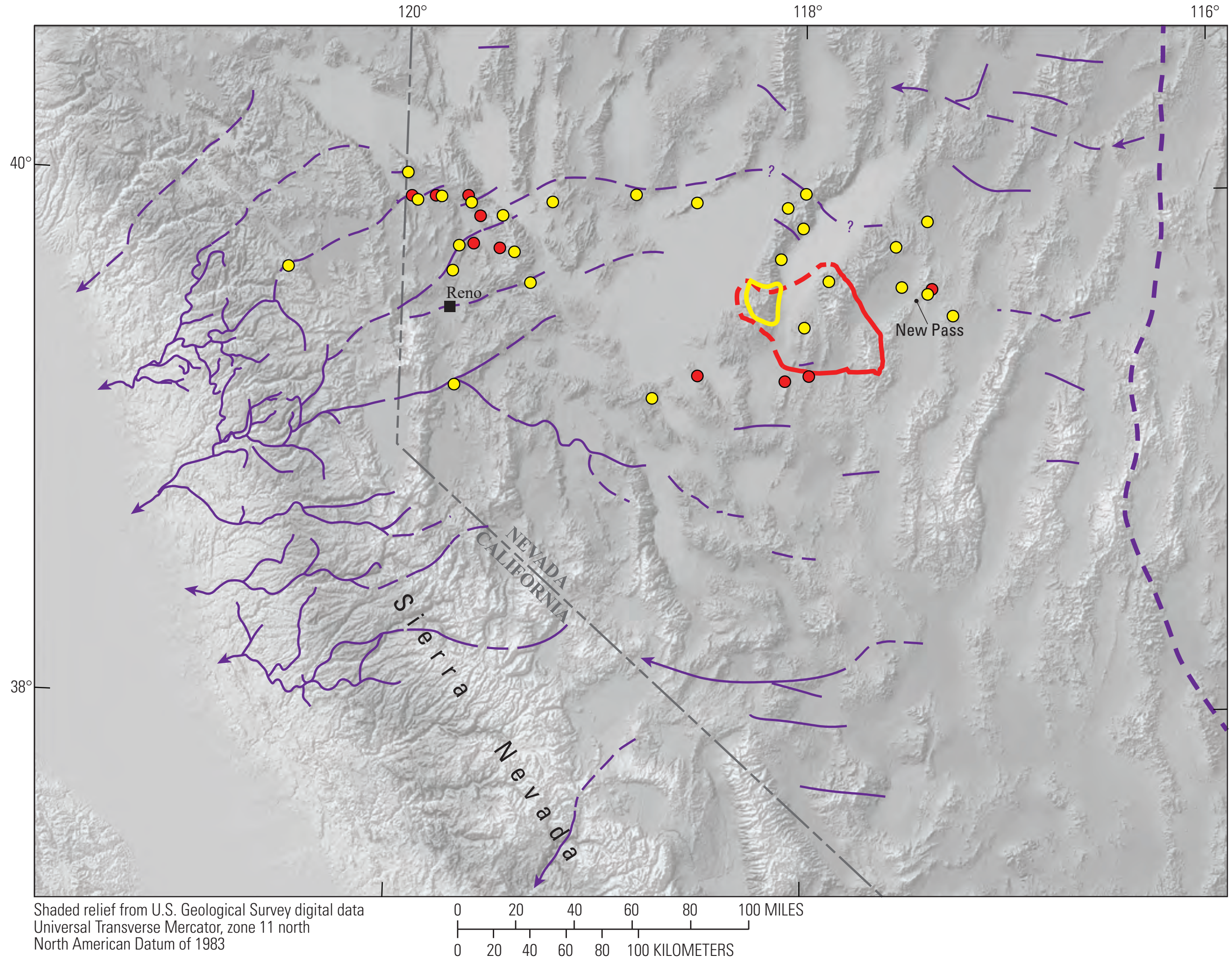


Figure 6. Stratigraphic sections for rocks of the Oligocene Poco Canyon caldera. A, East Lee Canyon, B, Coyote Canyon, and C, Poco Canyon.



EXPLANATION

Elevenmile Canyon caldera—Dashed where approximate

Poco Canyon caldera

Paleovalley—Dashed where approximate. Queried where existence uncertain. Arrows show direction of flow

Paleodivide

Tuff of Elevenmile Canyon

Tuff of Poco Canyon

Figure 7. Map showing outline of the Poco Canyon and Elevenmile Canyon calderas and locations of outflow tuff of Poco Canyon and tuff of Elevenmile Canyon. Outflow tuffs were mostly channelized into west-flowing paleovalleys that extended from a topographic paleodivide in central Nevada to the Pacific Ocean prior to uplift of the Sierra Nevada. Figure modified from Henry and John (2013).

porphyro-aphanitc rhyolite dike intrudes the tuff and breccia of Government Trail Canyon (unit Tpbr) and underlying andesite porphyry and tuff of upper Poco Canyon (units Tap and Tupc, respectively). Zircon U-Pb ages are 25.5±0.46 Ma for the granite porphyry (unit Tgp) and 25.44±0.63 Ma for the rhyolite porphyry (unit Trp). Geochemical data, field relationships, and geochronologic data indicate that the granite and rhyolite porphyry dikes are ring fracture dikes related to the Poco Canyon caldera (John, 1995b; Colgan and others, 2018).

Rhyolite of East Lee Canyon

The rhyolite of East Lee Canyon (unit Trelc) is a sequence of sparsely porphyritic lava flows, locally overlain by coarse-grained, smoky quartz-rich sandstone and sedimentary breccia (unit Tpsb), that overlies the lower cooling unit of the tuff of Poco Canyon. The breccias contain pebble-sized, subrounded to subangular clasts of the lower cooling unit of the tuff of Poco Canyon, and sparsely porphyritic lava flows, locally underlain by fine-grained andesites. The rhyolite of East Lee Canyon is petrographically identical to the rhyolite of Pirouette Mountain (unit Trpm), but these units can be distinguished by their trace element compositions (Colgan and others, 2017).

Elevenmile Canyon Caldera

The Elevenmile Canyon caldera is the youngest, largest, and most structurally disrupted caldera in the southern Stillwater Range (John, 1995b). The caldera extends about 55 km to the east across the Stillwater Range through the Louderback and southern Clan Alpine Mountains and into the northwestern Desatoya Mountains (fig. 2; Colgan and others, 2018). In the Stillwater Range, the caldera is recognized by thick (>4 km) sequences of the tuff of Elevenmile Canyon (unit Tec) and by abundant blocks and lenses of megabreccia that are enclosed within the tuff. The caldera is broken into several structural blocks that have varied directions and amounts of tilt (fig. 5; John and Silberling, 1994; John, 1995b). Three sequences of rocks, the tuff of Elevenmile Canyon (unit Tec), sedimentary tuff (unit Tst), and rhyolite lava flows (unit Tsf) comprise caldera-related deposits of the Elevenmile Canyon caldera in the Stillwater Range.

The tuff of Elevenmile Canyon is generally a densely welded, crystal-rich tuff that ranges in composition from low-silica trachydacite to high-silica rhyolite (about 64 to 77 weight percent SiO_2; John, 1995b; Stepner, 2017; Colgan and others, 2017). It contains 30–60 volume percent phenocrysts consisting of plagioclase, less abundant potassium feldspar and quartz, 1–5 percent biotite, ≤1 percent hornblende and opaque minerals, and local minor clinopyroxene (John, 1995b; Stepner, 2017). The tuff commonly contains abundant, strongly flattened, dark-green, chloritized, crystal-rich pumice clasts as long as 20 cm. Sparse fresh pumice commonly is orange colored. The tuff contains abundant lithic fragments of Mesozoic rocks (notably distinctive black argillite), sparsely porphyritic rhyolites, andesites, and locally, fragments of the tuff of Poco Canyon. In the Stillwater Range, the tuff has undergone variable but generally strong hydrothermal alteration; propylitic alteration is the most common type. The thickness of the tuff of Elevenmile Canyon is imprecisely known, but individual fault blocks are greater than or equal to (≥) 3,600 m thick (John, 1992a; John and Silberling, 1994). Outflow tuffs correlated with the tuff of Elevenmile Canyon extend from New Pass on the east to near the Nevada-California border north of Reno (fig. 7; Henry and John, 2013). The tuff has an estimated eruptive volume of 2,500–5,000 km^3 making it one of the most voluminous ignimbrites in the Great Basin (Best and others, 2013; Colgan and others, 2018). Three sanidine $^{40}Ar/^{39}Ar$ ages from unaltered samples in the Stillwater Range vary from 25.12±0.012 to 25.00±0.06 Ma; about 30 additional $^{40}Ar/^{39}Ar$ sanidine ages from other parts of the caldera and from outflow tuff average approximately 25.1 Ma (Henry and John, 2013; Colgan and others, 2018). Seven zircon U-Pb ages of intracaldera tuff range from 25.82±0.29 to 25.0±0.3 Ma (Colgan and others, 2018).

Megabreccia (unit Tecx) is common in the tuff of Elevenmile Canyon, occurring as blocks as much as 200 m in diameter near caldera walls (John and Silberling, 1994) and as slide(?) blocks as far as 6 km into the caldera (John, 1995a). Megabreccia blocks consist mostly of Mesozoic rocks that are exposed along the south wall of the caldera with less abundant blocks of andesite.

The tuff of Elevenmile Canyon is overlain locally by a sequence of argillically altered, water-laid silicic tuffs, fine-grained sedimentary rocks, and less abundant rhyolite lava flows (sedimentary tuff, unit Tst) that is overlain by more massive rhyolite lava flows (unit Tsf). Tuffaceous horizons commonly contain dark-colored clasts of silicified, finely bedded, fine-grained sandstone, siltstone, and mudstone as much as 50 cm long. The clasts commonly have intricate flame-like margins and complex internal folds. The sedimentary tuff unit and overlying rhyolite lava flows are as much as 600 m thick and crop out principally in the southern third of the caldera. A tuff in this sequence has a zircon U-Pb age of 25.05±0.67 Ma. These rocks are inferred to be post-collapse, caldera-filling lacustrine(?) deposits (John, 1995b).

Freeman Creek Pluton

The Freeman Creek pluton underlies the northern two-thirds of exposures of the tuff of Poco Canyon and the northern third of the Elevenmile Canyon caldera along the east side of the range, where the Oligocene rocks have been steeply tilted to the west. The pluton is a composite intrusion that consists of medium- to coarse-grained, equigranular to porphyritic, relatively leucocratic biotite granite (unit Tfcgr) that intrudes medium-grained biotite-hornblende granodiorite porphyry (unit Tfcgd). Both phases appear to intrude and truncate the east end of the granite porphyry dike (unit Tgp) along the north ring fracture of the Poco Canyon caldera and the granodiorite phase intrudes the IXL pluton. The granite phase has a zircon U-Pb age of 24.93±0.30 Ma and the granodiorite phase has zircon U-Pb ages of 25.71±0.38 and

25.16±0.23 Ma. Although most of the Freeman Creek pluton directly underlies the Poco Canyon caldera and neither phase is genetically related to the Poco Canyon caldera magma, geochemical and geochronologic data indicate the granodiorite phase is likely residual magma from the tuff of Elevenmile Canyon (Colgan and others, 2018; Watts and others, 2019).

Late Oligocene Post-Caldera Rocks

Small-volume silicic magmas erupted shortly after formation of calderas in the southern Stillwater Range. These rocks include rhyolite to dacite dikes and domes (units Tsi, Tyr, Tr, and Tdi) and small pyroclastic aprons around the domes (unit Tts). The younger rhyolite (unit Tyr) forms the largest exposures and intrudes the tuff of Elevenmile Canyon (unit Tec) and overlies or intrudes the upper cooling unit (unit Tpcu) of the tuff of Poco Canyon. These rhyolites are petrographically and geochemically identical to the rhyolite of East Lee Canyon (unit Trelc) and may represent renewed eruption of this magma along the western edge of the Elevenmile Canyon caldera. Biotite rhyolites (unit Tsi) intrude the tuffs of Poco Canyon and Elevenmile Canyon. The north wall and a parallel fault to the south that bound the thickest deposits in the Poco Canyon caldera were intruded by dacite porphyries (unit Tdi). Similar dacite intrusions are exposed in North Lee Canyon and between Sheep and Shirttail Canyons. A glassy biotite rhyolite dome (unit Tsi) and a sparsely porphyritic rhyolite (unit Tyr), both collected near the mouth of Poco Canyon, have sanidine $^{40}Ar/^{39}Ar$ ages of 25.18±0.03 and 25.17±0.03 Ma, respectively.

Early Miocene Silicic Dikes

A swarm of west-northwest-striking silicic dikes crops out in the southern part of the map area (unit Tsd). They are part of a dike swarm that intrudes the Elevenmile Canyon caldera and older rocks and which extends from upper Sheep Canyon in the Stillwater Range about 35 km eastward across the Louderback Mountains into the southwestern Clan Alpine Mountains (John, 1997; Henry and others, 2013). In the Stillwater Range, the dikes are exposed across a zone about 10 km wide. They include fine-grained biotite rhyolites and medium- to coarse-grained low-silica rhyolite or dacite porphyries; many dikes are composite. Dikes in the Stillwater Range are pervasively altered mostly to propylitic or argillic assemblages. A rhyolite porphyry dike in Elevenmile Canyon, a rhyolite or dacite porphyry dike in the La Plata Canyon pluton, and an aphyric rhyolite dike in upper La Plata Canyon have zircon U-Pb ages of 24.7±0.3, 23.36±0.39, and 22.19±0.2 Ma, respectively. Four $^{40}Ar/^{39}Ar$ ages for dikes from the Louderback and southwestern Clan Alpine Mountains and equivalent silicic lavas in the Westgate area at the south end of the southwestern Clan Alpine Mountains range from 22.82±0.09 to 21.81±0.07 Ma (Henry and John, 2013; C.D. Henry, Nevada Bureau of Mines and Geology, written commun., 2023), and most dikes in the Stillwater Range are likely approximately 23 to 21.5 Ma.

Miocene Sedimentary Rocks

Mesozoic rocks and rocks of the Elevenmile Canyon caldera are unconformably overlain by middle Miocene fluvial and lacustrine sedimentary rocks (unit Ts) at the south end of the map area. These rocks consist of pebble conglomerate, sandstone, siltstone, shale, and minor freshwater limestone. Near Mountain Well, coarse landslide or debris-flow deposits (unit Tlb) laterally interfinger with the basal(?) part of the sedimentary rocks. The landslide deposits contain unsorted blocks as much as tens of meters across of the andesite of Sheep Canyon, the tuff of Elevenmile Canyon, and silicic intrusive rocks (units Tsi and Tsd) but lack blocks of Mesozoic and younger Tertiary volcanic rocks; the clast association indicates that the landslide deposits formed during initial faulting and uplift of the southern Stillwater Range prior to deep erosion of the older Tertiary volcanic rocks and eruption of the younger Tertiary units. The upper part of the sedimentary rocks unit locally contains thin layers of intermediate to mafic composition tuff and basalt scoria, and basalt lava flows locally overlie fine-grained sedimentary rocks between lower La Plata and Elevenmile Canyons. The reworked tuff beds underlying basalt lava flows (unit Tb) west of Mountain Well have whole rock K-Ar ages ranging from 13.9±0.4 to 12.6±0.5 Ma (Stewart and others, 1994), whereas a glassy rhyolite tephra from lower La Plata Canyon in fine-grained sediments that overlie basalt lavas has a sanidine $^{40}Ar/^{39}Ar$ age of 12.25±0.087 Ma.

Middle Miocene Lava Flows

The middle Miocene sedimentary rocks are mostly overlain and intruded by middle Miocene intermediate and mafic composition lava flows, flow breccias, and debris flows; basalt flows locally underlie sedimentary rocks between La Plata and Elevenmile Canyons. Three principal types of rocks are present: hornblende andesite, pyroxene dacite, and basalt. The oldest lava flows are approximately 15 Ma hornblende andesites (unit Tha) that crop out near Mountain Well and in the southeastern part of the Elevenmile Canyon caldera. Porphyritic plagioclase-clinopyroxene dacite lava flows and flow breccias crop out extensively between Mountain Well and the west edge of the map area (unit Tddc). Several small plugs that probably were feeders for some of these flows (unit Tddci) intrude the lava flows. A lava flow near Mountain Well has a plagioclase $^{40}Ar/^{39}Ar$ age of 14.51±0.038 Ma. The dacite lavas interfinger laterally and are overlain by basalt lava flows (unit Tb) that form Table Mountain and the west flank of the southern Stillwater Range. The basalts have whole-rock K-Ar ages ranging from 14.4±0.4 to 13.0±0.4 Ma and a basalt dike (unit Tbi) that intrudes the Miocene sedimentary rocks has a whole-rock K-Ar age of 13.9±0.5 Ma (Stewart and others, 1994).

Surficial Deposits

A wide variety of surficial deposits are exposed in the map area, primarily on the margins of the Stillwater Range in Carson Sink and Dixie Valley. Many types of surficial deposits are related to former pluvial lakes Lahontan and Dixie, which filled Carson Sink and parts of Dixie Valley, respectively, at times during the Quaternary (Morrison, 1964, 1991; Bell and Katzer, 1987; Oleson-Elliot, 1994; Bell and others, 2010; Bell and House, 2010). The surficial deposits on this map are composed of beach and shoreline deposits, lacustrine sediments, tufa mounds, eolian sand, several ages of alluvial deposits, talus and colluvium, landslides, and basin fill (a mixture of alluvial, lacustrine, eolian, and playa deposits filling the former pluvial lake basin in Dixie Valley). Variable amounts of unmapped eolian silt, mostly blown off the Lahontan basin during times when the lake basin was largely dry, blanket many of the surficial deposits and underlie desert pavement formed on many of the deposit surfaces. In contrast to the Miocene sedimentary rocks, clasts of pre-Tertiary rocks are abundant in the Quaternary alluvial deposits.

Deep lakes that occupied the Lahontan basin at multiple times in the past (for example, Morrison, 1964; 1991; Reheis and others, 2002) have had a large effect on the type and distribution of surficial deposits on the west side of the map area. The last two major lacustral cycles of Lake Lahontan were the Eetza, which occurred during the late middle Pleistocene, and the Sehoo, which occurred during the late Pleistocene (Morrison, 1964; 1991). Shorelines associated with highest lake levels of the Eetza lacustral cycle vary in elevation owing to regional warping and tilting but have an average elevation of about 1,335 m (Morrison, 1991), similar to that of the high shorelines of the later Sehoo lacustral cycle (Mifflin and Wheat, 1979). The Eetza lacustral cycle is considered to have spanned from about 180–130 ka but could have extended back as far as 300 ka (Morrison, 1991; Reheis and others, 2002). Evidence of lake cycles predating the Eetza has been documented elsewhere in the Lahontan basin (for example, Morrison, 1991; Reheis and others, 2002) but was not recognized in the map area. Lake-level reconstruction for the younger lacustral cycles is based on numerous calibrated ^{14}C ages on tufa and other types of organic samples (Benson and others, 2013) and indicates that highest lake levels during the Sehoo lacustral cycle (about 1,336–1,338 meters in the map area) were reached at about 15.5 ka, but lake level fell precipitously to about 1,190 meters shortly thereafter (Thompson and others, 1986; Benson and others, 1990, 2013; Morrison, 1991). Lake level rose again to about 1,216 meters between 13–11.7 ka, just prior to the end of the lacustral cycle (Morrison, 1991; Benson and others, 2013). The youngest lakes of pluvial Lake Lahonton occurred during the Holocene and are grouped into the Fallon lacustral cycle. Highest lake levels in Carson Sink during the Fallon lacustral cycle were at about 1,205 meters, indicating a shoreline just west of the map area.

Most of the deposits associated with Lake Lahontan that are exposed in the map area were probably deposited during the Sehoo lacustral cycle. There is some evidence of deposits from the earlier Eetza lacustral cycle, but it is limited. Similar to buried stratigraphic relations seen locally in the Lahontan Mountains area to the southwest (Morrison, 1964; Bell and others, 2010), there are a few stream cut and borrow pit exposures into beach and shoreline deposits of Lake Lahontan (unit Qlbl) that provide limited view of older stratigraphic units marked by buried soils, including interlacustral deposits of alluvial sandy gravel (Pleistocene Wyemaha Alloformation, Morrison, 1964; 1991), and lake gravels thought to have been deposited during the Eetza lacustral cycle (Pleistocene Eetza Alloformation; Morrison, 1964, 1991). No unburied deposits from the Eetza lacustral cycle were identified in the map area, but this could be due to a lack of preservation. The highstand of the Sehoo lacustral cycle, herein the Sehoo highstand, was either within a few meters of (Morrison, 1964, 1991; Bell and others, 2010), or higher than (Russell, 1885; Adams and Wesnousky, 1998; 1999) the highstand of the Eetza lacustral cycle. Therefore, water levels combined with storm-wave action during the Sehoo lacustral cycle would have mostly or entirely inundated deposits of the earlier lake cycle, reworking or burying Eetza Alloformation deposits and making them difficult to distinguish from younger ones (Adams and Wesnousky, 1998, 1999; Bell and others, 2010). An example may be the large, rounded to subangular boulders locally common in the shoreline deposits, which may have been originally deposited during the Eetza lacustral cycle, but reworked later by shoreline processes during the Sehoo lacustral cycle. Morrison (1964) generally considered deposits of large-boulder gravel to be part of the Eetza Alloformation and mapped many as such in the Lahontan Mountains and Grimes Point quadrangles southwest of the map area. Bell and others (2010) and Bell and House (2010) reinterpreted most of these deposits (those at or below about 1,336–1,337 meters) as Sehoo Alloformation, but also acknowledged that large boulders in the deposits may have been reworked from Eetza Alloformation deposits.

On the eastern margin of the Stillwater Range, a pluvial lake referred to as Lake Dixie partly occupied Dixie Valley at times in the past. Evidence that the lake existed during the middle Pleistocene is provided by small, isolated exposures of fine-grained sediment (unit Qlfo) at an elevation as much as 12 m higher than the late Pleistocene highstand shoreline of Lake Dixie (about 1,097 meters, Mifflin and Wheat, 1979). Late Pleistocene to Holocene offset on adjacent strands of the Dixie Valley Fault, estimated to be about 3 m (Bell and Katzer, 1987), cannot account for the elevation difference between Qlfo deposits and the late Pleistocene high shoreline, supporting the interpretation that these deposits are from an earlier, middle Pleistocene lacustral cycle (Bell and Katzer, 1987; Reheis and others, 2002).

Most of the deposits associated with pluvial Lake Dixie that are exposed in the map area (units Qlb and Qlf) are considered late Pleistocene. Lake Dixie and Lake Lahontan were physically separate but coexistent lakes during the late Pleistocene, and radiocarbon ages for Lake Dixie shoreline deposits indicate its highstand was probably coeval with the Sehoo highstand of Lake Lahontan (Thompson and Burke, 1973; Bell and Katzer, 1987).

Alluvial deposits in the map area are mostly fan deposits left by sheetfloods and debris flows (Harvey, 2005) that typically grade upstream to terrace deposits in the canyons. Several age groups of alluvial deposits are identified and are similar to those recognized by previous workers on the west side (Harvey and Wells, 1996; Harvey and others, 1999) and east and south sides (Bell and Katzer, 1987, 1990; Calvin and others, 2012) of the Stillwater Range.

Very old alluvial deposits (unit QTa) are preserved mostly as isolated remnants at or near the mountain front on the south and southeast sides of the map area, where the mountain front is not bounded by an active normal fault, suggesting that active faulting has minimized their preservation elsewhere. Unlike other areas fringing the Stillwater Range, most of the surficial deposits in the southern region of the map are older than the young alluvial deposits (unit Qay), which probably also reflects the lack of an active normal fault bounding the southern mountain front, and distance from the influence of pluvial lake level fluctuations.

Old and intermediate alluvial deposits (units Qao and Qai) are cut by the Sehoo highstand shoreline on the west side of Stillwater Range, and therefore predate the Sehoo lacustral cycle. Qao deposits likely also predate the earlier Eetza lacustral cycle based on degree of soil development that suggests an estimated age of 500–200 ka for Qao fan surfaces (Bell and Katzer, 1987; 1990). These older fan deposits reflect a prolonged period of fan building prior to the late Pleistocene (Mifflin and Wheat, 1979; Harvey and others, 1999).

Young to intermediate alluvial deposits (unit Qam) are late Pleistocene and Holocene and locally grade to or cut highstand deposits from late Pleistocene pluvial lakes on both sides of the Stillwater Range (Bell and Katzer, 1987; 1990). These alluvial deposits (unit Qam) are common on the east side of the range, where they would have only locally been directly affected by the rise and fall of pluvial Lake Dixie. In contrast, on the west side of the range that sits on the margin of pluvial Lake Lahontan, the alluvial deposits (unit Qam) are sparse in number and small in extent. Lake-level fluctuations in Lake Lahontan likely had a large direct effect on the preservation of Qam deposits by causing periodic inundation and reworking by shoreline processes. The rise and fall of the lake level would also have changed the base level of streams draining into the lake, triggering episodic erosion of Qam deposits or their burial by younger alluvial deposits (unit Qay).

Young alluvial deposits (unit Qay) are Holocene and are common on both the west and east sides of the Stillwater Range, where they cut across late Pleistocene beach, shoreline, and lacustrine sediments. An atypical stretch along the eastern mountain front where deposits are interpreted as predominantly young alluvial deposits (unit Qay) corresponds to a section of mountain front where bedrock is made up mostly of rhyolite, granodiorite porphyry, and granite (units Trpm, Tfcgd, and Tfcgr, respectively), and where Quaternary faulting is focused at the mountain front. This scenario is unique to this part of the Stillwater Range and suggests that the lithology of bedrock combined with the location of recent faulting promotes young fan deposition that buries older units, creating a stacked sequence of deposits. Stacked sequences marked by buried soils that separate different age fan deposits were observed locally in stream cuts elsewhere in the map area.

Deposition of the alluvial fans in the map area has been variously influenced by changes in climate during the Quaternary, fluctuations in base level resulting from the rise and fall of pluvial lakes, topographic relief of the Stillwater Range, and active tectonics particularly along the eastern mountain front (for example, Harvey, 2005). Previous workers who evaluated the driving forces of fan deposition in the map area considered climate to be the primary factor because of its role in determining storm runoff and sediment supply, key variables in the formation of alluvial fans (Harvey and others, 1999; Harvey, 2002, 2005). Their reconstructions of vegetation suggest that during pluvials the map area was covered by relatively lush vegetation that would have inhibited storm runoff and subsequent erosion of the hillslopes (Harvey and others, 1999). Sediment supply for fan building during these relatively wet times would have been kept low as a result (Harvey, 2005). Their reconstructions also suggest that shifts to more arid climates during interpluvials resulted in changes to the vegetation cover that would have promoted storm runoff and subsequent hillslope erosion. Sediment supply for fan building during these dry times would have been high as a result and would have promoted fan aggradation or progradation (Harvey and others, 1999; Harvey, 2005). The latter scenario would likely also have applied to extended dry periods within pluvials that are inferred from reconstructed lake elevation plots (for example, Morrison, 1991; Benson and others, 2013). Changes in climate may have been the primary factor controlling the timing of fan deposition, but because climate probably affected the entire map area similarly, the variations observed in fan distribution probably reflect the influence of the secondary factors—base level change from fluctuating lake levels and the tectonic setting of the Stillwater Range, which provided the topographic relief and accommodation space for accumulating fan sediment (see Harvey [2005] for a discussion of the differential effects of base-level, tectonic setting, and climatic change on Quaternary alluvial fans in the Great Basin).

Pre-Cenozoic Structural History

Pre-Cenozoic structures in the La Plata Canyon area are incompletely understood, in part because of uncertainties in the ages of the rocks forming the tectonic blocks and in part because pre-Cenozoic structures have been significantly reoriented by Cenozoic faulting and tilting (John and Silberling, 1994). However, although they share some of the same polyphase deformation, the major tectonic blocks have partly different metamorphic and structural histories, suggesting that they were brought together by large horizontal displacements (Oldow and others, 1993; John and Silberling, 1994). The Clan Alpine sequence has undergone at least three successive deformations involving folding and faulting. Rocks of this sequence generally have little penetrative deformation except in proximity to the La Plata Fault. Crossing the La Plata Fault, the phyllite unit (unit Pzp) has a generally higher metamorphic grade and possibly a more complex structural history than does the Clan Alpine sequence. Because the Clan Alpine sequence generally overlies the phyllite unit on the La Plata Fault, Page (1965) first described this structure as a thrust fault. However, the original orientation and nature of the La Plata Fault prior to subsequent Mesozoic folding and Cenozoic tilting is uncertain (John and Silberling, 1994).

The oldest and most penetrative deformation, designated D1, is expressed in the rocks on either side of the La Plata Fault whose original displacement is evidently an effect of this deformation. The mylonitic foliation and conspicuous stretching lineation in the Clan Alpine sequence near this fault is an effect of D1 deformation, as is metamorphic foliation in unit Pzp. Folds of a second deformation, designated D2, affect both the Mountain Well and Clan Alpine sequences, as well as the La Plata Fault and the phyllite unit, and are notably more ductile than D3 folds. The youngest well-developed compressive structures in the pre-Cenozoic rocks are northwest-trending, southwest-verging, outcrop and map-scale folds of the Clan Alpine sequence rocks, the La Plata Fault, and the phyllite unit. These are brittle structures, in places associated with northwest-striking faults; they represent a final major compressional deformation, designated D3 (John and Silberling, 1994).

Pre-Cenozoic structures have been significantly reoriented by Cenozoic faulting and a large correction for generally down-to-the-east Cenozoic tilt is thus required before the geometry of pre-Cenozoic structural features of the La Plata Canyon area can be compared with that of other outcrop areas in western Nevada (John and Silberling, 1994). If Cenozoic tilt to the east about a generally north-trending axis was only moderate in amount, the three successive pre-Cenozoic deformations in rocks of the La Plata Canyon area could correspond to the three major phases of deformation recognized regionally by Oldow (1984) in western Nevada. Of these, Oldow's "D2" and "D3" faults and folds are characteristic of "Luning-Fencemaker" deformation and would originally have had traces trending northeast and northwest, respectively; his "D1" deformation is seen only in the Sand Springs "lithotectonic assemblage" and in the more western and structurally higher Mesozoic allochthons of western Nevada. Alternatively, if Cenozoic tilt is more than about 60 degrees (°) to the east, as suggested by Colgan and others (2020), the axial surfaces of D3 folds in the La Plata Canyon area would restore to a northeast strike similar to Oldow's regional "D2" folds; structures designated D1 and D2 in the La Plata Canyon area would then presumably represent a polyphase "D1" generation in Oldow's scheme. In either case, recognition of the regional "D1" generation of deformation in the La Plata Canyon area is reason to include the phyllite (unit Pzp) in the Sand Springs "lithotectonic assemblage" of Oldow (1984).

Mesozoic rocks at the north end of the map area north of the Job Canyon caldera record at least two deformations. The relatively older minor folds are commonly isoclinal, suggesting that, prior to the last folding, the structure consisted of recumbent folds having subhorizontal axial surfaces. Assuming that the present-day general structural trends reflect refolding of subparallel axial surfaces and long limbs of these early folds, correcting for the large west tilt of the Job Canyon caldera reorients both the west-northwest-trending structural grain along the west flank of the range and the east-northeast-trending structural grain along the east front of the range into a steep northwest-trending last fold set. The trend of this late fold set, after restoration of Cenozoic tilt, is similar to the latest major folds in the "mud pile" rocks of the Clan Alpine Mountains. In the Clan Alpine Mountains, these are the D3 folds of Oldow (1984), the youngest major folds regionally. Thus, significant Cenozoic tilt of the complexly deformed Mesozoic rocks, as mapped for at least 3 km north of the Job Canyon caldera margin, is suggested by the limited data on the pre-Tertiary geology of this part of the Stillwater Range.

Cenozoic Structural History

At least two major periods of tilting and extensional faulting are evident in the older Tertiary rocks in the southern Stillwater Range—middle to late Miocene and Pliocene to Holocene (John, 1992b, 1995b; Hudson and others, 2000; Colgan and others, 2020).

Middle Miocene Extension

Formation of the Elevenmile Canyon and Poco Canyon calderas and emplacement of the Freeman Creek pluton and the early Miocene dike swarm were followed by steep tilting of the Stillwater caldera complex and deposition of middle Miocene sedimentary rocks (John, 1992b; Hudson and others, 2000; Colgan and others, 2020) due to large-magnitude (>100 percent) crustal extension. The Job Canyon caldera, the IXL pluton, the northern parts of the Poco Canyon and Elevenmile Canyon calderas, and the Freeman Creek pluton were steeply tilted to the west (approximately 60°), whereas the southern parts of the Poco Canyon and Elevenmile Canyon calderas were tilted east. An accommodation zone separates the domains with differing tilt directions (fig. 5), although it is poorly understood because it occurs within highly altered tuff of Elevenmile Canyon that provides no stratigraphic markers. Another accommodation zone must separate the west-tilted Job Canyon domain from gently east-dipping Oligocene tuffs just north of the prominent bend in the Dixie Valley Fault. Colgan and others (2020) interpreted this boundary to be just north of Alameda Canyon, hypothesizing that it was a near-vertical, east-west striking Miocene fault that was partly reactivated later to become part of the modern Dixie Valley Fault.

Low-angle normal faults between steeply east-dipping tuff of Elevenmile Canyon and the steeply east-dipping sedimentary tuff (unit Tst) are the only mapped examples of the type of structures that accommodated steep tilting and exhumation. Cenozoic low-angle faults are otherwise unrecognized due to lack of markers in thick, altered intracaldera tuff, or are no longer exposed due to uplift and erosion during younger high-angle faulting. They are interpreted to have formed at high angles and rotated to shallow ones during slip (Hudson and others, 2000; Colgan and others, 2020), similar to middle Miocene extensional faults in the Yerington Mining District about 90 km southwest of the southern Stillwater Range (Proffett, 1977; Dilles and others, 1993).

Large magnitude Miocene extension and tilting took place between the end of caldera volcanism (circa [ca.] 25 Ma) and the deposition of intermediate-mafic lava flows (ca. 15–13 Ma, units Tha, Tddc, Tya and Tb) onto the tilted Oligocene tuffs in angular unconformity. Hudson and others (2000) interpreted paleomagnetic data to suggest that this event took place synchronously with the waning stage of volcanism, ca. 25–24 Ma. More recently, Colgan and others (2020) inferred that major tilting took place ca. 19–14 Ma on the basis of time-temperature paths from the La Plata and IXL plutons determined from apatite fission-track and apatite and zircon (U-Th)/He data. This timing is consistent with a 17–15 Ma age for major extension in the East Range approximately 80 km to the north along strike (Fosdick and Colgan, 2008) and with a widespread phase of middle Miocene extension across the northern Great Basin more generally (for example, Surpless and others, 2002; Stockli and others, 2002; Lee and others, 2009; Colgan and Henry, 2009; Colgan and others, 2010; Colgan and Henry, 2017).

Late Cenozoic Basin and Range Faulting and Extension

Modern basin-and-range extension and normal faulting in the area postdates middle Miocene (ca. 14–12 Ma) basalt lava flows that cap the west side of the southern Stillwater Range (Page, 1965; John, 1995b; Hudson and others, 2000). Colgan and others (2020) inferred that slip on the Dixie Valley Fault in the southern Stillwater Range began ca. 8 Ma on the basis of thermo-kinematic modeling of apatite (U-Th)/He and 4He/3He cooling ages. MacNamee (2015) suggested a slightly younger 6–5 Ma age for the onset of faulting at the latitude of the Dixie Valley geothermal plant about 10 km to the north of the study area. Late Miocene and younger extension is oriented west-northwest–east-southeast (Zoback and others, 1981) and formed the present topography of north-northeast-trending ranges—the Stillwater Range and the Louderback Mountains—and the intervening basin in Dixie Valley (figs. 1 and 2). The Stillwater Range has been tilted gently west, whereas the Louderback and Clan Alpine Mountains have been gently tilted east by Basin and Range faulting. High-angle normal faults (about 60° dip) related to modern extension have been active in Holocene time, including the 1954 Fairview Peak, Dixie Valley, and Rainbow Mountain earthquakes, which produced scarps as much as 3 meters high along the west sides of the Louderback and Clan Alpine Mountains and the east side of the Stillwater Range and smaller scarps on the southwest side of the Stillwater Range (Slemmons, 1957; Slemmons and others, 1959; Bell, 1984; Caskey and others, 1996). Many other Quaternary normal faults are present in surficial deposits in Dixie Valley (Bell, 1984; Bell and Katzer, 1987; John, 1995a; this study). The lateral continuity of the early Miocene rhyolite dike swarm westward across Dixie Valley indicates that little oblique-slip displacement has occurred along the late Cenozoic normal faults forming Dixie Valley, in accord with observations of the 1954 fault scarp in Dixie Valley (Slemmons, 1957; Bell and Katzer, 1987; Caskey and others, 1996).

Structural Features of Calderas in the Southern Stillwater Range

Steep Miocene tilting and exhumation of the southern Stillwater Range provide direct exposure of calderas and underlying plutons to paleodepths as much as 10 km, revealing typically unseen features that shed light on the evolutionary history of the calderas and place constraints on models of ignimbrite caldera genesis and pluton emplacement (John, 1995b; Colgan and others, 2018). These features include caldera floors and walls, megabreccia and other collapse features, post-caldera collapse resurgent magmatism, pluton geometry and emplacement mechanisms, and ring-fracture dikes.

Caldera Floors

Parts of the floors of all three calderas are exposed. The floor of the Job Canyon caldera is an undulatory surface that is cut by several high-angle faults that have displacements of several hundred meters (fig. 4). Some, with normal displacement, likely formed during caldera collapse, while others, with apparent reverse displacement, likely formed during structural doming related to emplacement of resurgent magmas (younger dacite and andesite sequence and IXL pluton). The floor of the north and middle blocks of the Poco Canyon caldera are subhorizontal surfaces that extend about 4 and 5 km along strike, respectively (blocks C and B, fig. 5). Compaction foliation in caldera fill (tuff and breccia of Government Trail Canyon and upper and lower cooling units of the tuff of Poco Canyon) is subparallel to the floor. The caldera floor in the southern part of the Elevenmile Canyon caldera is a subhorizontal surface exposed for about 5 km along strike. Compaction foliation in caldera-filling tuff of Elevenmile Canyon is subparallel to the floor. The Elevenmile Canyon caldera floor is a similar subhorizontal surface where it is well exposed for approximately 20 km along strike in the Louderback Mountains and for approximately 15 km along strike in the southwestern Clan Alpine Mountains. In contrast, there was notable topographic relief on the central part of the Elevenmile Canyon caldera floor in the Stillwater Range where it overlies the rhyolite of East Lee Canyon.

Caldera Walls and Collapse Features

Caldera floor blocks collapsed as piston-like bodies, subsiding along steeply dipping faults that penetrated the crust to depths of at least 5 km. Subvertical faults that mark both walls of the Job Canyon caldera and the south wall of the Elevenmile Canyon are well preserved (fig. 5). Coarse caldera-collapse breccias interbedded with caldera-filling tuffs are present both as lenses along caldera walls and as slide blocks several km inside the calderas.

The north margin of the Job Canyon caldera flares upward, transitioning from a subvertical structural margin at depth to a topographic margin approximately 1.5 km outward (north) at the top of the caldera (fig. 4). The northern edge of the IXL pluton generally conforms to the structural margin at paleodepths of approximately 5–10 km. The south wall of the Elevenmile Canyon caldera is a narrow subvertical fault zone that extends >5 km deep, with a topographic wall flaring outward (south) approximately 0.5 km in the upper 1 km. The south margin of the Job Canyon caldera apparently was reactivated as the north wall of the Poco Canyon caldera. This steeply dipping, west-striking fault zone extends to paleodepths of about 8–10 km and bounds both rocks filling the Poco Canyon caldera (units Tpbr and Tpcu) and underlying rocks erupted between emplacement of the approximately 28 Ma IXL pluton and eruption of Poco Canyon caldera rocks (units Trpm, Tot, Tap, Tjp, Tupc). The fault zone also was intruded by granite porphyry (unit Tgp) and rhyolite porphyry (unit Trp) dikes related to the Poco Canyon caldera which extend from paleodepths of approximately 4 to 9 km.

Geometry of Plutonic Rocks and Mechanism of Pluton Emplacement

Exposed parts of the IXL and Freeman Creek plutons indicate that the plutons are thick stocks or the upper parts of batholiths, which have steep sides and relatively flat roofs. Pluton roofs are generally concordant with bedding in overlying caldera fill and in Cenozoic pre-caldera rocks. Both plutons are >2–5 km thick and do not appear to be laccoliths. Few dikes are present above pluton roofs. Igneous flow foliation is not evident in either pluton.

Colgan and others (2018) provide a detailed model for emplacement of the plutons to explain the observed nearly total replacement of the Mesozoic upper crust within the caldera complex to depths of >9–10 km. Blocks of Mesozoic rocks and older volcanic rocks are small and rare, suggesting that the displaced crust sank to depths below current levels of exposure. The plutons rose to the base of caldera fill (IXL pluton) or about 2 km below the base of caldera fill (Freeman Creek pluton). They therefore must have replaced most of the original caldera floor blocks (see Colgan and others, 2018). Structural doming of the roofs of the plutons is not evident, although rocks forming the floor of the Job Canyon caldera and overlying tuff of Job Canyon are offset by faults with apparent reverse displacement likely caused by resurgent magmatism (fig. 4). Xenoliths of roof and wall rocks are scarce to absent in all exposed parts of the plutons. Strontium-isotope data for the IXL pluton suggest that there was only very local assimilation of Triassic roof and wall rocks by the IXL pluton, and that stoped blocks must have sunk to depths greater than present exposures (John, 1995b).

Ring-Fracture Dikes

Steeply dipping granite porphyry and rhyolite porphyry dikes intrude along the north margin of the Poco Canyon caldera (units Tgp and Trp). The dikes are exposed over a large vertical range of reconstructed Oligocene paleodepths from approximately 4 to 9 km and texturally change from porphyro-aphanitic at approximately 4 km to medium- to coarse-grained and equigranular in the deepest exposures (8–9 km). The deepest part of the granite porphyry dike is truncated by the Freeman Creek pluton. Geochronologic and geochemical data, including zircon trace element analyses, indicate that these are ring-fracture dikes genetically related to the Poco Canyon caldera magma, whereas the Freeman Creek pluton is unrelated to the caldera-forming magma (Colgan and others, 2018; Watts and others, 2019).

Economic Geology

Small amounts of mining have taken place in several areas in the southern Stillwater Range, primarily in Mesozoic wallrocks of the calderas in the Mountain Wells and IXL Mining Districts (Vanderburg, 1940; Willden and Speed, 1974; Quade and Tingley, 1987). Most of the ore mined was related to the La Plata Canyon and IXL plutons, although zones of quartz-carbonate veins have been prospected in altered caldera fill in both the Job Canyon and Elevenmile Canyon calderas.

IXL Mining District

The IXL Mining District is on the east side of the Stillwater Range along the north margin of the IXL pluton. Mineralization in the district was discovered in 1878, and most production was prior to 1908 (Vanderburg, 1940; Schrader, 1947). Two principal types of mineral deposits are present in the IXL district: (1) polymetallic skarns (for example, Black Prince Group) and (2) gold, silver, and base-metal bearing quartz-carbonate veins (for example, Bonanza Group) (Vanderburg, 1940; Willden and Speed, 1974). Both deposit types are hosted in Triassic carbonate wallrocks of the IXL pluton. In addition, sulfide-rich, silver- and base-metal-rich quartz veins are present in the IXL pluton a few kilometers south of the district (Creore Mine; Schrader, 1947). Mines in the IXL district produced small amounts of silver, gold, copper, lead, and zinc (Vanderburg, 1940), and the Creore Mine produced about 50 tons of silver-copper-lead ore (Schrader, 1947).

Cox Canyon Mining District

The Cox Canyon Mining District is on the west side of the Stillwater Range, west of the IXL district and along the north side of the Job Canyon caldera. Mesozoic metasedimentary and metavolcanic rocks that form the north wall of the Job Canyon caldera underlie the district. A small amount of fluorspar was produced from Triassic rocks near the range front (Willden and Speed, 1974). Narrow quartz veins present locally in Triassic rocks have been prospected for gold and silver, but there is no record of production (Willden and Speed, 1974). Oxygen isotope data indicate a different origin for these veins than for quartz-carbonate veins in the West Job Canyon area in the Job Canyon caldera a few kilometers to the south, which suggests that the veins may be older and unrelated to Cenozoic magmatism (John and Pickthorn, 1996).

West Job Canyon Area

Multiple hydrothermal systems affected most intracaldera rocks in the Job Canyon caldera, the underlying older dacite and andesite sequence, and the upper part of the IXL pluton (John and Pickthorn, 1996; this study). Small areas of intense, pyrite-rich quartz-illite and quartz-pyrophyllite alteration are associated with small andesite intrusions and dikes (unit Tydai) related to the younger dacite and andesite sequence. Illite $^{40}Ar/^{39}Ar$ ages from two locations of this alteration in the tuff of Job Canyon are 28.786±0.178 and 28.767±0.053 Ma. No known mineralization is associated with this alteration. A younger, much larger hydrothermal system was related to emplacement of the IXL pluton and formed sulfide-poor quartz-carbonate veins with low precious- and base-metal contents in West Job Canyon. The intensity of alteration decreases upward and changes from propylitic at depth to intermediate argillic at shallower paleodepths. Fracture-coating adularia in epidote-rich propylitic alteration in the older dacite and andesite sequence yielded a $^{40}Ar/^{39}Ar$ age of approximately 27.6 Ma. The veins are mostly in the tuff of Job Canyon and formed along small displacement, west-striking faults intruded by andesite dikes that were feeders for the younger dacite and andesite sequence. Prospect pits and shallow shafts are present along several of the veins, but there is no evidence of production from them.

Mountain Wells Mining District

The Mountain Wells (La Plata) Mining District was discovered in 1862 and gained prominence as a boom camp in the mid-1860s, although apparently little ore was produced (Vanderburg, 1940). The town of La Plata was established in about 1863 and was the seat of Churchill County from 1864 to 1868. The district contains three general types of deposits in Mesozoic rocks: (1) molybdenum-tungsten-copper-bearing skarn zones, (2) silver-copper-bearing quartz veins in shear zones, and (3) fluorite deposits in shear zones associated with aplite dikes and sills (Vanderburg, 1940; Butler, 1979; Quade and Tingley, 1987). All these deposits are thought to be genetically related to the Late Cretaceous La Plata Canyon pluton, and exploration in the late 1970s focused on the possibility of a porphyry molybdenum system underlying the district (Quade and Tingley, 1987). Muscovite alteration associated with the fluorite mineralization has a K-Ar age of 84.8±0.8 Ma (Garside and others, 1981). Most production and the discovery outcrops were copper- and silver-sulfide bearing quartz veins in the pluton and its Triassic metasedimentary wall rocks.

A fourth type of occurrence is quartz-carbonate veins in intracaldera tuff of Elevenmile Canyon. These veins commonly parallel west-northwest-trending silicic dikes (unit Tsd) and probably formed along minor faults. No production has been recorded from these veins.

DESCRIPTION OF MAP UNITS

ALLUVIAL DEPOSITS

Qaya **Main-stream alluvium (Holocene)**—Mapped separately from Qay only along Dixie Valley Wash. Forms low terrace where stream is incised. Interstratified coarse to fine sand, silty sand, very fine- to fine-pebbly sand, silt, and sandy pebble to cobble gravel. Sands thinly to thickly bedded, locally cross-bedded. Silts thinly laminated with mud partings. In channel fill, pebble and small cobble gravel overlain by coarse sands that fine upward. Pebbles and cobbles mostly subrounded

Qay **Young alluvial deposits (Holocene)**—Alluvial fan deposits (formed by sheetfloods and debris flows; Harvey, 2005), stream-channel and low-terrace deposits, and sheetwash deposits. Sandy pebble to boulder gravel, gravelly sand, sand, and sandy silt. Locally contains angular blocks as much as 3 meters (m) across. Unconsolidated, poorly to moderately sorted, weakly to moderately bedded. Clasts angular to subrounded. Surface clasts unweathered or minimally weathered with minor spalling of outer surfaces. Original depositional morphology on fan surfaces generally well preserved. Fan surfaces generally undissected to weakly dissected. Stream channels locally incised as much as 3–6 m. Desert pavement largely absent but where present, weakly to moderately developed and either unvarnished or lightly varnished. No or minimal soil development characterized by silty vesicular A horizon, thin color B horizon (about 10 centimeters [cm] thick), and locally, very weakly developed stage I pedogenic carbonate horizon (see Schoeneberger and others [2012] for description of stages of pedogenic carbonate development)

Qami **Young to intermediate alluvial deposits (Holocene and late Pleistocene)**—Alluvial fan deposits (formed by sheetfloods and debris flows; Harvey, 2005), and stream-terrace deposits. Locally includes young stream-channel deposits (unit Qay) too narrow to map separately. Sandy pebble to boulder gravel, gravelly sand, sand, and sandy silt. Unconsolidated, weakly bedded, and poorly to moderately sorted. Clasts mostly subangular or subrounded, locally rounded. Some surface clasts fractured or shattered by post depositional weathering processes. Minor weathering of biotite-rich surface boulders. Some original depositional morphology preserved. Fan surfaces weakly incised. Desert pavement typically weakly to moderately developed and moderately varnished, but ranges from lightly varnished to well varnished. Where pavement mostly stripped, silty sediments have polygonal fracture pattern with fractures lined by small pebbles. No pavement in areas heavily vegetated by grass. Soil development characterized by silty vesicular A horizon; thin (about 10 cm), reddened clay-enriched B horizon over a less well-developed color B horizon (about 30 cm thick); and weakly developed stage I carbonate horizon. Locally high infiltration of silt into soil profile

Qai **Intermediate alluvial deposits (late and middle Pleistocene)**—Alluvial fan deposits (formed by sheetfloods and debris flows; Harvey, 2005), and terrace deposits. Locally includes young stream-channel deposits (unit Qay) too narrow to map separately. Sandy pebble to boulder gravel, gravelly sand, sand, and sandy silt. Unconsolidated to weakly consolidated, weakly bedded, and poorly to moderately sorted. Clasts generally angular to subrounded, but locally rounded with some rounded boulders as much as 80 cm in diameter. Weathered and shattered surface clasts common. In subsurface, fractured clasts common and a few clasts are completely disintegrated by weathering processes. Original depositional morphology smoothed. Surfaces moderately incised, but generally planar between gullies. On west side of Stillwater Range, cut by highstand shoreline of pluvial Lake Lahontan (comprising a series of deep lakes that periodically occupied the Lahontan basin during the Quaternary). Desert pavement typically moderately to well developed and moderately to well varnished; locally weakly developed with light varnish. No pavement in areas heavily vegetated by grass. Soil development characterized by silty vesicular A horizon, reddened, clay-enriched B horizon generally 30–40 cm thick, and stage II–III carbonate horizons with common pedogenic silica. Carbonate horizons uncemented to locally well cemented

Qao **Old alluvial deposits (middle and early? Pleistocene)**—Alluvial fan deposits (formed by sheetfloods and debris flows; Harvey, 2005), and terrace deposits. Locally includes young stream-channel deposits (unit Qay) too narrow to map separately. Sandy pebble to boulder gravel, gravelly sand, sand, and sandy silt. Locally contains angular blocks as much as 3 m across. Weakly to moderately consolidated, weakly to moderately bedded, poorly to moderately sorted. Consolidated, fine to coarse sand, medium or thinly bedded, locally cross-bedded. Silts platy, fractured. Clasts generally subangular or subrounded but range from angular to rounded. Many surface clasts shattered by post-depositional weathering processes. In I X L Canyon area, granitic surface boulders deeply pitted and partly altered to grus. Fan surfaces moderately to deeply incised with rounded interfluves (ridge and ravine topography). Cut by highstand shoreline of pluvial Lake Lahontan on west side of Stillwater Range. Desert pavement on fan surfaces typically absent or present only in poorly preserved patches with weak to locally moderate varnish. No pavement in areas heavily vegetated by grass. Soil development characterized by locally preserved, reddened, clay-enriched B horizons, and moderately to well cemented stage III–IV carbonate horizons. Pedogenic silica common. Laminar caps on horizons with stage IV carbonate morphology typically 2–3 cm thick. Shattered and weathered clasts in subsurface common. Surfaces covered by variable amounts of unmapped eolian silt

QTa **Very old alluvial deposits (early Pleistocene and Pliocene?)**—Alluvial fan and stream deposits. Locally includes young stream-channel deposits (unit Qay) too narrow to map separately. Sandy pebble to boulder gravel, gravelly sand, sand, and sandy silt. Weakly to moderately bedded and poorly to moderately sorted. Moderately consolidated, with secondary carbonate and probable silica cement locally visible between grains. Consolidated fine to coarse sands medium or thinly bedded, locally cross-bedded. Clasts generally subangular or subrounded but range from angular to rounded. Surface clasts shattered by post-depositional weathering processes are common. Deposits deeply incised and dissected into rounded, segmented ridges or hills and ravines. Many clasts well varnished but pavement mostly absent or present in weakly or moderately developed patches that probably formed relatively recently, subsequent to stabilization of the eroded surfaces. No soil profile observed but thick detached carbonate rinds as much as 5 millimeters (mm) thick present on shoulder of some slopes

QTs **Very old sediments (early Pleistocene and Pliocene?)**—Fluvial deposits of interstratified, weakly to moderately consolidated sand, silt, pebbly sand, and sandy pebble and cobble gravel. Forms near horizontal stacked packets 1–2 m thick of alternating fine and coarse sediment. Fine sediment packets made up of pale brown sands and laminated silts. Coarse sediment packets made up of brownish gray, weakly bedded, poorly sorted, pebbly sand and sandy gravel; some sandy gravel beds pinch out laterally. Sands and pebbly sands locally cross-bedded. Outcrops typically capped by large pebble and cobble gravel. Large pebbles and cobbles mostly rounded or subrounded; small pebbles subrounded or subangular. Unit mapped in southeast corner of map along Dixie Valley Wash

EOLIAN DEPOSITS

Qes **Eolian sand (Holocene to middle Pleistocene)**—Forms sand sheets, sand ramps, and sand dunes. Unconsolidated medium sand with scattered granules. Very pale brown. Upper few centimeters of deposits typically silty and vesicular, probably owing to an influx of eolian silt. Stabilized by grass and brush vegetation. Sands likely sourced mostly from pluvial Lake Lahontan deposits, but may also include sand reworked from deeply weathered Tertiary sedimentary rocks (Ts) in the southwestern part of the Stillwater Range

BASIN-FILL DEPOSITS

Qbf **Basin-fill deposits (Holocene to middle Pleistocene)**—Undifferentiated alluvial, lacustrine, eolian, and playa deposits filling basin formerly occupied by Lake Dixie, a pluvial lake that filled parts of Dixie Valley at times during the Quaternary (Bell and Katzer, 1987, 1990). Unconsolidated sand, silt, clayey silt, silty clay, and pebble and small cobble gravel. Contains Mazama ash (7,627±150 calibrated years before present [cal yr B.P.]; Zdanowicz and others, 1999) at about 1-m depth below deposit surface (Bell and Katzer, 1987, 1990)

COLLUVIAL, ALLUVIAL, AND MASS-WASTING DEPOSITS

Qtc **Talus, colluvium, and alluvium, undifferentiated (Holocene to middle Pleistocene)**—Includes gravity deposits of angular rock fragments, colluvial mixtures of sand, gravel, silt, and clay derived mostly from weathered residuum and eolian deposits, and alluvium deposited mostly by sheetwash processes. Only large deposits mapped. Much of the rubble derived from basalt (unit Tb) and granite porphyry (unit Tgp)

Qls **Landslide deposits (Holocene to middle Pleistocene)**—Hummocky landslide deposits in northwest part of map area. Made up of basalt (unit Tb) debris

LACUSTRINE DEPOSITS

Qlb **Beach and shoreline deposits of Lake Dixie (late Pleistocene)**—Sandy pebble and cobble gravel, pebbly sand, sand, and silty sand in remnant shoreline deposits from the late Pleistocene lacustral cycle of Lake Dixie, a pluvial lake that filled parts of Dixie Valley at times during the Quaternary (Bell and Katzer, 1987, 1990). Locally covered by thin deposits of unmapped alluvial gravel, eolian silt, or eolian sand. Typically forms gravelly beach ridges or locally a thin veneer overlying fine grained lacustrine sediments (unit Qlf). Locally contains dendritic tufa heads (based on descriptions of Russell, 1885; Morrison, 1964) or is cemented by dense tufa coatings on pebbles and cobbles (lithoid tufa of Russell [1885] and Morrison [1964]; Benson [2004]). Beach gravels subrounded to rounded, many disc shaped. Desert pavement moderately developed with moderate varnish. Surface clasts shattered by post-depositional weathering processes are common. Remnant beach deposits mark Lake Dixie highstand shoreline at about 1,097 m (Mifflin and Wheat, 1979)

Qlf **Sediments of Lake Dixie (late Pleistocene)**—Sandy silt, silty sand, sand, clayey silt, silty clay, pebbly sand, and pebble gravel deposited during late Pleistocene lacustral cycle of pluvial Lake Dixie in Dixie Valley. Pale brown. Typically has polygonal fracture pattern at surface; fractures lined by small pebbles. Silts at surface typically vesicular

Qlbl **Beach and shoreline deposits of Lake Lahontan (late Pleistocene)**—Part of the Sehoo Alloformation (Morrison, 1964, 1991). Sandy pebble to small-boulder gravel, pebbly sand, sand, silty sand, and locally large-boulder gravel deposited during the late Pleistocene lacustral cycle (named the Sehoo lacustral cycle [Morrison, 1964, 1991]) of pluvial Lake Lahontan (comprising a series of deep lakes that periodically occupied the Lahontan basin during the Quaternary). Includes deposits associated with wave-formed beach terraces, barrier ridges, and spits, and thin patches of boulder and cobble lag along shorelines cut in hillslopes of mostly basalt bedrock. Highstand shoreline at about 1,336–1,338 m. Dense tufa coatings on pebbles and cobbles (lithoid tufa of Russell [1885] and Morrison [1964]), slabs of tufa-cemented sand and gravel (beachrock of Benson [2004]), and dendritic tufa heads and colonies (Russell, 1885; Morrison, 1964) locally extensive. Clasts well rounded to subrounded. Many surface and near-surface clasts fractured or shattered by post-depositional weathering processes. Gravels and sands weakly bedded. Sands brownish gray. Distribution of cobbles of the basalt (unit Tb) and the tuff of Poco Canyon (unit Tpcu) indicates that at high lake levels longshore drift was to the northeast at least part of the time

Qlfl **Sediments of Lake Lahontan (late Pleistocene)**—Part of the Sehoo Alloformation (Morrison, 1964; 1991). Sand, silty sand, sandy silt, silt, pebbly sand, clayey silt, and pebble and cobble gravel deposited during the Sehoo lacustral cycle of pluvial Lake Lahontan. Associated with offshore, beach, and back-barrier lagoon depositional environments. Generally poorly exposed. Surface silts vesicular. Silts light gray to very pale brown. Sands brownish gray. In incised drainages, locally could include buried deposits from older lake cycles

Qtf **Tufa deposits (late Pleistocene)**—Part of the Sehoo Alloformation (Morrison, 1964; 1991). Large tufa mounds made of calcium carbonate precipitated from a mixture of spring and lake water. Formed during the Sehoo lacustral cycle of pluvial Lake Lahontan

Qlfo **Older sediments of Lake Dixie (middle Pleistocene)**—Fine sandy silt, clayey silt, and minor scattered pebbles. Silts light gray. Pebbles angular to subangular. Surface covered by single layer of angular and subangular clasts of alluvial gravel forming desert pavement; pavement moderately developed and moderately varnished. Pavement includes several clasts of tufa. Unit mapped on west side of Dixie Valley at an elevation as much as 12 m above highest late Pleistocene shoreline of pluvial Lake Dixie (1,097 m, Mifflin and Wheat, 1979). Holocene to late Pleistocene offset on adjacent strands of the Dixie Valley Fault, estimated to be about 3 meters (Bell and Katzer, 1987), cannot account for the elevation difference between this unit and the late Pleistocene high shoreline, suggesting that this unit is from an earlier, middle Pleistocene lacustral cycle (Bell and Katzer, 1987; Reheis and others, 2002)

CENOZOIC VOLCANIC, SEDIMENTARY, AND INTRUSIVE ROCKS

Tb **Basalt (middle Miocene)**—Basalt lava flows and flow breccias. Dark-gray to black, aphyric to sparsely porphyritic rocks containing fine-grained phenocrysts of plagioclase, clinopyroxene, and locally olivine. Locally vesicular. Minor coarse-grained volcaniclastic sandstone locally interbedded with lava flows. Whole-rock K-Ar ages of 13.0±0.4, 13.3±0.4, and 14.4±0.4 Ma from lava flows collected in Table Mountain and Diamond Canyon quadrangles. Alm (2016) reported $^{40}Ar/^{39}Ar$ ages of 14.92±0.35 and 15.02±0.0.6 Ma for lava flows about 8 kilometers (km) southeast of Mountain Well

Tbi **Basalt intrusions (middle Miocene)**—Plugs and dikes that fed the lava flows of the basalt (unit Tb) unit. Intrudes Miocene sedimentary rocks and landslide breccia deposits (units Ts and Tlb, respectively). Whole rock K-Ar age of 13.9±0.5 Ma from dike collected about 1 km north of Mountain Well

Tbs **Basaltic sedimentary rocks (middle Miocene)**—Coarse-grained sandstone and granule and small pebble conglomerate containing abundant clasts of basalt. Locally interbedded with and underlying basalt lava flows. Only mapped in southwestern part of map area

Td **Diabase (middle Miocene)**—Dikes of dark-reddish-brown to black, fine-grained pyroxene diabase intruding the rhyolite of Pirouette Mountain (unit Trpm), andesite porphyry (unit Tap), older tuff (unit Tot) units and Freeman Creek pluton (units Tfcgd, Tfcgr)

Tya **Andesite (middle Miocene)**—Dark-red, brown, and black, generally coarsely porphyritic, hornblende or clinopyroxene-plagioclase andesite and dacite lava flows and flow breccias. Mapped along range front between Elevenmile and Slaughter Canyons

Tddc **Dacite of Diamond Canyon (middle Miocene)**—Dark-gray to black, generally coarsely porphyritic hornblende-plagioclase or clinopyroxene-plagioclase dacite lava flows, flow breccias, and debris-flow deposits. Locally includes shallow intrusive rocks. Plagioclase $^{40}Ar/^{39}Ar$ age of 14.51±0.038 Ma for sample collected near Mountain Well. Alm (2016) reported $^{40}Ar/^{39}Ar$ ages of 14.34±0.05 and 14.92±0.04 Ma for lava flows about 6 km southeast of Mountain Well

Tddci **Porphyritic dacite intrusions (middle Miocene)**—Dark-red, brown, and black, generally coarsely porphyritic, hornblende or clinopyroxene-plagioclase dacite intrusions. Generally flow banded. Forms several semicircular plugs intrusive into lava flows and breccias of the dacite of Diamond Canyon (unit Tddc) in southwest part of map area

Tha **Hornblende andesite (middle Miocene)**—Gray to reddish-brown, fine- to medium-grained porphyritic hornblende andesite lava flows. Contain about 10 to 15 percent medium-grained hornblende phenocrysts in dark-gray aphanitic groundmass. Hornblende K-Ar age of 15.3±0.5 Ma. Mapped in vicinity of Mountain Well and near the mouth of Elevenmile Canyon

Ts **Sedimentary rocks, undifferentiated (middle Miocene)**—Generally well-indurated, white, tan, and yellowish-brown, fine- to coarse-grained fluvial and lacustrine sedimentary rocks that unconformably overlie the tuff of Elevenmile Canyon (unit Tec), andesite of Sheep Canyon (unit Tasc), and Mesozoic rocks and underlie the basalt, dacite of Diamond Canyon, and hornblende andesite (units Tb, Tddc, and Tha, respectively); sedimentary rocks between La Plata and Elevenmile Canyons locally overlie basalt lavas. Consists of siltstone, sandstone, cobble to boulder conglomerate, and minor freshwater limestone; cobbles commonly well rounded. Clasts are composed of Tertiary rocks, including tuff of Elevenmile Canyon, andesite of Sheep Canyon, and silicic intrusive rocks; sparse clasts of Mesozoic rocks. Locally contains abundant plant impressions and petrified wood. Rocks near Mountain Well commonly contain abundant basalt scoria. Sanidine $^{40}Ar/^{39}Ar$ age of 12.25±0.087 Ma for glassy tephra sample collected in La Plata Canyon; hornblende K-Ar age of 12.6±0.5 Ma and biotite K-Ar ages of 13.5±0.4 and 13.9±0.4 Ma for reworked tephras near Diamond Canyon

Tlb **Landslide breccia (Miocene)**—Coarse deposits consisting of unsorted blocks of tuff and rhyolite set in coarse-grained sandstone to pebble conglomerate matrix. Contains blocks of the tuff of Elevenmile Canyon and silicic intrusive rocks (units Tec and Tsi, respectively) as much as 10 m in diameter. Limited to area near Mountain Well, where deposits grade laterally into the sedimentary rocks (unit Ts)

Tsd **Silicic dikes (Miocene)**—Swarm of west-northwest-trending rhyolite and dacite dikes in the southern half of the map area. Dikes mostly consist of sparsely porphyritic, fine-grained biotite rhyolite and coarsely porphyritic hornblende-biotite-quartz-plagioclase-K-feldspar rhyolite porphyry; many dikes are composite. Most dikes are propylitically altered. Zircon U-Pb ages of 22.19±0.26 Ma on large sparsely porphyritic rhyolite intrusion in upper La Plata Canyon, 23.36±0.39 Ma on rhyolite porphyry dike in La Plata Canyon pluton, and 24.7±0.3 Ma on rhyolite porphyry dike near the south wall of the Elevenmile Canyon caldera

Tr **Rhyolite (Miocene or Oligocene)**—White to light-red, crystal-poor rhyolite containing about 10 percent fine- to medium-grained phenocrysts consisting of K-feldspar, plagioclase, and less abundant quartz and biotite in a microfelsitic to spherulitic groundmass. Forms small outcrops just east of Dixie Valley Fault near mouth of Little Box Canyon. Age relation to other units unknown

Tdi **Dacite intrusions (Miocene? and Oligocene)**—Scattered small plugs and dikes of porphyritic dacite that intrude the tuff of Elevenmile Canyon (unit Tec) and sedimentary tuff (unit Tst) in the Elevenmile Canyon caldera; thick dike along north margin of the Poco Canyon caldera that intrudes the tuff of Job Canyon (unit Tjc) and upper cooling unit of the tuff of Poco Canyon (unit Tpcu). Rocks are reddish-brown to black where unaltered and locally vitrophyric to green where propylitically altered, commonly flow-banded, and locally columnar jointed. They contain about 20 to 30 percent fine- to medium-grained phenocrysts of plagioclase with less abundant hornblende, biotite, and local clinopyroxene in a microfelsitic to altered aphyric groundmass. The intrusions are locally gradational with the silicic intrusive rocks unit (unit Tsi). Overlain by lava flows of the younger andesite (unit Tya) unit near Slaughter Canyon and basalt (unit Tb) unit west and north of Table Mountain

Tyr **Younger rhyolite (Oligocene)**—Red, light-purple, green, black, and gray, generally sparsely porphyritic rhyolite lava flows, flow breccia, shallow intrusive rocks and minor welded tuff, accretionary lapilli tuff and epiclastic sandstone. Generally contains 5 to 10 percent fine- to medium-grained phenocrysts of white K-feldspar and minor plagioclase and altered biotite(?) in a devitrified aphanitic groundmass. Locally strongly flow banded. Locally includes thin, interbedded sequences of coarse-grained volcaniclastic sandstone and accretionary lapilli tuff. Intrudes and overlies tuffs of Job Canyon, Poco Canyon, and Elevenmile Canyon. Lava flows and shallow intrusions are petrographically similar to the rhyolites of Pirouette Mountain and East Lee Canyon

Tsi **Silicic intrusive rocks (Oligocene)**—Numerous texturally and compositionally distinct silicic dikes and domes and minor pyroclastic aprons and lava flows. Includes aphyric felsite, sparsely porphyritic biotite rhyolite and quartz rhyolite, coarsely porphyritic biotite-quartz-plagioclase-K-feldspar rhyolite(?) porphyry, and coarsely porphyritic biotite-hornblende-plagioclase dacite porphyry. Most rocks are strongly argillized or propylitized, although glassy domes are locally present along west side of the Stillwater Range in West Lee and Poco Canyons. Biotite K-Ar age of 24.8±0.6 Ma on glassy dome in West Lee Canyon, and sanidine $^{40}Ar/^{39}Ar$ ages of 25.17±0.03 and 25.18±0.03 Ma on intrusions near the mouth of Poco Canyon

Tts **Tuffs and sedimentary rocks (Oligocene)**—Mostly argillized, poorly welded lapilli tuff, fine-grained sedimentary rocks, sedimentary breccia, and lava flows locally associated with rhyolite domes that are part of the younger rhyolite and silicic intrusive rocks units (units Tyr and Tsi, respectively). Only mapped in the lower parts of West Lee, Long, and Poco Canyons in the northwest part of map area and at the north end of Elevenmile Canyon

Freeman Creek pluton (Oligocene)—Composite pluton composed of fine- to medium-grained biotite-hornblende granodiorite porphyry and medium- to coarse-grained biotite granite.

Tfcgr **Granite**—Light- to dark-gray to pinkish-gray, fine- to coarse-grained, equigranular to porphyritic biotite granite containing about 5 to 7 percent fine-gained anhedral biotite that locally replaces hornblende and sparse to abundant white to pink, anhedral to subhedral K-feldspar phenocrysts as long as 1.5 cm. Intrudes granodiorite phase (unit Tfcgr) and granite porphyry dike (unit Tgp). Zircon U-Pb age of 24.93±0.37 Ma from near mouth of Freeman Creek

Tfcgd **Granodiorite porphyry**—Dark-gray, fine- to medium-grained biotite-hornblende granodiorite porphyry containing about 10 to 15 percent fine-grained biotite and hornblende and local fine-grained clinopyroxene, small (1–3 mm) dark-gray quartz eyes, scattered 5- to 10-mm white K-feldspar and dark-gray plagioclase phenocrysts set in a fine-grained microgranular groundmass of quartz and feldspar. Hornblende phenocrysts commonly have rusty orange-colored clinopyroxene cores. Intrudes the IXL pluton (unit Tixl) and granite porphyry dike (unit Tgp). Zircon U-Pb ages of 25.16±0.23 Ma on granodiorite porphyry block in granite phase collected near mouth of Freeman Creek and 25.71±0.37 Ma on granodiorite porphyry in northernmost part of the Freeman Creek pluton

Trp **Rhyolite porphyry**—Dike of white, generally orange-weathering biotite rhyolite porphyry. Rock is porphyroaphanitic containing about 20 percent fine- to medium-grained phenocrysts of altered feldspar, clear bipyramidal quartz, and minor chloritized biotite in an aphanitic groundmass. Strongly argillically altered with several percent disseminated pyrite that is mostly oxidized. Intrudes andesite porphyry (unit Tap), tuff of upper Poco Canyon (unit Tupc), and tuff and breccia of Government Trail Canyon (unit Tpbr). Zircon U-Pb age of 25.44±0.63 Ma

Tgp **Granite porphyry**—Composite dike of white, pink, and orangish-gray biotite granite porphyry. Consists of 40 to 60 percent, fine- to coarse-grained phenocrysts of subhedral to euhedral K-feldspar, quartz, and plagioclase with about 1 to 3 percent altered biotite and (or) hornblende. Groundmass varies from microcrystalline (aplitic) to fine-grained allotriomorphic granular. Graphic granite intergrowths of K-feldspar and quartz locally abundant in groundmass. Commonly hydrothermally altered (argillic or propylitic alteration) with abundant clay minerals and pyrite with local epidote and chlorite. Miraolitic cavities present locally. Intrudes older dacite and andesite sequence (units Tobr and Tolf), older rhyolite (unit Tor), IXL pluton (unit Tixl), rhyolite of Pirouette Mountain (unit Trpm), older tuff (unit Tot), andesite porphyry (unit Tap), tuffs of Job Peak (unit Tjp) and upper Poco Canyon (unit Tupc), and tuff and breccia of Government Trail Canyon (unit Tpbr). East end intruded by granite and granodiorite phases of Freeman Creek pluton (units Tfcgr and Tfcgd, respectively). Zircon U-Pb age of 25.50±0.46 Ma

ELEVENMILE CANYON CALDERA

[Units Tsf, Tst, Tec,Tecx]

Tsf **Silicic lava flows (Oligocene)**—White to light-green, aphyric to sparsely porphyritic silicic lava flows that overlie and interfinger with the sedimentary tuff (unit Tst) unit. Rocks are devitrified and commonly argillically altered

Tst **Sedimentary tuff (Oligocene)**—White to light-green, crystal-poor, pumice-rich, water-laid rhyolite tuff and fine-grained tuffaceous sedimentary rocks. Tuff contains about 10 percent phenocrysts consisting of K-feldspar, less abundant plagioclase, and minor quartz and biotite. Tuff commonly contains distinctive clasts as long as 50 cm of dark-gray to black, finely bedded siltstone and fine-grained sandstone with wavy soft-sediment folds and irregular, flame-textured margins. Locally includes white to light-green, crystal-poor, rhyolite lava flows. Rocks are devitrified and commonly are argillically altered. Zircon U-Pb age of 25.05±0.67 Ma on a tuff sample

Tec **Tuff of Elevenmile Canyon (Oligocene)**—Black, greenish-gray, white, reddish-brown, blue-gray, and lavender-gray crystal-rich rhyolite to low-silica dacite ash-flow tuff. Contains 30 to 60 percent phenocrysts consisting of medium-grained plagioclase, less abundant sanidine and quartz, 1 to 5 percent biotite, <1 percent hornblende, and locally trace amounts of clinopyroxene. Generally densely welded. Commonly contains abundant dark-green (where altered) to orange (where unaltered), crystal-rich, flattened pumice clasts as long as 6 cm with abundant, mostly chloritized biotite and abundant fragments of pre-Cenozoic rocks and flow-banded rhyolites and porphyritic andesites. Megabreccia blocks consisting of internally shattered andesite (unit a), marble (unit m), and black argillite (unit s) as large as 100 m are common. Tuff is devitrified and generally strongly propylitized or argillized. Three sanidine $^{40}Ar/^{39}Ar$ ages from the Stillwater Range are 25.00±0.06 to 25.12±0.012 Ma, and about 30 additional $^{40}Ar/^{39}Ar$ sanidine ages from other parts of the caldera and from outflow tuff average approximately 25.1 Ma (Henry and John, 2013; Colgan and others, 2018). Eight zircon U-Pb ages range from 25.00±0.26 to 25.90±0.49 Ma (Colgan and others, 2018)

Tecx **Megabreccia, undivided**—Beds of mega- and mesobreccia consisting of coarse blocks of Mesozoic rocks and (or) Oligocene rocks in the tuff of Elevenmile Canyon in East Lee and Elevenmile Canyons

Tasc **Andesite of Sheep Canyon (Oligocene)**—Dark-green, dark-gray, and dark-lavender-gray, aphyric to medium-grained, porphyritic andesite and dacite lava flows. Phenocrysts consist of medium-grained tabular plagioclase, hornblende, and local biotite. Locally flow banded. Generally altered to propylitic mineral assemblages containing abundant epidote, chlorite, calcite, and illite or argillic assemblages. Cut by several quartz±calcite veins east of Mountain Well. Forms outcrops in Sheep Canyon, near Mountain Well, and between La Plata and Elevenmile Canyons and occurs as megabreccia blocks (unit a) enclosed within the tuff of Elevenmile Canyon. Zircon U-Pb age of 25.07±0.41 Ma

POCO CANYON CALDERA

[Units Tpcu, Tpbr, Tpsb, Tpcl]

Tuff of Poco Canyon (Oligocene)—Multiple cooling units of rhyolite and high-silica rhyolite ash-flow tuff.

Tpcu **Upper cooling unit**—Reddish-brown, white, and greenish-gray, medium-grained, crystal-rich rhyolite and high-silica rhyolite ash-flow tuff. Tuff is mostly devitrified, densely welded, locally vuggy due to leached pumice, and commonly contains abundant, small (generally less than 2 cm) fragments of intermediate composition lava flows and less common Mesozoic rocks. Locally contains coarse fragments (as large as 20 cm) of intermediate to silicic lava flows. In Poco Canyon, contains large megabreccia blocks of underlying tuff and breccia of Government Trail Canyon and rhyolite of Pirouette Mountain (unit Tpcux). Generally contains 30 to 50 percent phenocrysts of sanidine, quartz, lesser plagioclase, and trace amounts of biotite. Sanidine locally is iridescent and quartz commonly is smoky. Basal part of unit in Poco Canyon locally contains black glassy fiamme as much as 6 cm long. Sanidine $^{40}Ar/^{39}Ar$ ages of 25.16±0.08 and 25.26±0.07 Ma, and zircon U-Pb ages of 25.60±0.25 and 25.66±0.51 Ma in the Stillwater Range

Tpbr **Tuff and breccia of Government Trail Canyon**—Heterolithic megabreccia consisting of unsorted blocks of older Oligocene igneous units in a moderately welded rhyolite ash-flow tuff matrix. Breccia matrix consists of pale-green, moderately pumiceous, crystal-poor tuff containing about 2 to 5 percent phenocrysts of quartz and altered feldspar. Pumice fragments are dark-green, crystal-poor, and generally less than 4 cm in maximum dimension. Breccia fragments range from millimeters to hundreds of meters in diameter and include rhyolite of Pirouette Mountain (unit Trpm), tuff of Job Peak (unit Tjp), and lower cooling unit of tuff of Poco Canyon (unit Tpcl). Breccia horizons commonly are clast supported. Unit locally contains thin beds of sandstone and accretionary lapilli. Zircon U-Pb age of 25.99±0.20 Ma

Tpsb **Sandstone and breccia**—Dark-red, reddish-brown and lavender-gray, medium-bedded to massive, quartz-rich sandstone and sedimentary breccia and minor quartz-rich ash-flow tuff. Breccia layers contain abundant pebble- to cobble-size, subangular to subrounded clasts of rhyolite of Pirouette Mountain (unit Trpm) and lower cooling unit of tuff of Poco Canyon (unit Tpcl) in a quartz-rich sandy matrix derived in large part from the underlying tuff of Poco Canyon. Present locally west of Coyote Canyon where it overlies the lower cooling unit of tuff of Poco Canyon

Tpcl **Lower cooling unit**—White, gray, reddish-brown, lavender-gray, and greenish-gray, crystal-rich rhyolite and high-silica rhyolite ash-flow tuff. Contains 30 to 55 percent medium-grained phenocrysts comprised of K-feldspar and smoky quartz, less abundant plagioclase, minor biotite, and locally trace hornblende. Generally lithic- and pumice-poor and densely welded. Commonly hydrothermally altered and recrystallized. In East Lee Canyon, locally contains meso- and megabreccia consisting of large blocks of the rhyolite of Pirouette Mountain and pebbly sandstone containing rhyolite clasts (unit Tpclx). Sanidine $^{40}Ar/^{39}Ar$ age of 25.257±0.008 Ma from clast in conglomerate bed in overlying rhyolite of East Lee Canyon and zircon U-Pb age of 25.74±0.19 Ma

Trelc **Rhyolite of East Lee Canyon (Oligocene)**—White, gray, and pale lavender gray, sparsely porphyritic, fine- medium-grained rhyolite lava flows locally overlain by sandstone and pebbly conglomerate mostly derived from underlying rhyolite lava flows and lower cooling unit of tuff of Poco Canyon. Overlies lower cooling unit of tuff of Poco Canyon and underlies the tuff of Elevenmile Canyon. Petrographically similar to rhyolite of Pirouette Mountain (unit Trpm) and younger rhyolite (unit Tyr)

Tupc **Tuff of upper Poco Canyon (Oligocene)**—Light-gray-green to dark-green, crystal- and lithic-rich rhyolite ash-flow tuff. Contains about 20–30 percent fine- to medium-grained phenocrysts of clear quartz and altered K-feldspar and plagioclase with 1–2 percent chloritized biotite. Pervasive strong propylitic alteration with abundant clay minerals, calcite, and chlorite. Blocks of intermediate and silicic lavas as much as 5 m across are abundant. Zircon U-Pb age of 25.90±0.49 Ma

Tjp **Tuff of Job Peak (Oligocene)**—White to light green-gray, densely welded, moderately crystal-rich, lithic-rich rhyolite ash-flow tuff. Contains 10–20 percent, fine-grained phenocrysts of altered plagioclase and K-feldspar and locally trace quartz and biotite. Small (<6 cm) lithic fragments of Mesozoic metamorphic rocks, flow-banded rhyolite, and andesite are abundant, and much of tuff contains 30 to 50 volume percent lithic fragments. Locally includes coarse blocks of propylitized andesite (unit pa) derived from andesite porphyry (unit Tap). Zircon U-Pb age of 25.78±0.49 Ma

Tap **Andesite porphyry (Oligocene)**—Dark-green to black, coarse-grained, strongly porphyritic andesite and dacite. Mostly consists of hornblende-plagioclase andesite porphyry containing about 30 percent, medium- to coarse-grained phenocrysts of plagioclase, hornblende, and minor resorbed quartz in a microcrystalline groundmass. Generally strongly propylitically altered and (or) thermally metamorphosed with formation of abundant epidote, illite, calcite, and chlorite. Intrudes and overlies the rhyolite of Pirouette Mountain (unit Trpm) and older tuffs (Tot) units south of the IXL pluton. Zircon U-Pb age of 26.36±0.42 Ma

Tot **Older tuffs, undifferentiated (Oligocene)**—At least three separate densely welded, lithic- and crystal-rich, pumice-poor rhyolite to dacite ash-flow tuffs. Consists of (1) dark-green dacite tuff containing about 30 to 35 percent phenocrysts comprised mostly of fine- to medium-grained plagioclase, (2) light-greenish-gray, quartz-rich rhyolite tuff containing about 15 to 20 percent fine-grained phenocrysts, and (3) dark-green to black, biotite-hornblende dacite tuff containing about 30 percent medium-grained phenocrysts consisting mostly of plagioclase with 4 to 5 percent biotite+hornblende. All units are weakly to strongly propylitically altered and thermally metamorphosed with development of abundant hydrothermal epidote and fine-grained biotite. Relative ages of three tuffs uncertain. Zircon U-Pb age of 26.10±0.54 Ma on tuff 3

Trpm **Rhyolite of Pirouette Mountain (Oligocene)**—Red, light-purple, green, black, and gray, generally sparsely porphyritic rhyolite lava flows and shallow intrusive rocks, with less abundant welded tuff and volcaniclastic sedimentary rocks. Rocks generally contain 0 to 10 percent fine- to medium-grained phenocrysts composed of altered plagioclase and K-feldspar, minor strongly resorbed quartz, and trace amounts of altered mafic minerals (hornblende and [or] pyroxene) in a microfelsite groundmass. Commonly strongly flow banded and locally flow folded. Locally includes thin interbedded sequences of moderately to densely welded, pumice-rich, crystal-poor ash-flow tuff and coarse-grained volcaniclastic sandstone and conglomerate. Tuffs locally show rheomorphic flow textures, and contain locally abundant, small lithic fragments consisting mostly of flow-banded rhyolite. Top of unit locally overlain by poorly exposed fine-grained sandstone and shale, notably on the north side of Coyote Canyon. Unit is generally equivalent to the latite flows, tuffs, and breccias unit of Page (1965; therein unit “T ⁻ Jl”). Zircon U-Pb ages of 24.97±0.66 and 25.24±0.25 Ma from near top of unit in the Stillwater Range

Tixl **IXL pluton (Oligocene)**—Dark-gray, fine- to medium-grained, equigranular to porphyritic granodiorite and quartz monzodiorite. The northern and western margins of the pluton have a conspicuous porphyritic texture consisting of medium-grained feldspar and scattered biotite and hornblende phenocrysts set in a small amount of fine-grained groundmass composed of quartz, feldspar, and biotite. The color index is about 12 to 15. The lowest exposed part of the pluton along the Dixie Valley Fault is a medium-grained, equigranular rock with a color index of about 25 including hornblende crystals containing clinopyroxene cores. Irregular, spongy, hornblende-rich mafic enclaves as much as 1 m long with chilled margins are common near the roof (western margin) of the pluton; smaller mafic enclaves are scattered elsewhere in the pluton. Aplite dikes mostly ≤10 cm wide locally common in eastern half of pluton. Zircon U-Pb ages of 28.07±0.33 and 28.45±0.35 Ma

Tdg **Diorite and granodiorite (Oligocene)**—Light-grayish-green, fine-grained, sparsely porphyritic clinopyroxene diorite and medium-grained, sparsely porphyritic, biotite-hornblende granodiorite and granodiorite porphyry exposed in northwestern part of map area. Diorite contains small (2–4 mm) plagioclase phenocrysts and about 15 percent clinopyroxene partially altered to chlorite. Granodiorite contains about 15 percent mafic minerals. Both rock types are weakly to strongly propylitically altered or locally strongly argillically altered. Intrudes tuff of Job Canyon. Age relation to younger dacite and andesite sequence (unit Tyda) uncertain because of strong alteration of both units

Tor **Older rhyolite (Oligocene)**—Light-gray, sparsely porphyritic, locally vesicular, flow-banded rhyolite exposed along southern margin of Job Canyon caldera. Contains 5 to 10 percent phenocrysts of fine- to medium-grained altered plagioclase and K-feldspar and trace to 1 percent clear quartz in microcrystalline quartz-feldspar groundmass. Intrudes(?) or overlies older dacite and andesite sequence (units Tolf, Tobr, and Todt) and intruded by the IXL pluton (unit Tixl). Western outcrop is propylitically altered with clots of epidote, quartz, and hematite filling vesicles and in groundmass. Other outcrops are hornfelsed by IXL pluton

Younger dacite and andesite sequence (Oligocene)—Dacite and andesite lava flows, flow breccias, shallow intrusive rocks, and less abundant tuff and volcaniclastic sedimentary rocks.

Tyda **Younger dacite and andesite sequence, undivided**—Generally dark- to pale-green to black, aphyric to coarsely porphyritic dacite and andesite lava flows, flow breccias, and minor air-fall and ash-flow tuff and epiclastic sedimentary rocks. Porphyritic units contain plagioclase, less abundant hornblende, biotite, and clinopyroxene, and rare quartz phenocrysts. Generally weakly to strongly altered to propylitic and intermediate argillic assemblages with development of chlorite, illite or smectite, and (or) calcite. Quartz commonly fills vesicles. Dacitic ash-flow tuff beds locally present near base of unit. Siltstone and fine-grained sandstone beds common in upper part of unit. Plagioclase and biotite $^{40}Ar/^{39}Ar$ ages 28.89±0.40 and 28.81±0.01 Ma, respectively, on glassy lava flows near top of unit, and zircon U-Pb age of 28.54±0.51 Ma on propylitized lava flow in middle of unit

Tydai **Dacite and andesite intrusions**—Dark-green to dark-gray, fine- to medium-grained, moderately to abundantly porphyritic biotite-hornblende(?)-plagioclase dacite and andesite intrusions. Generally strongly propylitized with abundant epidote and chlorite. Plagioclase phenocrysts commonly white to pale pink. Forms narrow dikes and small irregular intrusions in the tuff of Job Canyon (unit Tjc) and older dacite and andesite sequence and likely fed overlying lava flows in the younger dacite and andesite sequence (unit Tyda)

Tydas **Lacustrine sedimentary rocks**—White to light-gray, finely bedded siltstone, fine-grained sandstone, and water-lain dacitic tuff. Forms small outcrops mostly near base of younger dacite and andesite sequence (unit Tyda)

Tydat **Dacite tuff**—Small exposures of dark green-gray, densely welded dacite tuff. Contains about 30 to 40 percent fine- to medium-grained phenocrysts comprised of plagioclase, K-feldspar, hornblende, and biotite. Contains abundant, small (≤2 cm) crystal-rich flattened pumice clasts. Strongly propylitically altered with abundant calcite, illite, and chlorite. Only present near the base of the younger dacite and andesite sequence (unit Tyda) along northern and southern margins of the Job Canyon caldera

JOB CANYON CALDERA

[Units Tjc, Tjcx, Tjv, Tjq]

Tjc **Tuff of Job Canyon (Oligocene)**—White, light-gray, and green-gray, densely welded, generally lithic-rich and crystal-poor rhyolite ash-flow tuff. Tuff is devitrified and commonly strongly altered to propylitic, argillic, and local advanced argillic assemblages. Locally contains abundant disseminated pyrite. Generally contains less than 10 to 15 percent fine-grained phenocrysts of altered plagioclase and K-feldspar with local trace amounts of quartz and biotite. Highly variable pumice contents. Small (<6 cm) lithic fragments of Mesozoic metamorphic rocks and Cenozoic volcanic rocks are common, and small outcrops of brecciated metashale and metasiltstone (unit ms) locally exposed near top of the tuff near the north caldera wall. Zircon U-Pb ages of 29.25±0.47 and 29.30±0.45 Ma

Tjcx **Megabreccia, undivided (Oligocene)**—Coarse breccia deposits consisting of blocks of andesitic metavolcanic rocks, marble, argillite, siltstone, quartzite and the older dacite and andesite sequence as much as 50 m across in an unsorted, lithic-rich tuffaceous matrix. No discernable bedding. Breccia is generally matrix supported although matrix is seldom exposed. Quartzite and metavolcanic blocks are commonly internally brecciated and cemented with quartz

Tjv **Metavolcanic megabreccia (Oligocene)**—Small outcrops of dark red to dark green, commonly iron-stained, brecciated, aphyric to finely porphyritic andesitic metavolcanic rocks exposed along the top of the Job Canyon caldera. Interpreted as megabreccia deposited into the Job Canyon caldera

Tjq **Quartzite megabreccia (Oligocene)**—Small outcrop of brecciated quartzite exposed along the top of the Job Canyon caldera. Interpreted as megabreccia deposited into the Job Canyon caldera

Older dacite and andesite sequence (Oligocene)—Dacite and andesite lava flows, flow breccias, shallow intrusive rocks and less abundant tuff and volcanic-clast rich conglomerate.

Todt **Dacite tuff**—Dark-gray to green, densely welded, lithic- and crystal-rich dacite tuff. Contains about 15–30 percent, fine- to medium-grained phenocrysts of altered sanidine and plagioclase with prominent strongly resorbed quartz and fine-grained biotite, and minor strongly altered hornblende(?). Contains abundant lithic fragments of Cenozoic intermediate and silicic lava flows and less abundant Mesozoic quartzite and granite. Tuff is pervasively propylitically altered with abundant illite, epidote, chlorite, calcite and disseminated pyrite. Zircon U-Pb age of 29.32±0.97 Ma and biotite $^{40}Ar/^{39}Ar$ age of 29.17±0.09 Ma. Only mapped where tuff forms top of older dacite and andesite sequence

Tolf **Lava flows**—Heterogeneous sequence of aphyric to coarsely porphyritic dacite and andesite lava flows and flow breccias, hypabyssal intrusions, and minor pyroclastic rocks and conglomerate. Porphyritic rocks contain fine- to coarse-grained phenocrysts of plagioclase, hornblende, biotite, and clinopyroxene. Pyroclastic rocks are lithic-rich welded tuffs. Generally strongly propylitically altered with abundant calcite, chlorite, epidote, illite, and local specular hematite. Zircon U-Pb age of 29.38±0.38 on a lava flow near top of unit

Tobr **Breccia, conglomerate, and tuffs, undifferentiated**—Dark-green, gray-green, and reddish-brown lithic-rich tuff breccia, flow breccia, and conglomerate. Lithic fragments consist of small (<10 cm), subangular to subrounded clasts of Cenozoic andesitic to rhyolitic lavas and less common Mesozoic quartzite and granitic rocks. Locally contains blocks as much as 10 m across of andesite breccia in tuffaceous matrix composed of fine- to medium-grained, moderately porphyritic dacite(?) similar to tuff in dacite tuff unit (Todt). Generally strongly propylitically altered with abundant clots and fracture coatings of epidote and specular hematite. Zircon U-Pb ages of 29.27±0.49 Ma on lithic-rich tuff breccia near top of unit and 29.65±0.52 Ma on densely welded tuff in lower part of unit

CRETACEOUS INTRUSIVE ROCKS

Klp **La Plata Canyon pluton (Cretaceous)**—Composite, light-colored granitic intrusion consisting of fine- to medium-grained, equigranular biotite granite, quartz monzonite, and associated leucocratic dikes (Butler, 1979). Commonly altered with formation of abundant fine- to coarse-grained muscovite and pyrite with local fluorite and milky-white quartz veins. Between Elevenmile and La Plata Canyons, contains small bodies of propylitized, coarsely porphyritic biotite-hornblende dacite or rhyolite porphyry that probably are early Miocene intrusions. K-Ar alteration age of 84.4±0.8 Ma from muscovite in vein within Mesozoic wall rocks at fluorite prospect near mouth of La Plata Canyon (Garside and others, 1981), and zircon U-Pb age of 87.25±0.50 Ma on biotite granite in La Plata Canyon

Kf **Felsite (Cretaceous)**—Light-colored felsite containing sparse, 1 to 2 mm phenocrysts of resorbed quartz and altered feldspar in a fine-grained, allotriomorphic granular groundmass of quartz, altered plagioclase and K-feldspar(?), illite, minor pyrite, and ghosts of tabular mafic minerals outlined by ragged aggregates of epidote. Zircon U-Pb age of 104.8±1.4 Ma

MESOZOIC METASEDIMENTARY AND METAVOLCANIC ROCKS

LA PLATA CANYON AREA

Mountain Well sequence (Lower Cretaceous?)—Poorly dated, metamorphosed volcanic and sedimentary rocks; provisional age assignment based on a Cretaceous zircon U-Pb age of meta-andesite lava flow (unit Kmv) and association with Cretaceous felsite unit (unit Kf). Divided into:

Kmv **Andesitic metavolcanic rocks**—Foliated metamorphosed andesite, andesite breccia containing stretched clasts, and dacitic welded tuff and tuff breccia. Zircon U-Pb age of 103.9±1.5 Ma on andesite lava flow

Kms **Metasedimentary rocks, undifferentiated**—Heterogeneous, interstratified and intergradational, subaqueous gravity-flow sequence mainly of gray to black (1) slaty siliceous argillite, (2) massive fine- to medium-grained orthoquartzite, (3) turbiditic quartz siltstone or fine-grained sandstone in well-bedded, thin- to medium-thick, T_b A(B)C(E) Bouma sequences, (4) calcareous quartz siltstone, (5) fine-grained mud-chip or lime-mudstone-chip sedimentary breccia, and (6) lithic sandstone of dense felsitic or plagioclase-lath volcanic rocks along with minor quartzite and quartz grains. Also included are minor amounts of foliated marble and tuffaceous(?) greenstone. Less competent rock types strongly flattened on foliation and with grain-stretch lineation. Discontinuous channel(?) deposits of tectonically flattened limestone- and orthoquartzite-clast sedimentary breccia crop out in two places near stratigraphic base of unit, and at one of these localities the breccia forms coarse-grained base of a T_b AB(C) Bouma sequence of black orthoquartzite

Kmd **Dacitic volcanic-felsite flows and sedimentary breccia**—White to dark-gray, mostly weathered light-brown massive felsite completely aphyric and featureless in hand specimen; in thin section, composed entirely of more or less flow-aligned laths of altered plagioclase in altered, probably originally glassy, groundmass. Tectonically flattened, crudely bedded sedimentary breccia of felsite clasts interstratified in upper part of unit, and upper part of unit interfingers with unit Kms. Stratigraphic base of unit Kmd everywhere faulted

Clan Alpine sequence (Lower Jurassic and Upper Triassic)—Limestone and argillite provisionally correlated with units assigned to the Clan Alpine sequence of Speed (1978) in the Clan Alpine Mountains, about 50 km northeast of map area. Divided into:

J₹cl **Upper limestone (Lower Jurassic and (or) Upper Triassic)**—Massive, gray-weathering, lime mudstone; bedding mostly obscure, commonly veined with calcite, and locally foliated; in places abundantly oncolitic. Interpreted as a carbonate-platform deposit. Exposures of contact with unit ₹cl are limited in extent and difficult to interpret. Believed to depositionally overlie unit ₹cl and thus be laterally equivalent to the Mud Springs Canyon Formation of Speed (1978) in the Clan Alpine sequence of the Clan Alpine Mountains

₹cl **Lower limestone (Upper Triassic)**—Regularly thin-bedded to medium-bedded, black-lime mudstone. Weakly metamorphosed except where conspicuously flattened, foliated, and lineated near La Plata Fault and where thermally metamorphosed to marble near contact with La Plata Canyon pluton. Turbiditic interbeds as thick as 20 cm formed of crinoid ossicles (and more rarely of molluscan shell fragments) exhibit T_bA and AB Bouma sequences; in southwesternmost exposures, crinoidal turbidites form as much as 50 percent of section through stratigraphic thicknesses of several tens of meters and are associated with rare units of limestone sedimentary breccia containing clasts as large as several centimeters. Lime mudstone beds commonly have internal planar lamination and locally have laminae of quartz silt or subordinate interbeds of black argillite. Interpreted as slope, and possibly partly basinal, deposit. Conspicuous white alteration lenses, several millimeters thick and as long as 20 cm, and composed of neomorphosed calcite, are locally abundant within lime mudstone beds. Age-diagnostic fossils scarce but include ammonite *Choristoceras* (at map locality C), spherical hydrozoan *Heterastridium* (locality H), and pelagic bivalve *Monotis subcircularis* (at localities labeled M), all of Late Triassic (Norian) age and in southwestern part of outcrop area (John and Silberling, 1994). Similar in lithic character, age, and depositional setting to, and is regarded as a lateral equivalent of the Hoyt Canyon Formation of Speed (1978), which forms part of the Clan Alpine sequence of the Clan Alpine Mountains. Although generally contains overturned beds that stratigraphically overlie unit ₹ca, stratigraphic superposition of rocks assigned to these two units is locally ambiguous

₹ca **Argillite (Upper Triassic)**—Predominantly planar laminated argillite with subordinate quartzose siltstone and fine-grained sandstone that occurs as laminae or in thin, locally graded beds. Light brown, olive gray, or gray but black where hornfelsed near La Plata Canyon pluton. Weakly developed slaty foliation away from areas of thermal metamorphism. Minor intercalations of limestone. Interpreted as laterally equivalent to the slope or basinal siliciclastic rocks that are either interstratified with limestone strata of the Hoyt Canyon Formation of Speed (1978) or form the underlying Bernice Formation of Speed (1978) in the typical Clan Alpine sequence of the Clan Alpine Mountains. In southwesternmost part of pre-Cenozoic outcrop area, rocks of unit ₹ca are clearly overlain stratigraphically by generally overturned, fossiliferous, turbiditic limestone of unit ₹cl; elsewhere in map area, stratigraphic superposition of rocks assigned to these two units is ambiguous

LOWER PLATE OF LA PLATA FAULT

Mzp **Phyllite (lower Mesozoic?)**—Strongly foliated phyllite, commonly containing intrafoliation andalusite porphyroblasts (chiastolites) that are locally aligned, forming a pronounced lineation. In contact zone of La Plata Canyon pluton, younger generation of andalusite porphyroblasts is superimposed upon and crosscuts foliation and lineation. Locally, phyllite grades into foliated, medium- to coarse-grained, impure, volcanic sandstone having only a small percentage of quartz grains; volcanic-lithic and feldspar(?) grains generally strongly stretched on foliation. No direct evidence for age, but its lithology and metamorphic and structural history resembles rocks included in the Sand Springs “lithotectonic assemblage” of Oldow (1984) (Oldow and others, 1993), which lies to the south of the La Plata Canyon area, and from which fossils of probable Triassic and Jurassic ages are known (Satterfield, 2002)

COX AND I X L CANYONS AREA

Jrmb **Rhyolite megabreccia (Upper Jurassic)**—White, commonly orange-weathering, locally flow banded, aphyric to very sparsely porphyritic rhyolite. Commonly strongly kaolinite altered and locally strongly brecciated. Zircon U-Pb ages of 155.2±2.4 and 156.33±0.37 Ma. Forms massive outcrops along northwest edge of the Job Canyon caldera, where it is interpreted as megabreccia deposited near the top of the caldera following eruption of caldera-filling tuff of Job Canyon (unit Tjc) and during eruption of the overlying younger dacite and andesite sequence (unit Tyda)

Jq **Quartzite (Middle and (or) Lower Jurassic)**—Massive, fine-grained white quartzite. Inferred age assignment is based on regional distribution of quartzite (Page, 1965; Willden and Speed, 1974)

Clan Alpine sequence (Triassic)—Divided into:

ŦRcs **Calcareous siltstone and sandstone (Triassic)**—Pale red-purple and yellow-brown calcareous siltstone and sandstone with some intercalated bedded gray limestone. Matrix-supported chert grit and fine-grained pebbles in some beds. Small, glogose ammonites of indeterminate species suggest Triassic rather than Early Jurassic age

ŦRs **Siltstone and argillite (Triassic)**—Mostly dark olive-gray siltstone and argillite, with intercalated beds and units of fine- to medium-grained brownish sandstone and partly bioclastic limestone. Some sandstone and limestone beds have Bouma layering, and flute casts locally well developed. Unit characteristic of basinal part of Auld Lang Syne Group or Clan Alpine sequence of Speed (1978)

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