Stratigraphy, Regional Distribution, and Reconnaissance Geochemistry of Oligocene and Miocene Volcanic Rocks in the Paradise Range and Northern Pactolus Hills, Nye County, Nevada

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Stratigraphy, Regional Distribution, and Reconnaissance Geochemistry of Oligocene and Miocene Volcanic Rocks in the Paradise Range and Northern Pactolus Hills, Nye County, Nevada

By DAVID A. JOHN

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Stratigraphy, Regional Distribution, and Reconnaissance Geochemistry of Oligocene and Miocene Volcanic Rocks in the Paradise Range and Northern Pactolus Hills, Nye County, Nevada

By David A. John

Abstract

Thick sequences of Oligocene to middle Miocene volcanic rocks form three stratigraphic sections in the Paradise Range and northern Pactolus Hills, northwestern Nye County, Nevada. At the northern end of the Paradise Range, five silicic ash-flow tuff units that are locally intercalated with intermediate lavas and unconformably overlain by intermediate to mafic lavas form the Ellsworth section, which is 1,300+ m thick. No ash-flow tuff units are regionally widespread. On the east side of the Paradise Range and in the northern Pactolus Hills as many as nine silicic ash-flow tuff units that are unconformably overlain by intermediate to mafic lavas form the Menter Canyon section, which is as much as 2,800 m thick. Three ash-flow tuff units in this section are regionally widespread and have caldera sources west (tuff of Gabbs Valley) and east (tuffs of Arc Dome and Toiyabe) of the Paradise Range. The tuff of Toiyabe probably is correlative with the tuff of Copper Mountain as defined previously in the Gabbs Valley Range. The present distribution of these tuffs suggests approximately 35 km of post-early Miocene, right-lateral displacement on the Petrified Spring fault. On the southwestern side of the Paradise Range and in the northern Pactolus Hills, the Sheep Canyon section consists of thick accumulations of intermediate to silicic lavas (older andesite sequence) that are overlain by silicic ash-flow tuffs (middle tuff sequence) and unconformably overlain by intermediate to silicic lavas (younger andesite sequence). All three units are intruded by small hypabyssal bodies of intermediate to silicic composition. The total thickness of the Sheep Canyon section exceeds 3,500 m, and as many as 11 ash-flow tuff units are present. Only the oldest ash-flow tuffs in this section (the tuffs of Davis Mine and Pactolus) may be regionally widespread and probably have sources in the southern Shoshone Mountains.

Early Miocene normal faulting, locally extreme crustal extension, and associated synextensional to postextensional, dominantly intermediate-composition magmatism are widespread in west-central Nevada and appear to play significant roles in the genesis of several major epithermal gold-silver deposits, including the Paradise Peak deposit in the southwestern Paradise Range. Tertiary volcanic rocks in the Paradise Range have undergone two or more periods of normal faulting; most contacts between pre-Tertiary and Tertiary rocks are high- or low-angle normal faults. A major period of normal faulting and crustal extension occurred approximately 22 to 19 Ma, and prominent angular unconformities separate earliest Miocene silicic ash-flow tuffs and overlying early to middle Miocene intermediate lavas (younger andesite sequence) present both on the east side of the Paradise Range and in the northern Pactolus Hills. This period of faulting also is evident in the Sheep Canyon section, although an angular unconformity is absent.

Most ash-flow tuff in the Paradise Range is rhyolite or high-silica rhyolite in composition. Thick exposures of the tuff of Arc Dome (350+ m thick) are normally zoned from a high-silica rhyolite base (77 weight percent SiO_2 recalculated volatile-free) to normal rhyolite in its upper part (73 weight percent SiO_2). The thick (600+ m) tuff of Sheep Canyon shows significant compositional zoning (68 to 72.5 weight percent SiO_2), although most compositional changes apparently occur between cooling units. Most other ash-flow tuffs show little evidence for significant compositional zoning. No evidence is found for reverse compositional zoning in ash-flow tuffs exposed in the Paradise Range, in contrast to reverse compositional zoning reported in ash-flow tuff units in nearby ranges to the west.

The older (late Oligocene) and younger (early Miocene) andesite sequences have significant compositional differences. Although both sequences show considerable compositional variation ranging from andesite or basaltic andesite to high-silica dacite or low-silica rhyolite (approximately 55 to 70 weight percent SiO_2), the younger andesites have significantly higher Ca, Sr, P, and Sr/Rb, and lower K, Mg, Rb, K/Rb, and initial $^{87}Sr/^{86}Sr$ than the older andesites at a constant silica content. Comparison of these data to limited chemical data from adjacent areas suggests that the compositional differences are present regionally in early Miocene intermediate lavas and reflect regional changes in magma genesis that occurred about 20 Ma.

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Younger lavas appear spatially limited to areas that underwent early Miocene normal faulting and extension, suggesting that the chemical changes reflect changes in the tectonic environment of magma genesis.

Comparison of the Tertiary volcanic-tectonic history of the Paradise Range to other highly extended terranes in the Basin and Range Province indicates that there are several significant differences in the Paradise Range, including: (1) there is a hiatus in volcanic activity during early Miocene extensional faulting in the Paradise Range; (2) synextensional sedimentary rocks are absent in the Paradise Range; and (3) there is little apparent systematic compositional variation in the synextensional to postextensional volcanic rocks and an absence of true basalts in the Paradise Range. It is not clear if these differences are minor variations on regional patterns or represent a fundamentally different volcanic-tectonic evolutionary style.

INTRODUCTION

Thick sections of Oligocene and Miocene volcanic rocks crop out on the north, east, and south sides of the Paradise Range and in the Pactolus Hills in the northwestern corner of Nye County, Nev. (figs. 1, 2). Recent detailed geologic mapping (John, 1986, 1988, unpublished data; John and Kelleher, 1987; Silberling and John, 1989) and K-Ar dating (McKee and John, 1987; John and others, 1989b) reveal that there are much thicker and more complex sequences of Tertiary volcanic rocks in these areas than previously recognized (Vitaliano and Vitaliano, 1972; Kleinhampl and Ziony, 1985). Several units identified in the Paradise Range are regionally extensive and provide time-stratigraphic links with other well-studied areas to the west in the Gabbs Valley and Gillis Ranges (Ekren and others, 1980) and the Yerington district (Proffett and Proffett, 1976) and to the east in the southern Toiyabe Range (Brem and others, 1985; 1991) and the southern Toquima Range (Boden, 1986; Mills and others, 1988). Correlation of one regionally extensive ash-flow tuff unit allows estimation of late Cenozoic offset along the Petrified Spring fault, a major northwest-trending strike-slip fault on the east side of the Walker Lane. In addition, a sequence of early Miocene intermediate to silicic lava bodies are synextensional and provide new data on the nature of magmatism associated with crustal extension in the Great Basin.

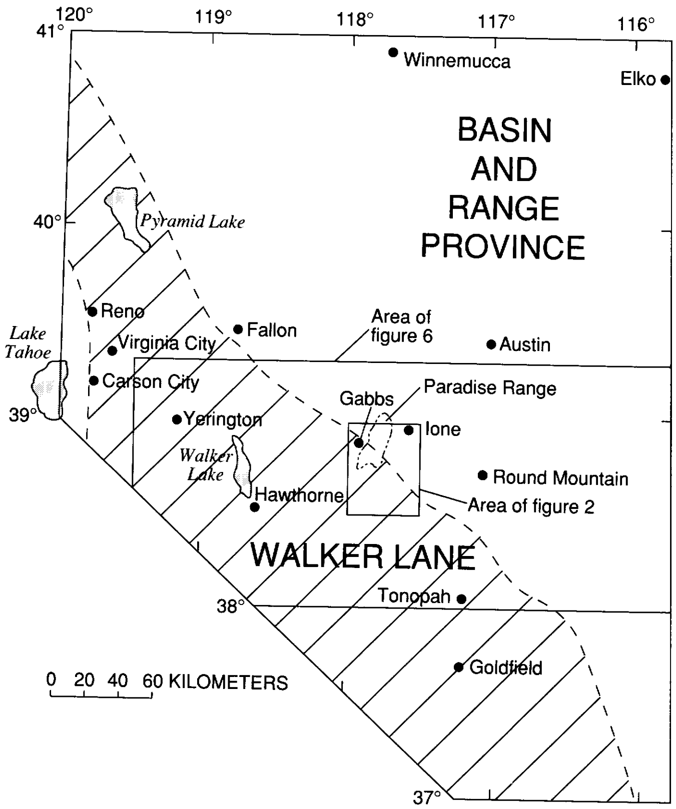


Figure 1. Index map of part of Nevada showing location of Paradise Range, Walker Lane (diagonal lines), and Basin and Range province. Outline of Walker Lane taken from Stewart (1988).

This paper presents detailed descriptions of the Tertiary volcanic stratigraphy of the Paradise Range and northern Pactolus Hills and discusses the regional distribution of major ash-flow tuff units present in these areas. Field, petrographic, modal, and chemical data are presented for about 40 units, and these data are compared to data from adjacent ranges and to recent descriptions of middle to late Tertiary volcanic rocks elsewhere in the Great Basin (Best and others, 1989a, b; Gans and others, 1989). The late Cenozoic volcanic and tectonic history of the area is discussed and compared to other areas in the Basin and Range province that were highly extended during the late Cenozoic.

Acknowledgments

Many people contributed to this study of the volcanic rocks in the Paradise Range. Field trips and discussions with R.F. Hardyman, G.F. Brem, N.J. Silberling, D.H. Whitebread, J.J. Rytuba, R.E. Thomason, P.L. Kelleher, J. Bosma-Douglas, and M.L. Hudson immeasurably helped. Discussions with J.H. Stewart, D.R. Boden, J.H. Dilles, R.P. Ashley, and M.L. Sorensen helped clarify some of the regional aspects of volcanism and tectonism in the Paradise Range. A special word of thanks also goes to J.S. Oldow for the inspiration he provided, when, after driving through exposures of Tertiary volcanic rocks in the southwestern Paradise Range during a 1983 field trip, he turned to me and asked, "Who's the poor sucker that has to map these rocks?"

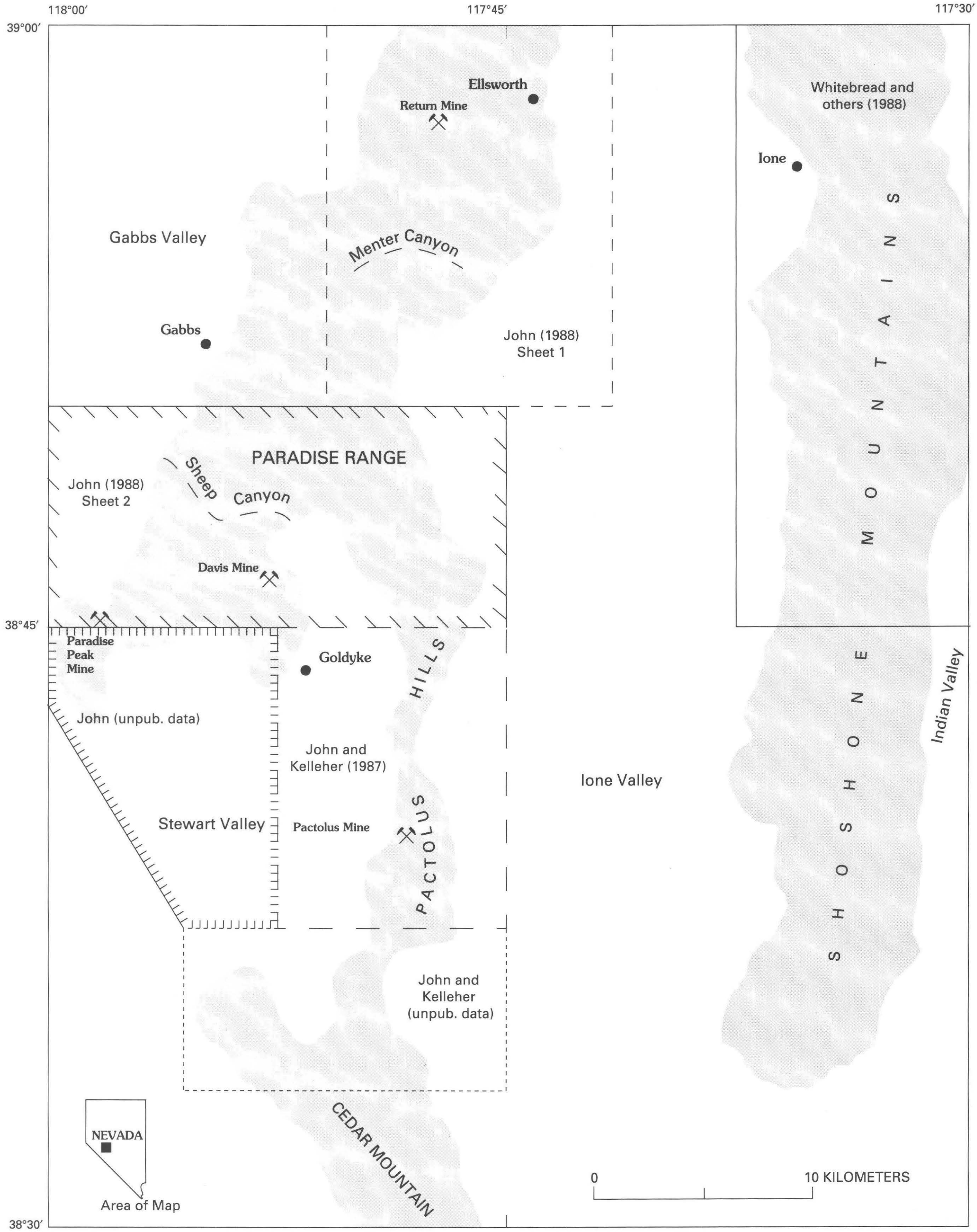


Figure 2. Index map showing location of Paradise Range and Pactolus Hills and areas recently mapped and described in this report.

PREVIOUS WORK

Previous descriptions of Tertiary volcanic rocks in the Paradise Range and the southern Shoshone Mountains were published by Vitaliano (1963), Vitaliano and Callaghan (1963), Vitaliano and Vitaliano (1972), and Kleinhampl and Ziony (1985). Vitaliano (1963) and Vitaliano and Callaghan (1963) presented 1:62,500-scale maps of Tertiary volcanic rocks in the Ione and Paradise Peak 15-minute quadrangles, respectively. They divided Tertiary volcanic rocks in the Paradise Range into three units: lower and upper volcanic sequences and trachyandesite lavas that locally overlie the upper volcanic sequence. The lower volcanic sequence primarily consists of propylitized intermediate lavas, whereas the upper volcanic sequence consists of ash-flow tuffs locally intercalated with silicic to intermediate lavas. Vitaliano and Vitaliano (1972) presented more detailed descriptions of these two volcanic sequences and attempted to correlate volcanic units in the Paradise Range with units in the southern Shoshone Mountains. My own work reported here indicates that the stratigraphic and structural relations of the Tertiary volcanic rocks are much more complex than suggested by Vitaliano and Vitaliano (1972).

Kleinhampl and Ziony (1985) generalized the maps of Vitaliano (1963) and Vitaliano and Callaghan (1963) and mapped the northern Pactolus Hills at a scale of 1:250,000. Ekren and others (1980) described thick sections of Tertiary volcanic rocks in the Gabbs Valley and Gillis Ranges immediately west of the Paradise Range and showed the possible extent of some of these volcanic units in the southwestern Paradise Range.

GEOLOGIC SETTING

The Paradise Range lies in the western part of the Great Basin region of the Basin and Range physiographic province in west-central Nevada (fig. 1). The Basin and Range province is an area of alternating linear north- to north-northeast-trending ranges and broad alluviated basins formed during late Cenozoic crustal extension. The basin-and-range physiography is disrupted near the west margin of the Great Basin by the Walker Lane, a northwest-trending zone of irregular topography and strike-slip faults (fig. 1; Locke and others, 1940; Stewart, 1988). The Paradise Range lies along the east edge of the Walker Lane.

The oldest rocks exposed in the Paradise Range are early Paleozoic(?) metasedimentary rocks including dolomite, quartzite, argillite, and phyllite (Silberling and John, 1989). Early Paleozoic rocks are in fault contact with late Paleozoic and Mesozoic metavolcanic and metasedimentary rocks including andesitic breccia and tuff, volcaniclastic mudstone, sandstone, and conglomerate, metamorphosed gabbro and basalt, limestone and dolomite, phyllite and calcareous phyllite, and sandstone and quartzite (Silberling and John, 1989). These rocks range in age from Permian(?) to Jurassic and form several allochthons that are juxtaposed by Jurassic thrust faults (Oldow, 1984; Silberling and John, 1989).

The metamorphic rocks are intruded by numerous plutonic bodies that range in composition from diorite and granite, in texture from coarse-grained coarsely porphyritic to fine-grained porphyroaphanitic, and in size from thin dikes to large stocks (John, 1987; Silberling and John, 1989). Limited radiometric dating suggests that most of the plutonic rocks are Late Cretaceous in age (John, 1987; John and McKee, 1987), although several undated, metamorphosed bodies may be Jurassic (Silberling and John, 1989).

Pre-Tertiary rocks are overlain by and are in fault contact with thick sections of Oligocene and Miocene volcanic rocks (fig. 3). About 40 mappable units were defined by recent geologic mapping (John, 1988 and unpublished data; John and Kelleher, 1987). Total thicknesses of Tertiary volcanic sections exceed 2,800 m on both the east and southwest sides of the range. Figure 4 shows generalized composite stratigraphic sections of Tertiary volcanic rocks in the Paradise Range and northern Pactolus Hills.

LATE CENOZOIC STRUCTURAL GEOLOGY

The Paradise Range has undergone a complex history of middle to late Cenozoic extensional faulting that strongly affected the deposition and present distribution of Tertiary rocks (John, 1986, 1988; John and others, 1989b). Evidence of at least two periods of normal faulting is present throughout the Paradise Range, and most, if not all, contacts between pre-Tertiary basement rocks and Tertiary volcanic rocks are faults (John, 1988). Unlike the case in the Yerington district to the west (Proffett, 1977; Proffett and Dilles, 1984) and nearby ranges east of the Paradise Range, a prominent early Tertiary erosion surface and sedimentary rocks at the base of the Tertiary section are absent in the Paradise Range.

Several sets of low- and high-angle normal faults cut Tertiary volcanic rocks in the Paradise Range. The present physiography of the range is dominantly controlled by north- to north-northeast-trending high-angle normal faults related to modern Basin and Range extension. These faults cut several sets of older normal faults related to one or more periods of Oligocene(?) and early

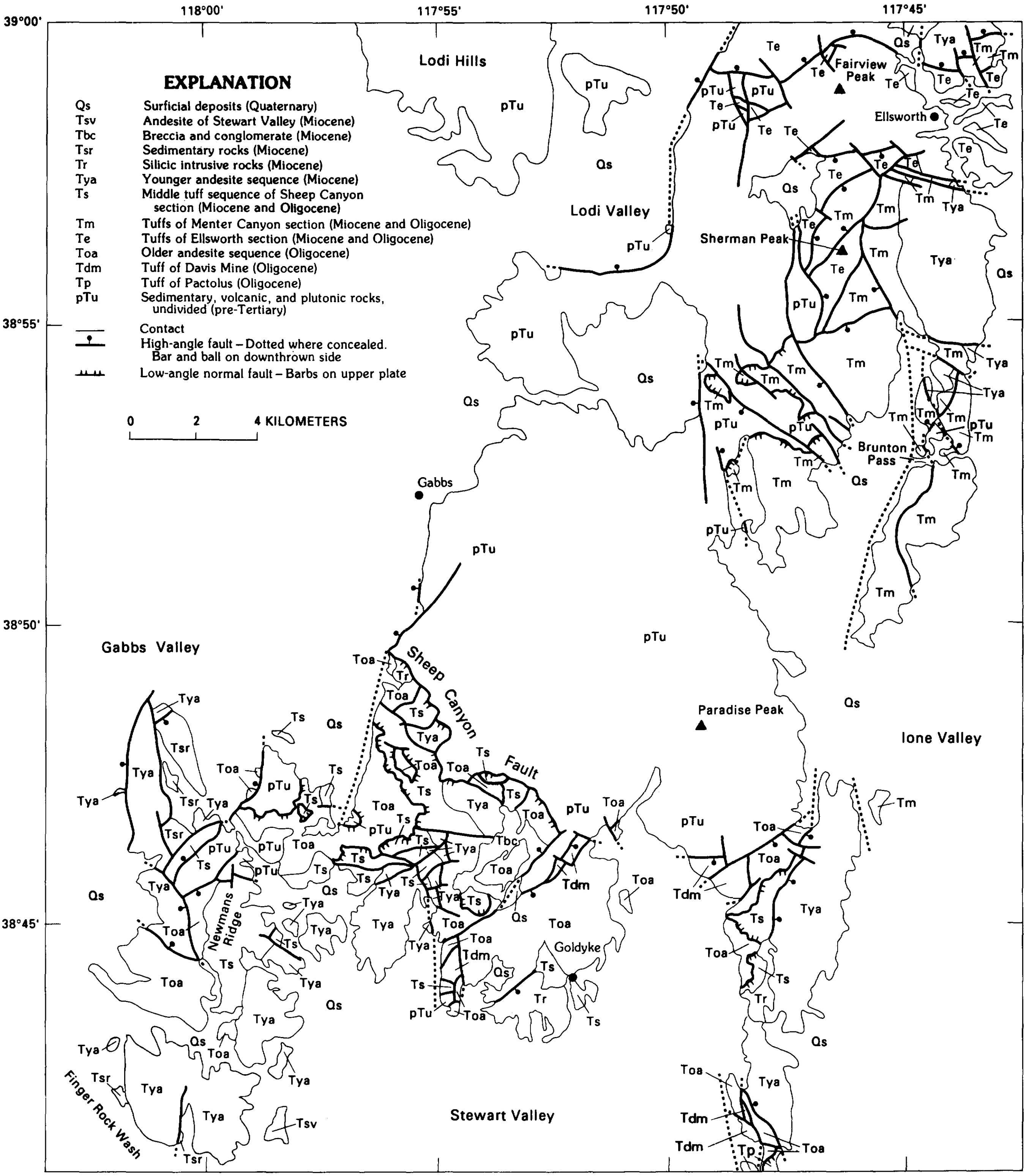


Figure 3. Generalized geologic map of Tertiary volcanic rocks in Paradise Range and northern Pactolus Hills showing distribution of Menter Canyon, Ellsworth, and Sheep Canyon sections, and older and younger andesite sequences. Geology simplified from John (1988 and unpublished mapping), John and Kelleher (1987), John and others (1989b), and Silberling and John (1989).

Miocene normal faulting and crustal extension. These older faults generally trend northwest to north-northwest and east-northeast. The northwest-trending faults commonly now dip at low angles (<20°) (John, 1988; John and others, 1989b). Compaction foliation in ash-flow tuffs in upper plates of the low-angle faults generally is at high angles to the fault planes, and many of the low-angle normal faults may be similar to low-angle normal faults in the Yerington district that Proffett (1977) has shown originated as high-angle faults and subsequently were rotated to their present orientation by continued extension and formation of younger sets of normal faults. Examples of possible rotated high-angle faults include the fault contact between pre-Tertiary and Tertiary rocks in the lower part of Menter Canyon on the east side of the range and numerous low-angle faults between Tertiary units in the southwestern part of the range (fig. 3). Other low-angle normal faults, notably the Sheep Canyon fault in the southwestern part of the Paradise Range (fig. 3), appear to be younger than rotated high-angle faults and may have originated as low-angle, detachment-style faults (John, 1988; John and others, 1989b).

The structure of Tertiary rocks varies throughout the Paradise Range. Tertiary rocks on the east side of the range generally strike north-northeast to northwest and have moderate dips to the east (rocks at the extreme north end of the range strike west-northwest and have moderate to steep northeast dips). The early Miocene andesite and basaltic andesite unit has notably shallower dips than underlying ash-flow tuff, and there commonly is a 10°–25° angular unconformity between these units. Contacts between pre-Tertiary and Tertiary rocks are both low- and high-angle faults. Tertiary rocks from Menter Canyon south generally are in low-angle fault contact with pre-Tertiary rocks (fig. 3). This fault contact is cut by numerous northwest-trending high-angle faults and has been interpreted as a rotated high-angle normal fault (John, 1988).

In the southwestern Paradise Range, Tertiary rocks generally strike northwest and have moderate to steep northeast dips. Most contacts between pre-Tertiary and Tertiary rocks are low-angle normal faults, most notably the Sheep Canyon fault (fig. 3). At least five different sets of faults have been identified (John, 1988); the most prominent fault sets are northwest-trending low-angle normal faults and east-northeast- and north-northeast-trending high-angle normal faults. The north-northeast-trending faults generally are the youngest faults.

In the northern Pactolus Hills, Tertiary ash-flow tuff generally strikes north to northwest and dips moderately to steeply to the east. Early Miocene andesite unconformably overlies these tuffs and generally dips less than 15° east. Several orientations of faults are present, including northwest-trending low-angle normal faults that may be rotated high-angle faults and north- to north-east-trending high-angle faults. Contacts between pre-Tertiary and Tertiary rocks are high-angle faults that trend north to northeast (fig. 3).

STRATIGRAPHY OF TERTIARY VOLCANIC ROCKS IN THE PARADISE RANGE

Detailed geologic mapping of Tertiary volcanic rocks in the Paradise Range and northern Pactolus Hills shows that these rocks can be divided into three major stratigraphic sections: the Menter Canyon, Ellsworth, and Sheep Canyon sections, and a fourth composite section in the northern Pactolus Hills where the Menter Canyon and Section Canyon sections are juxtaposed by high-angle faults (fig. 4; John, 1988). The Menter Canyon section crops out on the east side of the Paradise Range and in the northern Pactolus Hills, the Ellsworth section crops out on the northeast side of the Paradise Range, and the Sheep Canyon section crops out at the south end of the Paradise Range (principally on the southwest side) and in the northern Pactolus Hills. Only one ash-flow tuff unit, the tuff of Camel Spring, is present in more than one stratigraphic section.

Two major stratigraphic sections, the Menter Canyon and Ellsworth sections, dominantly composed of thick sequences of silicic ash-flow tuffs unconformably overlain by intermediate to mafic lavas, are present on the east side of the Paradise Range (figs. 3, 4). Contacts between these sections are faults, and only the tuff of Camel Spring is present in both sections. Thirteen distinct ash-flow tuff units have been recognized in these sections. In general, the older tuffs are relatively crystal-poor, thinner, and less widespread than the younger tuffs. The two thickest and most regionally widespread tuffs, the tuff of Arc Dome and the tuff of Toiyabe, cap the ash-flow tuff sequence along most of the east side of the range. Ash-flow tuff units in these sections locally are intercalated with andesitic lavas that appreciably thicken to the north. In the part of the range mapped (south of lat 39° N.), silicic lava flows and intrusions are nearly absent; this is in striking contrast to the south end of the range, where they are relatively abundant.

The southwestern part of the Paradise Range and the northern Pactolus Hills are underlain by a thick series of silicic ash-flow tuffs and intermediate to silicic lavas that make up the Sheep Canyon section (fig. 4). This section consists of a thick sequence of late Oligocene intermediate to silicic lavas overlain by a thick sequence dominantly composed of late Oligocene to early Miocene silicic ash-flow tuffs. Both sequences are unconformably overlain by a thick sequence of early to middle Miocene intermediate to silicic lavas. The Sheep Canyon section is locally more than 3,500 m thick. All three extrusive rock sequences are intruded by numerous small bodies of early to middle Miocene rhyolite.

Menter Canyon section

The Menter Canyon section consists of six major ash-flow tuff units that locally are intercalated with three additional thin ash-flow tuff units (fig. 4). The ash-flow tuffs are unconformably overlain by a thick series of andesite and basaltic andesite lava flows. Units in this section are, from bottom to top, the tuff of Green Springs, the tuff of Menter Canyon, the tuff of Camel Spring, the tuff of Gabbs Valley, the tuff of Arc Dome, the tuff of Brunton Pass, two unnamed tuffs, the tuff of Toiyabe, and andesite to basaltic andesite lavas. Total thickness of this section is more than 2,800 m. Major features of ash-flow tuff units in the Menter Canyon section are summarized in figure 5 and table 1.

Tuff of Green Springs

The tuff of Green Springs is the basal unit in the Menter Canyon section. It is exposed in Menter Canyon, where it is in low-angle fault contact with a Cretaceous(?) granitoid (porphyry of Menter Canyon; Silberling and John, 1989). The tuff is a compound cooling unit that consists of dark-red to reddish-brown, devitrified, densely welded, locally lithic-rich, crystal-poor high-silica rhyolite ash-flow tuff. Two ash-flow cooling units are present; the upper cooling unit contains small blocks of the lower cooling unit as well as clasts of flow-banded rhyolite. The lower cooling unit is more pumice-rich than the upper cooling unit and locally shows rheomorphic flow textures. Both cooling units

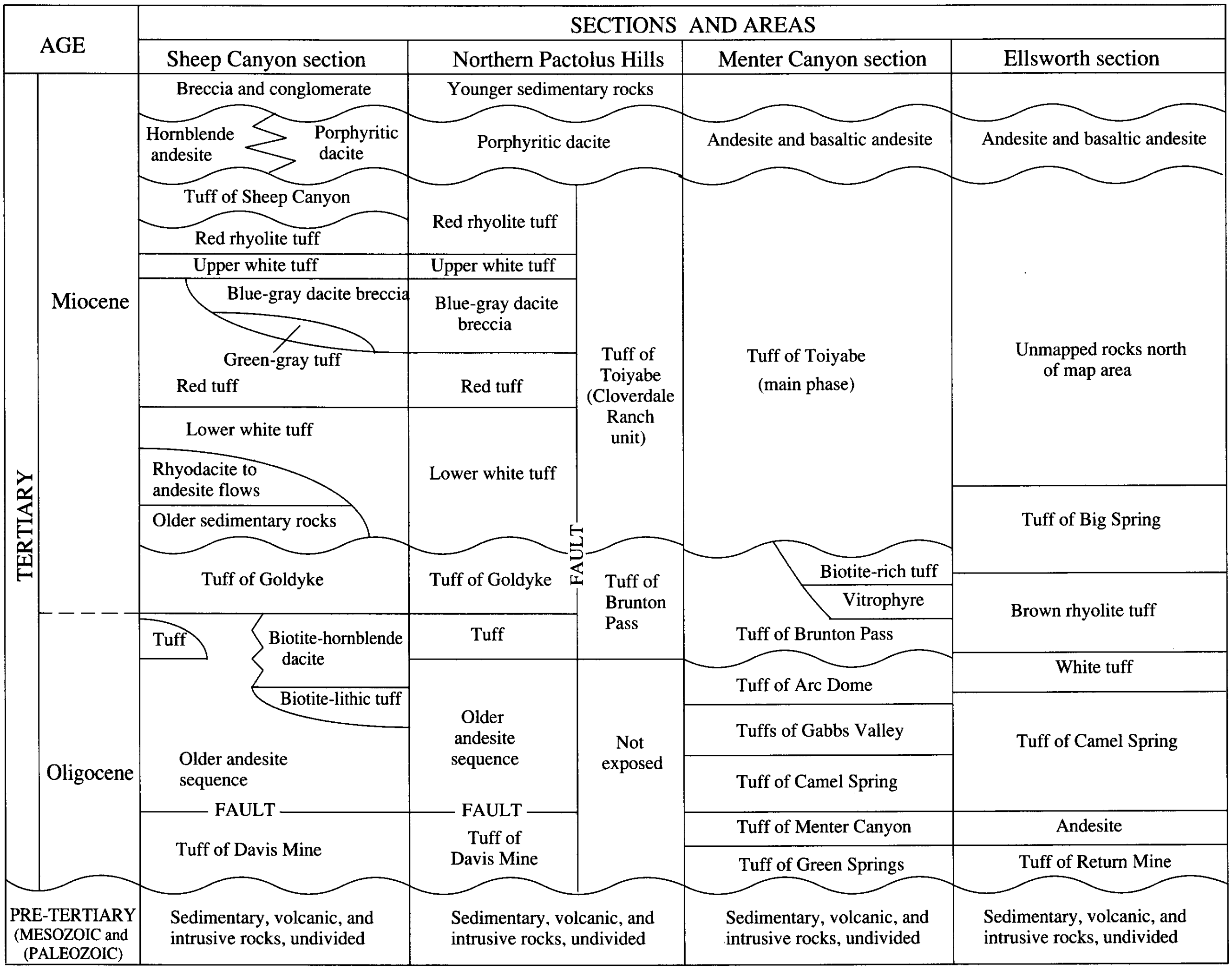


Figure 4. Simplified, composite stratigraphic sections for Tertiary volcanic rocks in Paradise Range and northern Pactolus Hills. In northern Pactolus Hills, parts of both Sheep Canyon and Menter Canyon sections are present and are juxtaposed by high-angle faults. Most contacts between pre-Tertiary and Tertiary rocks are faults, although there also is a significant erosional unconformity as portrayed in this figure. See text, table 3, and John (1988) for discussion of precise ages of units. Placement of Oligocene-Miocene boundary is at 23.7 Ma (Palmer, 1983). See figure 2 for area locations.

generally contain less than 4 percent phenocrysts, which are mostly sanidine (fig. 5; table 2). The thickness of the tuff of Green Springs is uncertain due to faulting but may be as much as 300 m. The precise age of the tuff of Green Springs also is unknown; it is older than the tuff of Gabbs Valley, which is about 26–25 Ma (nos. 22, 23, table 3), but regional K-Ar age data suggest that it probably is no older than about 30 Ma (Armstrong, 1970; McKee and others, 1971; Ekren and others, 1980; Kleinhampl and Ziony, 1985; McKee and John, 1987). The tuff of Green Springs megascopically, petrographically, and chemically resembles the Nine Hill Tuff in the Carson City area (Bingler, 1978; Deino, 1985). However, the apparent age of the tuff of Green Springs (greater than 26–25 Ma) is somewhat inconsistent with recent high precision ^{40}Ar-^{39}Ar age determinations of 25.11±0.017 Ma on the Nine Hill Tuff (Deino, 1989), and possible correlation of these tuffs requires more precise dating of the tuff of Green Springs.

Tuff of Menter Canyon

The tuff of Menter Canyon conformably overlies the tuff of Green Springs in Menter Canyon and consists of two lithologically similar, lithic-rich, high-silica rhyolite ash-flow tuff cooling units. In Menter Canyon the tuff consists of black, lithic-rich, densely welded, crystal-poor vitrophyric ash-flow tuff that grades upward into white, poorly welded, devitrified pumice-rich ash-flow tuff. Lithic contents commonly are 15 to 25 volume

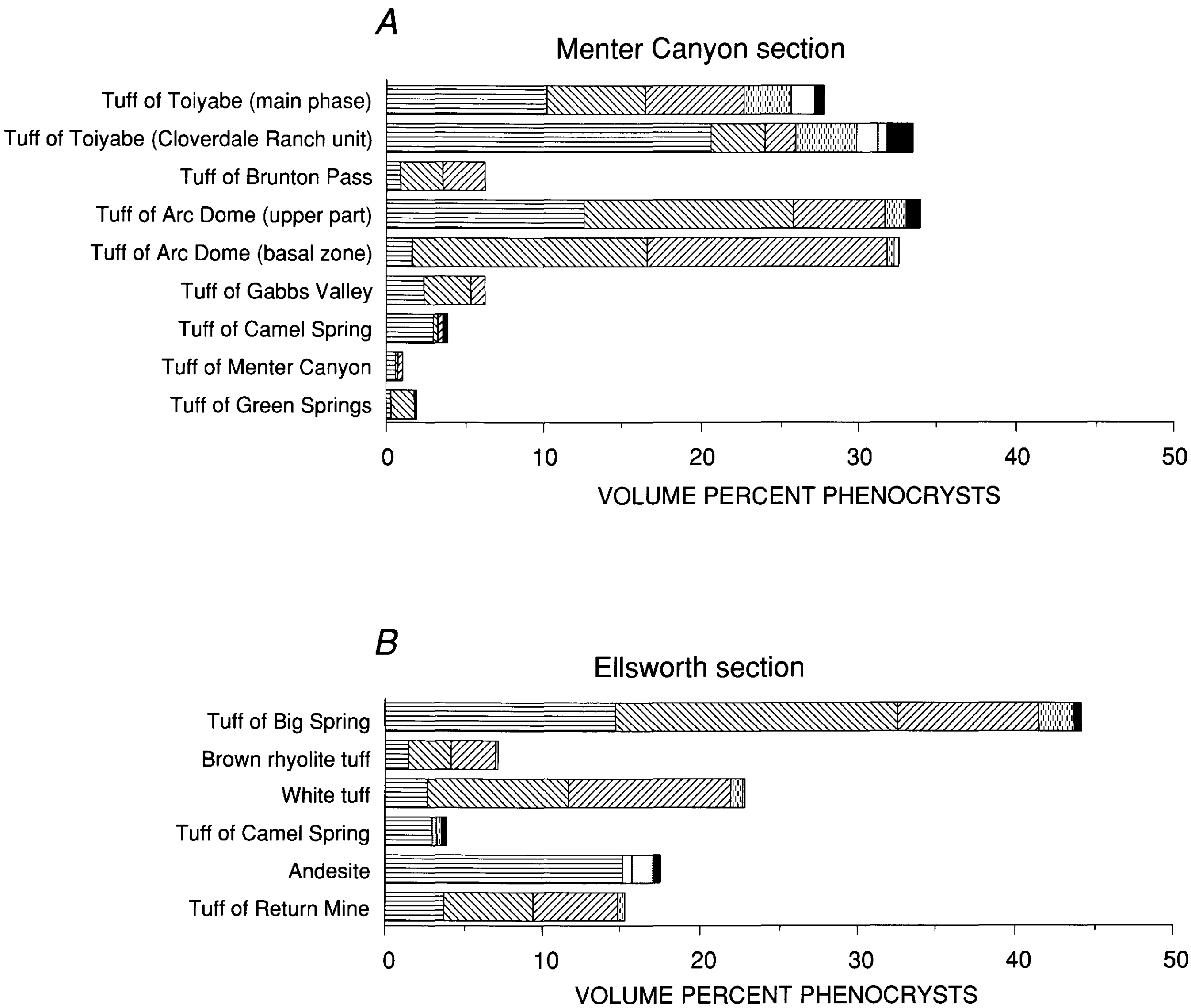


Figure 5. Representative modal compositions for major Tertiary volcanic units in Paradise Range and northern Pactolus Hills. Several modes representing extreme compositions are shown for units with highly variable compositions. Modes are based on point counts of individual thin sections (800–1,200 points per thin section).

percent. Small (≤2 cm), rounded clasts of pink to red rhyolite lava are abundant and characteristic. Other lithic fragments include intermediate lava and granitoid rocks. The tuff generally contains about 1 percent phenocrysts mostly of fine-grained plagioclase (table 2). Outside of Menter Canyon only the densely welded, vitrophyric basal part of this unit has been found. In Menter Canyon this tuff is as much as 200 m thick and is underlain by a thin (<2 m thick), white, aphyric, air-fall tuff that is exposed in road cuts in Menter Canyon. The tuff of Menter Canyon also is present locally on the east side of the Shoshone Mountains, where it has been included as part of the tuff of Union Canyon (Whitebread and others, 1988).

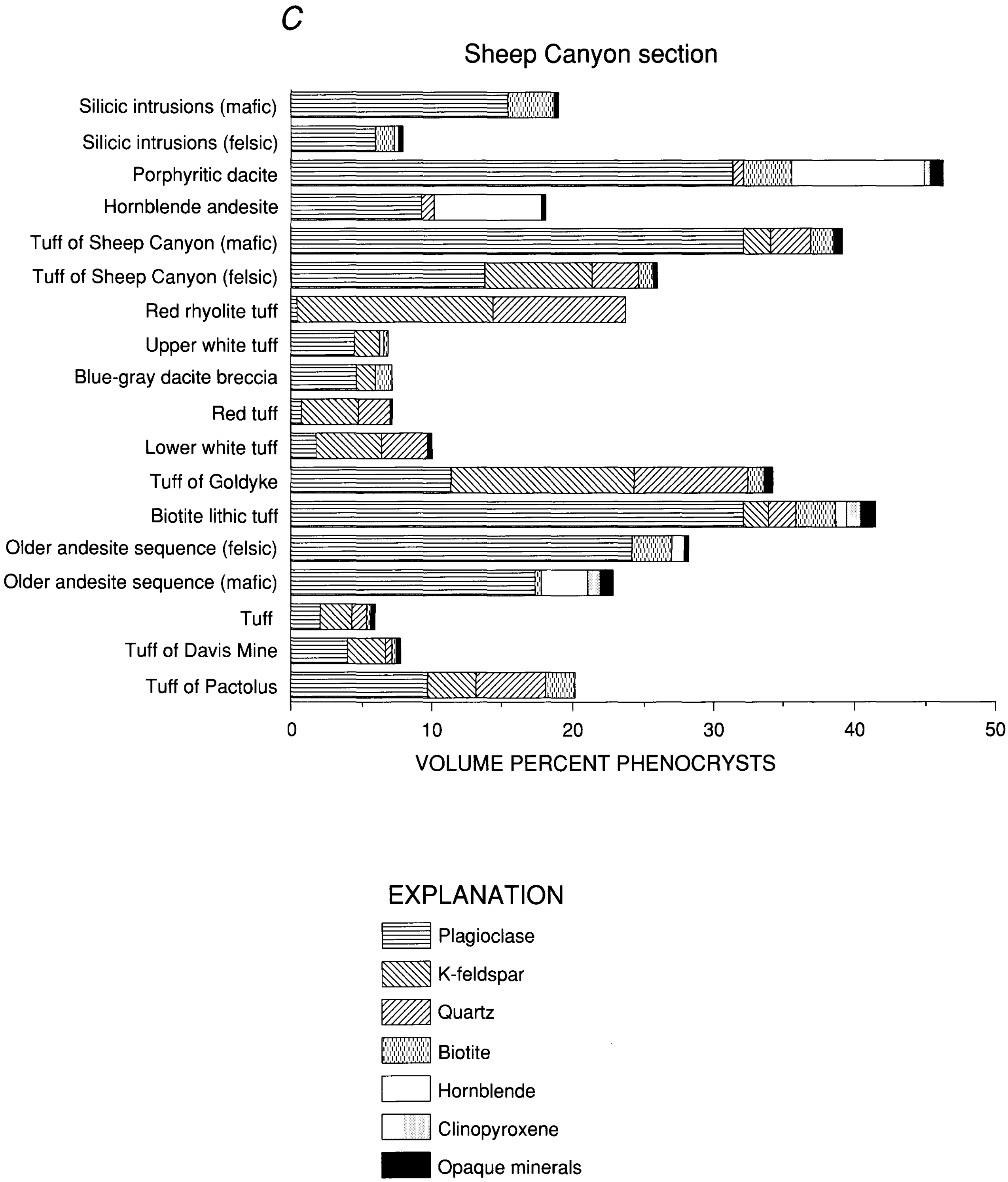


Figure 5. Continued.

Tuff of Camel Spring

The tuff of Camel Spring is a compound cooling unit of red to orange to dark-brown, generally crystal-poor rhyolite ash-flow tuff. It is the most laterally continuous unit on the east side of the Paradise Range and occurs in both the Menter Canyon and Ellsworth sections. In the Menter Canyon section it overlies the tuff of Menter Canyon, whereas in the Ellsworth section it overlies andesitic lavas. In the Menter Canyon section at least two cooling units are present; the basal part of the upper cooling unit contains a thin, black vitrophyric zone. The tuff of Camel Spring varies from nearly aphyric to sparsely porphyritic containing about 10 percent phenocrysts of feldspar and minor quartz (fig. 5; table 2). Feldspar phenocrysts vary from anorthoclase in some samples to mixtures of sanidine and plagioclase in others; anorthoclase appears to be more abundant in the upper cooling unit. Pumice and lithic contents vary from nearly absent to abundant. Most of the tuff is devitrified except for a thin vitrophyric zone at the base of the upper cooling unit. Most of the tuff is densely welded. The tuff of Camel Spring is as much as 250 m thick in Menter Canyon. Whitebread and others (1988) correlated tuffs megascopically similar to the tuff of Camel Spring that are present at a similar stratigraphic horizon in the southern Shoshone Mountains with the tuff of Camel Spring. The tuff of Camel Spring also may be correlative with a thin (15 m) ash-flow tuff exposed in Gabbs Valley and described by Ekren and Byers (1986) as a discontinuous, sporadically exposed, anorthoclase-bearing tuff underlying and mapped as part of the lowest member of the tuff of Gabbs Valley.

Tuff of Gabbs Valley

The tuff of Gabbs Valley was named by Ekren and others (1980) for composite flow, crystal-poor ash-flow tuffs that crop out in the Gabbs Valley and Gillis Ranges and which they inferred had sources in Gabbs Valley. The tuff of Gabbs Valley is correlative with the Bluestone Mine Tuff of Proffett and Proffett (1976) in the Yerington district (Bingler, 1978; Ekren and others, 1980; Deino, 1985), and is possibly correlative with the tuff of Hackett Canyon in the Carson City area (Deino, 1985). The lower part of the tuff of Gabbs Valley also megascopically resembles the Nine Hill Tuff in the Carson City area (Bingler, 1978; Deino, 1985). Chemical and modal data, however, indicate that the Nine Hill Tuff and the tuff of Gabbs Valley are not correlative (Deino, 1985). The ash-flow tuff exposed in the Paradise Range is the lowest of three cooling units of the tuff of Gabbs Valley exposed in Gabbs Valley, where it forms the wallrocks of a fissure vent from which the upper cooling unit of this tuff was erupted (fig. 6; Ekren and Byers, 1976). The lower cooling unit also crops out along the crest and east side of the southern Shoshone Mountains near Union Canyon, where it was included as part of the tuff of Union Canyon by Whitebread and others (1988).

In the Paradise Range, the lower cooling unit of the tuff of Gabbs Valley is a very distinctive black to dark-brown, crystal-poor, pumice- and lithic-rich rhyolitic ash-flow tuff. It contains abundant black, glassy, strongly flattened, banded crystal-poor fiamme as much as 15 cm long and less than 1 cm thick. Many of the pumice bodies show contorting banding apparently resulting from rheomorphic flow. Lithic fragments of flow-banded rhyolite, intermediate lavas, and granitoids also are abundant. The tuff contains about 5 percent phenocrysts consisting of sanidine, plagioclase, quartz, and trace amounts of biotite (fig. 5; table 2). Much of the tuff is vitrophyric. This cooling unit is as much as 350 m thick near Fifteenmile Spring and in Menter Canyon but is absent north of Camel Spring. This tuff appears to conformably overlie the tuff of Camel Spring and conformably underlie the tuff of Arc Dome. The tuff of Gabbs Valley in the Gillis Range has two sanidine K-Ar ages, 25.0 and 26.1 Ma (nos. 22, 23, table 3).

Tuff of Arc Dome

The tuff of Arc Dome is a thick, crystal-rich rhyolite and high-silica rhyolite ash-flow tuff that forms the lower flanks of Sherman Peak along the crest of Paradise Range. This tuff is named for thick exposures of ash-flow tuff underlying Arc Dome in the southern Toiyabe Range (fig. 6; Brem and others, 1991; G.F. Brem, written commun., 1985, 1986). In the Paradise Range, the tuff is a simple cooling unit that is as much as 400 m thick near Sherman Peak.

The tuff of Arc Dome is a devitrified, moderately pumice-rich, densely welded ash-flow tuff. Crystal-rich pumice fragments are strongly flattened and commonly as much as 8 cm long and less than 1 cm thick. The tuff is characterized by abundant, 1 to 3 mm, bipyramidal smoky quartz phenocrysts. Phenocryst contents range from about 30 to 40 volume percent (figs. 5, 7; table 2). Modal analyses indicate that there are large variations in quartz and plagioclase contents, the base being richer in quartz and poorer in plagioclase than the upper parts of the tuff (fig. 7). Sanidine content is fairly constant, forming about 10 to 15 percent of the rock at all stratigraphic levels (fig. 7). Mafic mineral contents average about 1 percent biotite and trace amounts of hornblende, but tend to be slightly greater in the upper parts of the tuff (figs. 5, 7). Allanite is a common accessory mineral. Unlike many compositionally zoned ash-flow tuffs, this tuff shows little vertical variation in total phenocryst content (fig. 7; compare with Lipman and others, 1966;

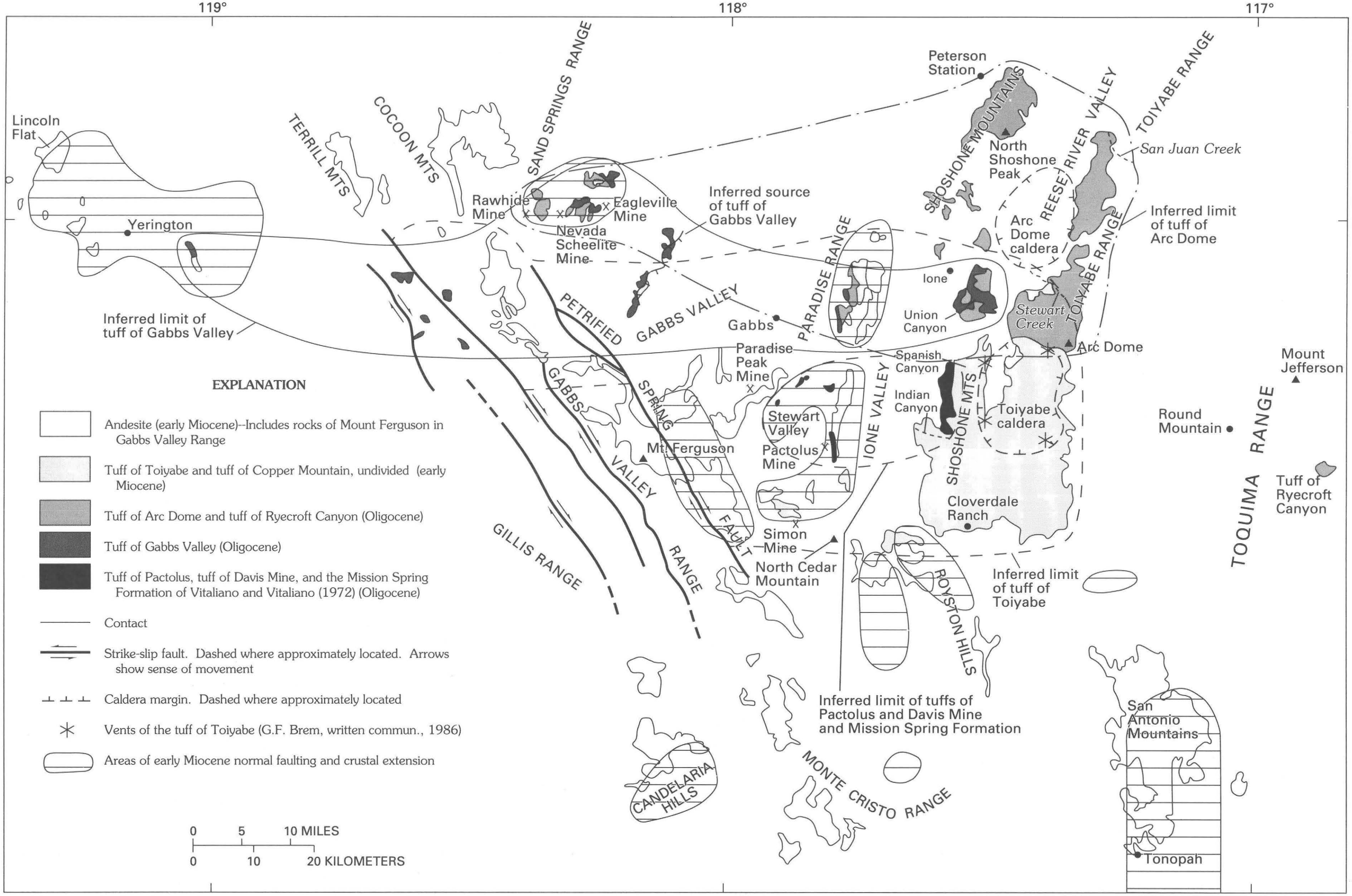


Figure 6. Distribution and inferred maximum extent of regionally extensive ash-flow tuff units present in Paradise Range and northern Pactolus Hills, distribution of younger andesite sequence and age-equivalent (early Miocene) intermediate lavas, and areas of early Miocene (approximately 20 Ma) normal faulting and crustal extension. Shown are inferred sources for tuffs of Davis Mine and Pactolus and the Mission Spring Formation, tuff of Gabbs Valley, tuff of Arc Dome, and tuff of Toiyabe, and major strike-slip faults in Gabbs Valley and Gillis Ranges. Regional distribution of tuffs and early Miocene lavas based on Stewart and others (1982) and references therein, Whitebread (1986 and unpublished mapping), Bonham (1970), Kleinhampl and Ziony (1985), R.F. Hardyman (written commun., 1989), M.L. Sorensen (written commun., 1989), and Deino (1985) (see text). Areas of early Miocene faulting based on John and others (1989b); strike-slip faults from Ekren and others (1980); locations of inferred calderas from Ekren and Byers (1986) and G.F. Brem (written commun., 1986-1987).

Gans and others, 1989). Compositional zoning also is evident in major- and trace-element chemical analyses of devitrified whole-rock samples (table 4); these data indicate that the lower 50 m of the tuff is a high-silica rhyolite (SiO_2=77 wt percent) that abruptly changes upward into rhyolite (SiO_2=73 wt percent). A cooling break has not been observed, and this compositional zoning probably represents compositional zoning in the magma chamber.

The basal part of the tuff of Arc Dome is marked by prominent, strongly flattened, 1- to 5-cm-long, black, glassy, crystal-rich fiamme that form 10 to 20 percent of the tuff; other parts of the the tuff are entirely devitrified. Quartz phenocrysts in the basal part of the tuff are notably darker colored than in other parts of the tuff. Small (≤2 cm) lithic fragments of silicic to intermediate lava and less common granitoid clasts also are abundant near the base of the tuff, and markedly decrease in abundance upward.

A biotite K-Ar age of 24.9±0.6 Ma determined on the tuff of Arc Dome in the Paradise Range (no. 20, table 3) is analytically indistinguishable from a biotite K-Ar age of 24.4±0.4 Ma (recalculated using the new I.U.G.S. constants) determined by Armstrong (1970) on a sample of this tuff collected near Ione in the southern Shoshone Mountains (no. 21, table 3).

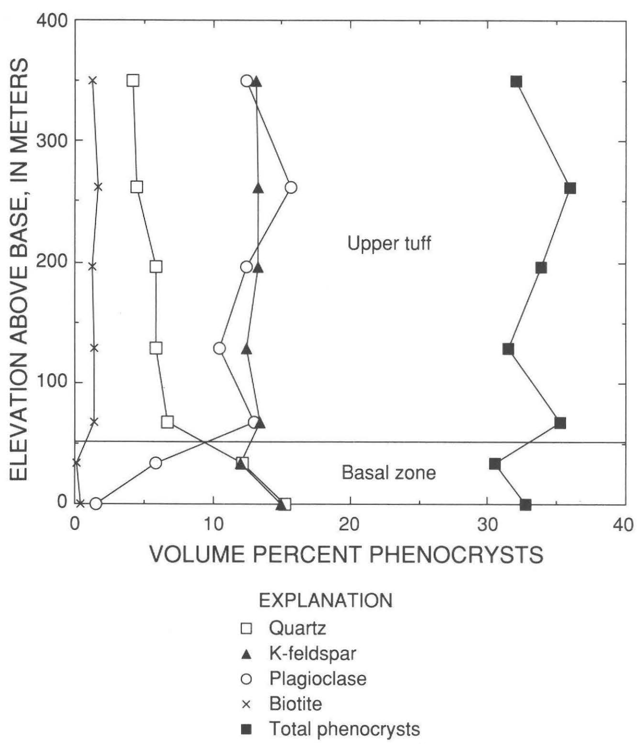


Figure 7. Variations in modal mineralogy of tuff of Arc Dome with increasing elevation above base of tuff. Modes are from thin sections of samples collected in thick section of densely welded tuff about 1 km south of Sherman Peak (fig. 3) on northeast side of Paradise Range.

Tuffs Between the Tuff of Arc Dome and the Tuff of Toiyabe

Three thin ash-flow tuffs locally are present between the tuff of Arc Dome and the tuff of Toiyabe near Brunton Pass on the east side of the Paradise Range. These units are, from oldest to youngest, the tuff of Brunton Pass, an unnamed black, crystal-poor vitrophyre, and an unnamed crystal- and biotite-rich tuff. These tuffs are only present on the east side of the Paradise Range, and the two younger tuffs have aggregate outcrop areas totaling less than 1 km^2. However, the presence of these tuffs indicates that there was a significant erosional hiatus between eruptions of the tuff of Arc Dome and the tuff of Toiyabe and suggests that high-angle normal faulting may have begun on the east side of the Paradise Range between eruptions of these units. Elsewhere on the east side of the Paradise Range and in the southern parts of the Shoshone Mountains and Toiyabe Range, the tuff of Toiyabe lies directly on the tuff of Arc Dome.

The tuff of Brunton Pass is the thickest and most widespread unit between the tuff of Arc Dome and the tuff of Toiyabe. It crops out discontinuously for about 12 km between Brunton Pass and the north end of the Pactolus Hills and is as much as 90 m thick. It is an orange to dark-reddish brown, crystal-poor devitrified high-silica rhyolite ash-flow tuff containing 5 to 10 percent phenocrysts of sanidine and smoky quartz (table 2; fig. 5). The smoky quartz phenocrysts distinguish it from the underlying tuffs of Green Springs and Camel Spring. The tuff of Brunton Pass ranges from poorly to densely welded, probably reflecting variations in original thickness. Pumice and lithic fragments are relatively sparse.

Locally overlying the tuff of Brunton Pass is a black, densely welded vitrophyric tuff containing about 10 percent plagioclase and sanidine phenocrysts and trace amounts of orthopyroxene (table 2). Pumice and lithic fragments are very scarce. The tuff is as much as 60 m thick.

Locally overlying the black vitrophyre is a white, devitrified, densely welded, crystal-rich dacite(?) ash-flow tuff that contains about 25 percent plagioclase and 5 percent biotite phenocrysts (table 2). Quartz and sanidine phenocrysts are nearly absent, in contrast to the tuff of Arc Dome and the tuff of Toiyabe. This tuff contains abundant strongly flattened, crystal-rich pumice fragments as much as 5 cm long. Maximum thickness of this tuff is about 20 m. The biotite tuff possibly is correlative with either the tuff of Sheep Canyon, which is exposed in the southwestern part of the Paradise Range, or with the Cloverdale Ranch unit of the tuff of Toiyabe, which is exposed in the northern Pactolus Hills. The modal mineralogy of the biotite tuff is similar to more mafic parts of the tuff of Sheep Canyon, whereas it lacks small amounts of hornblende and clinopyroxene phenocrysts that are present in the Cloverdale Ranch unit (see below). The inferred age of the biotite tuff would permit correlation to either of these other units.

Tuff of Toiyabe

Ferguson and Cathcart (1954) applied the name "Toiyabe Quartz Latite" to thick sections of crystal-rich ash-flow tuff exposed along the crest and west sides of the southern Toiyabe Range that they erroneously thought were lava flows. Kleinhampl and Ziony (1967, 1985) recognized that these rocks are densely welded ash-flow tuff that is widely distributed in northwestern Nye County, and they provided modern descriptions and K-Ar ages for this tuff. Additional descriptions of crystal-rich tuffs that have previously been correlated with the herein abandoned Toiyabe Quartz Latite in the Paradise Range and Shoshone Mountains were given by Vitaliano (1963), Vitaliano and Vitaliano (1972), and Bonham (1970).

Recent mapping in the Paradise and southern Toiyabe Ranges and in the southern Shoshone Mountains indicates that the many rocks heretofore mapped as the Toiyabe Quartz Latite belong to several different units. As defined by this study of the Paradise Range and mapping of the southern Toiyabe Range (Brem and others, 1985; 1991) and of the southern Shoshone Mountains (Whitebread and others, 1988), the Toiyabe Quartz Latite is here abandoned owing to its previous use as a name for several genetically unrelated ash-flow tuff units, and its rocks are reassigned to several informally named tuff units, namely, the tuffs of Toiyabe, Arc Dome, Big Spring, Camel Spring, and Brunton Pass. In the Paradise Range, most of the rocks heretofore mapped as the Toiyabe Quartz Latite are assigned to the tuffs of Toiyabe and Arc Dome. Compared to the tuff of Arc Dome, the tuff of Toiyabe is notably finer grained, less crystal- and pumice-rich, more mafic, and lacks large bipyramidal smoky quartz phenocrysts (tables 1, 2; fig. 5). Sphene, a characteristic accessory mineral in the tuff of Toiyabe, is absent in the tuff of Arc Dome, and allanite, common in the tuff of Arc Dome, is absent in the tuff of Toiyabe. There also are major chemical differences between these tuffs (compare FeO*, CaO, TiO_2, Rb, Sr, and Ba contents, tables 4 and 5).

On the east side of the Paradise Range, the main phase of the tuff of Toiyabe appears to be a simple cooling unit of pale-lavender-gray, densely welded, devitrified, rhyolitic ash-flow tuff. The tuff contains 20 to 30 percent phenocrysts of fine- to medium-grained plagioclase, sanidine, and quartz in about a 2:1:1 ratio, 1 to 3 percent biotite, and about 1 percent hornblende (fig. 5; table 2). Sphene is a ubiquitous and characteristic accessory mineral that commonly is visible in hand specimen. A 5- to 10-m-thick body of dark gray to black vitrophyre generally is present at the base of the tuff. Small lithic fragments (dominantly intermediate lavas) are concentrated near the base of the tuff and decrease in abundance upward. On the east side of the Paradise Range near Sherman Peak, the tuff of Toiyabe has a minimum thickness of about 400 m. A biotite K-Ar age of 21.4±0.7 Ma was determined on a sample of the tuff collected at Brunton Pass (no. 16, table 3). Other published ages of megascopically identical tuffs from the southern Toiyabe Range and the east side of the southern Shoshone Mountains are 22.0±0.4 and 22.5±0.7 Ma, respectively (nos. 18, 19, table 3).

In the northern Pactolus Hills, a second ash-flow tuff is exposed locally beneath andesite and dacite lavas. This tuff is believed to be equivalent to the lower part of the tuff of Toiyabe and has been informally termed the Cloverdale Ranch unit for exposures in the southern Shoshone Mountains (G.F. Brem, oral commun., 1986). This tuff is a light-lavender-gray, densely welded, crystal-rich low-silica rhyolite. The Cloverdale Ranch unit is more mafic and crystal-rich than other parts of the tuff of Toiyabe and contains as much as 1 percent clinopyroxene, 5 percent biotite, and relatively small amounts of quartz and K-feldspar (figs. 5; tables 2, 5). Sphene is an uncommon accessory mineral. A biotite K-Ar age of 22.9±0.7 Ma determined on a sample collected in the northern Pactolus Hills suggests that the Cloverdale Ranch unit is slightly older than the main part of the tuff of Toiyabe (no. 17, table 3).

Andesite and Basaltic Andesite Flows

Unconformably overlying the tuff of Toiyabe is a thick series of intermediate to mafic lava flows, flow breccia, volcanic debris-flow deposits (lahars), and minor volcaniclastic sedimentary rocks. The lava flows and flow breccias range from aphyric to moderately porphyritic with aphanitic to microcrystalline groundmasses. Most of these rocks are sparsely porphyritic containing fine- to medium-grained phenocrysts of plagioclase, pyroxene, and locally olivine or hornblende in pilotaxitic to hyalopilitic groundmasses. The more mafic flows commonly are vesicular and locally microcrystalline. Two whole-rock chemical analyses suggest that the lavas are basaltic andesite (nos. 1, 2, table 6); unanalyzed lavas north of Ellsworth Canyon probably are hornblende andesite or dacite, judging from their phenocryst mineralogy. Volcaniclastic sedimentary rocks and andesitic lahars commonly occur near the base of this unit along the crest of the range. This unit may be as much as 800 m thick along the crest of the Paradise Range east of Sherman Peak. A whole-rock K-Ar age of 18.9±0.9 Ma was obtained from a basaltic andesite flow near the base of this unit (no. 15, table 3).

Ellsworth Section

The Ellsworth section consists of as many as seven ash-flow tuff units locally intercalated with andesite lava flows and unconformably overlain by andesite lava flows. From bottom to top, units in this section are the tuff of Return Mine, andesite, the tuff of Camel Spring, the white tuff, the brown rhyolite tuff, the tuff of Big Spring, and andesite and basaltic andesite (fig. 4). Two additional ash-flow tuffs, the purple tuff and the purple biotite tuff, and rhyolite lava flows locally crop out, but their ages relative to other units are unknown. Total thickness of the Ellsworth section exceeds 1,300 m. Major features of ash-flow tuff units in this section are summarized in figure 5 and tables 2 and 7.

Tuff of Return Mine

The tuff of Return Mine (fig. 2), the basal unit in the Ellsworth section, is a white to light-green to pink, poorly to moderately welded, devitrified, moderately crystal- and lithic-rich rhyolitic(?) ash-flow tuff. It consists of several ash flows that have variable phenocryst contents ranging from about 10 to 25 percent consisting of smoky quartz, sanidine, plagioclase, and minor biotite (table 2). Subangular fragments of pre-Tertiary rocks and older volcanic rocks as much as 6 cm in diameter are abundant locally, particularly near the mouth of Marble Falls Canyon (fig. 3). This tuff commonly is strongly argillized, and pumice fragments commonly are leached leaving cavities partially filled with yellow and green clay minerals. The tuff of Return Mine is as much as 300 m thick along the range front on the east side of Lodi Valley (fig. 3); elsewhere it is much thinner due to faulting. This tuff crops out north of Camel Spring in the Paradise Range and in the southern Shoshone Mountains near Ione (Whitebread and others, 1988). The precise age of the tuff of Return Mine is unknown, although it probably is between 30 and 26 Ma given the regional age relations and the ages of overlying units.

Andesite Flows

Flows of aphyric to moderately porphyritic, locally vesicular hornblende and pyroxene andesite and dacite(?) lava lie between the tuff of Return Mine and the tuff of Camel Spring north of Camel Spring (fig. 3). The lavas are lavender-gray to reddish gray where relatively fresh, and white, orange-brown, or greenish gray where hydrothermally altered. They contain as much as 30 percent fine- to medium-grained phenocrysts consisting of plagioclase with lesser clinopyroxene or hornblende and local biotite in pilotaxitic groundmasses. Many of these lavas, particularly along the range front on the east side of Lodi Valley, are strongly altered either to argillic or propylitic assemblages. These lavas reach thicknesses of as much as 400 m.

Tuff of Camel Spring

The tuff of Camel Spring crops out between andesite flows and the white tuff in the Ellsworth section. See the Menter Canyon section for a complete description of this tuff. One cooling unit, believed to be the upper cooling unit based on the presence of anorthoclase phenocrysts, was recognized in the Ellsworth section.

White Tuff

The white tuff is a thin (0 to 50 m thick) ash-flow tuff that is discontinuously exposed at the north end of the Paradise Range. It is a moderately welded, devitrified, lithic- and pumice-poor rhyolite tuff that contains about 20 percent phenocrysts consisting of equal amounts of fine-grained quartz and sanidine, subordinate plagioclase, and trace amounts of biotite (fig. 5; table 2). It lies between the tuff of Camel Spring and the brown rhyolite tuff and has been identified only in the northern Paradise Range.

Brown Rhyolite Tuff

The brown rhyolite tuff is a simple cooling unit of light- to dark-brown, densely welded crystal-, lithic-, and pumice-poor high-silica rhyolite ash-flow tuff. It contains less than 10 percent phenocrysts of quartz, sanidine, and plagioclase commonly set in a glassy matrix (fig. 5; table 2). This tuff locally crops out between the white tuff and the tuff of Big Spring at the north end of the Paradise Range and reaches a maximum thickness of about 125 m. McKee and others (1971) reported a sanidine K-Ar age of 23.7±0.7 Ma for this tuff (no. 24, table 3). The brown rhyolite tuff has not been recognized outside of the northern Paradise Range.

Tuff of Big Spring

The tuff of Big Spring is a simple cooling unit of light-gray to bluish-gray, crystal-rich, pumice- and lithic-poor, densely welded, rhyolitic ash-flow tuff. Other authors included it as part of the herein-abandoned Toiyabe Quartz Latite (Vitaliano, 1963; Vitaliano and Vitaliano, 1972; Kleinhampl and Ziony, 1985), but modal and chemical analyses show that it is distinct from the tuff of Toiyabe (table 2; fig. 5). It generally contains 35 to 45 percent medium-grained phenocrysts of sanidine, plagioclase, and clear quartz in about a 3:3:2 ratio and 1 to 2 percent biotite. Most of the tuff is devitrified, although the base of the tuff commonly is vitric. The tuff of Big Springs is the youngest tuff at the north end of the map area. It overlies the brown rhyolite tuff along a contact that commonly appears to be a fault contact. The tuff of Big Spring is younger than the brown rhyolite tuff (approx. 23.5 Ma, see above) and is overlain by hornblende andesite flows that probably are about 19 Ma. The age relation of the tuff of Big Spring to the tuff of Toiyabe is unknown. The tuff of Big Spring is as much as 200 m thick in the Paradise Range. Similar appearing tuffs also are present near Ione in the southern Shoshone Mountains (Whitebread and others, 1988).

Other Units of Uncertain Stratigraphic Position

Small exposures of three additional volcanic units occur north of Ellsworth near the northeast corner of the area mapped. These units are the purple tuff, the purple biotite tuff, and rhyolite lava flows.

The purple tuff crops out about 1.5 km west of Big Spring in two small fault slivers. It is a dark-purple, moderately pumice- and crystal-rich, densely welded, devitrified rhyolitic ash-flow tuff that contains about 15 to 20 percent phenocrysts mostly consisting of quartz and sanidine with subordinate plagioclase and minor biotite (fig. 5; table 2). This tuff is faulted against Mesozoic rocks, andesite flows, and the tuff of Camel Spring and is intruded by a small rhyolite plug. It may be as much as 350 m thick.

The purple biotite tuff is exposed in four small outcrops about 0.5 km southeast of Big Spring, where it lies in depositional(?) contact on Mesozoic rocks. The tuff is purple to dark-red, densely welded, devitrified, crystal-poor, biotite- and pumice-rich rhyolite(?) ash-flow tuff. It contains less than 10 percent phenocrysts consisting of roughly equal quantities of quartz, plagioclase, sanidine, and biotite (fig. 5; table 2). Small lithic fragments, including clasts of Mesozoic greenstone, are common near its base and decrease in abundance upward. The thickness of this tuff is unknown.

Light-gray to red, flow-banded rhyolite lava flows form a small outcrop about 4 km northeast of Ellsworth that is fault-bounded against the tuff of Toiyabe on three sides and covered by alluvium on its other side. The flows are sparsely porphyritic containing 5 to 10 percent phenocrysts of fine- to medium-grained sanidine and quartz crystals in devitrified, locally spherulitic, aphyric groundmasses. The thickness and age of these flows are unknown, but they may be equivalent to rhyolite domes, plugs, flows and breccias described by Kleinhampl and Ziony (1984, 1985) in the Bruner district about 10 km to the northwest.

Sheep Canyon Section

The southwestern part of the Paradise Range and the northern Pactolus Hills are underlain by a thick series of silicic ash-flow tuff and intermediate to silicic lava that constitutes the Sheep Canyon section (fig. 4). This section consists of a thick sequence of intermediate to silicic lava overlain by a thick sequence of silicic ash-flow tuff that locally is intercalated with intermediate lava and volcaniclastic sedimentary rock. Both of these sequences are unconformably overlain by a thick younger sequence of intermediate to silicic lava. John and others (1989b) referred to these three sequences as the older andesite, middle tuff, and younger andesite sequences, respectively (fig. 3). The total thickness of the Sheep Canyon section locally is in excess of 3,500 m. All three extrusive rock sequences are intruded by numerous small rhyolitic domes and dikes that are the same age as the younger andesite sequence. Several additional ash-flow tuff units, which may be older than the older andesite sequence, crop out southeast of Sheep Canyon in the southwestern Paradise Range and in the Pactolus Hills, where they are in fault contact with pre-Tertiary rocks and the older andesite sequence. The sources of all of the tuff units in the Sheep Canyon section are unknown. Major features of ash-flow tuff units in the Sheep Canyon section are summarized in figure 5 and tables 2 and 8.

Tuff of Pactolus

The tuff of Pactolus crops out in the central part of the Pactolus Hills near Pactolus, where it apparently is the oldest exposed Tertiary unit. The tuff of Pactolus may be correlative with the lower part of the Mission Spring Formation of Vitaliano and Vitaliano (1972), which is exposed in the southern Shoshone Mountains (fig. 6; G.F. Brem, oral commun., 1986; Whitebread and others, 1988). In the Pactolus Hills, the tuff of Pactolus appears to be conformably overlain by the tuff of Davis Mine.

The tuff of Pactolus is a white, densely welded, crystal-poor to moderately crystal-rich rhyolite ash-flow tuff. It contains 10 to 25 percent fine- to medium-grained phenocrysts of quartz, plagioclase, potassium feldspar, and biotite (fig. 3; table 2). It is everywhere strongly argillized or silicified. Lithic fragments are uncommon, in contrast to the overlying tuff of Davis Mine. This tuff is as much as 500 m thick near Pactolus but is exposed for only about 4 km along strike. The precise age of the tuff of Pactolus is uncertain, but it may be as old as 34 Ma (see below).

Tuff of Davis Mine

The tuff of Davis Mine is a distinctive, lithic-rich ash-flow tuff that forms prominent exposures near the Davis Mine and Everett Mine in the southwestern Paradise Range and in the Pactolus Hills near Pactolus (figs. 2, 3). It is probably correlative with the upper part of the Mission Spring Formation of Vitaliano and Vitaliano (1972), which is exposed in the southern Shoshone Mountains (fig. 6; G.F. Brem, oral commun., 1986; Whitebread and others, 1988). In the southern Shoshone Mountains and in the Pactolus area, the tuff of Davis Mine is underlain by lithic-poor tuffs (tuff of Pactolus), whereas in the Davis Mine area, the tuff of Davis Mine may be the oldest exposed Tertiary unit.

The tuff of Davis Mine is a dark-green to black to white, densely welded, crystal-poor rhyolite(?) ash-flow tuff. It generally contains about 10 percent phenocrysts consisting of plagioclase and K-feldspar in roughly equal proportions and minor quartz and biotite (fig. 5; table 2). Small (generally <8 cm), rounded lithic fragments of pre-Tertiary rocks (marble, quartzite, argillite, greenstone) and less commonly Tertiary intermediate lavas are abundant and characteristic throughout this tuff. The tuff of Davis Mine is everywhere strongly propylitized or silicified. Propylitized rock contains abundant chlorite, calcite, white mica, and locally, epidote. The tuff of Davis Mine is as much as 600 m thick near the Davis Mine, 600–800 m thick in the northern Pactolus Hills, and 350 m thick near Pactolus.

The precise age of the tuff of Davis Mine is poorly known. In the southwestern Paradise Range, this tuff is everywhere in fault contact with pre-Tertiary rocks and older andesites. Compaction foliation in this tuff strikes north-northeast and locally has steep northwest dips. This orientation is unique relative to other tuff units, which generally strike northwest and have moderate to steep dips to the east. This structural orientation suggests that the tuff of Davis Mine may be older than the other tuffs and may have undergone an episode of faulting and tilting prior to eruption of the other tuffs. This postulated older age also is suggested by an imprecise, four point whole-rock Rb-Sr isochron age of approximately 34 Ma (A.C. Robinson, oral commun., 1988).

Older Andesite Sequence

The older andesite sequence is the most widespread unit in the southwestern Paradise Range and commonly forms the basal Tertiary unit. It is crudely correlative with the older volcanic sequence of Vitaliano and Callaghan (1963) and Vitaliano and Vitaliano (1972) and consists of numerous lava flows and flow breccias that range in composition from andesite to low-silica rhyolite. Thin, laterally discontinuous beds of fine-grained volcaniclastic sandstone and siltstone locally are present, and a thin dacite ash-flow tuff (biotite lithic tuff unit) is interbedded with the lavas in Sheep Canyon. A thicker, rhyolitic ash-flow tuff is interbedded in these lavas west of Goldyke, in the northern Pactolus Hills, and north of the Paradise Peak Mine (tuff unit of John, 1988; see below).

Lava flows in the older andesite sequence range from nearly aphyric (notably near the mouth of Sheep Canyon) to medium-grained porphyritic with as much as 30 to 40 percent phenocrysts (fig. 5). Plagioclase forms the most common phenocryst mineral; less abundant are hornblende, biotite, clinopyroxene, and opaque oxides. Strongly resorbed quartz phenocrysts are rarely present. Many of the more siliceous lavas have well-developed flow banding. Most lavas in this sequence are weakly to strongly propylitically altered and contain abundant secondary calcite, chlorite, white mica, and locally, epidote. These altered rocks characteristically are dark purple to dark green, and a dark-green copper(?) oxide mineral commonly coats joint surfaces.

The thickness and age range of the older andesite sequence are unknown. Most contacts between pre-Tertiary rocks and the older andesites are fault contacts, commonly low-angle normal faults such as the Sheep Canyon fault (fig. 3); possible depositional contacts occur in an area of very poor exposure about 1 km south of the Gold Ledge Mine (figs. 2, 3). Structural attitudes of the older andesites generally are poorly known, although local flow banding in the lavas and bedding in thin sedimentary units suggests that the lavas are moderately to steeply tilted to the northeast similar to the overlying tuffs. Preliminary paleomagnetic studies also indicate that these lavas are steeply tilted (M.R. Hudson, oral commun., 1989; John and Hudson, 1990). The older andesites have a minimum thickness of more than 400 m based on drilling near the Paradise Peak Mine and Davis Mine (fig. 2; R.E. Thomason, oral commun., 1987; John and others, 1989b). Structural attitudes in the older andesites may indicate total thicknesses in excess of several kilometers in the Sheep Canyon area. McKee and John (1987) obtained biotite K-Ar ages of 24.4±0.7 and 25.6±0.8 Ma (nos. 32, 33, table 3) on a dacite flow near the Gold Ledge Mine and on the biotite lithic tuff, respectively, and the ages of the overlying tuffs range from about 24 to 22 Ma (table 3). These data suggest that the older andesite sequence probably ranges in age from about 26 to 24 Ma.

Biotite Lithic Tuff

The biotite lithic tuff forms a distinctive marker unit in the older andesite sequence near the mouth of Sheep Canyon. This tuff is a light-gray to tan, crystal-rich, pumice-poor dacite ash-flow tuff. It is more mafic than other ash-flow tuffs in the Paradise Range, containing 30 to 40 percent plagioclase phenocrysts, 5 to 7 percent biotite phenocrysts, and about 1 percent each hornblende and clinopyroxene phenocrysts (fig. 5). Small (less than 4 cm) subrounded lithic fragments of intermediate lava are abundant in this tuff. The biotite-lithic tuff appears to be conformably interbedded in the older andesites in Sheep Canyon. The tuff pinches out or is faulted out about 2 km south of the mouth of Sheep Canyon (fig. 3). McKee and John (1987) reported a biotite K-Ar age of 25.6±0.8 Ma on this tuff (no. 33, table 3).

Tuff

An unnamed crystal-poor rhyolite tuff (tuff unit of John, 1988; see also John and Kelleher, 1987) crops out in the northern Pactolus Hills, north and northwest of Goldyke, and north of the Paradise Peak Mine (fig. 2). The tuff is gray to reddish-brown to light-blue-gray, generally densely welded, locally lithic- and pumice-rich rhyolite tuff that contains about 5 to 10 percent phenocrysts of plagioclase, sanidine, and quartz and sparse 3- to 5-mm-wide biotite flakes (fig. 5; table 2). Pumice lapilli commonly are weathered out, giving the tuff a vesicular texture. This tuff generally is devitrified and commonly is hydrothermally altered. Northwest of Goldyke, this tuff is interbedded in the older andesites and is overlain by about 20 m of intermediate lavas that are overlain by the tuff of Goldyke; elsewhere it is faulted against the older andesites or pre-Tertiary rocks. These relations suggest that this tuff is about 24 Ma. The tuff unit may be as much as 500 m thick in a poorly exposed area north of the Paradise Peak Mine; elsewhere it generally is between 100 and 300 m thick.

Tuff of Goldyke

The tuff of Goldyke is a distinctive crystal-rich rhyolite ash-flow tuff that is exposed throughout the southwestern Paradise Range and northern Pactolus Hills. It is dark purple to light gray-green to tan, densely welded, devitrified, and locally pumice-rich. It contains 20 to 35 percent phenocrysts of plagioclase, sanidine, quartz, and about 2 percent biotite (fig. 5; table 2). Quartz phenocrysts commonly are strongly resorbed and filled with devitrified glass inclusions, giving them a "wormy" or sieve texture. In the northern Pactolus Hills, this tuff consists of multiple ash flows, although cooling breaks have not been observed. There is a fairly wide range in phenocryst proportions (table 2), but detailed sampling was not done to determine if compositional zoning is present. The maximum exposed thickness of the tuff of Goldyke is about 450 m in the northern Pactolus Hills; elsewhere it is much thinner (≤150 m) due to faulting and (or) a general westward thinning of the tuff. The tuff of Goldyke has biotite K-Ar ages of 23.6±0.7 and 23.0±0.9 Ma (nos. 30, 31, table 3).

Rocks Between the Tuff of Goldyke and the Lower White Tuff

Discontinuous exposures of volcaniclastic and epiclastic sedimentary rocks and intermediate lavas locally crop out between the tuff of Goldyke and the overlying lower white tuff unit. The sedimentary rocks (older sedimentary rocks unit of John, 1988) consist of buff to light-mustard-yellow, thin-bedded shale, sandstone, and fine-grained conglomerate. These sedimentary rocks primarily crop out at the north end of the ridge northwest of the Paradise Peak Mine (Newmans Ridge, fig. 3) and near the Poleline Road. They have a maximum exposed thickness of about 30 m.

Locally overlying the sedimentary rocks are a thin series of medium-grained porphyritic biotite-hornblende andesite and dacite lava flows (rhyodacite to andesite unit of John, 1988). The flows are dark-gray to black, devitrified, medium- to coarse-grained porphyries containing 20 to 35 percent phenocrysts consisting of plagioclase with lesser fine-grained hornblende and biotite in microcrystalline to devitrified aphyric groundmasses. The flows reach a maximum thickness of about 30 m at the north end of Newmans Ridge.

Lower White Tuff

The lower white tuff is a crystal-poor rhyolite tuff exposed throughout the southwestern Paradise Range and northern Pactolus Hills; the unit is particularly thick and well exposed just north and west of the Paradise Peak Mine, where it forms most of Newmans Ridge (fig. 3). The lower white tuff is gray to white to reddish brown where devitrified and black to green-gray where vitrophyric. It generally is pumice-rich, lithic-poor, densely welded near its base, and poorly welded near its top. A locally lithic-rich vitrophyric zone 5 to 20 m thick commonly is present near the base of this tuff. Elsewhere, the tuff is devitrified and commonly has undergone vapor-phase alteration. Chalcedony veinlets commonly cut the tuff in the southwestern Paradise Range. The tuff contains about 10 percent medium-grained phenocrysts consisting of roughly equal quantities of quartz, locally iridescent sanidine, and plagioclase, and less than 1 percent biotite (fig. 5; table 2). Allanite is a common accessory mineral. The lower white tuff is as much as 250 m thick in the northern Pactolus Hills and may be somewhat thicker on Newmans Ridge. John and others (1989b) and McKee and John (1987) reported sanidine K-Ar ages of 22.3±0.7, 21.8±0.7, and 25.1±1.0 Ma on this tuff (nos. 28, 29, table 3).

Red Tuff

The red tuff is a prominent marker unit that is exposed throughout the southern Paradise Range and northern Pactolus Hills. In the northern Pactolus Hills the red tuff locally is separated from the underlying lower white tuff by about 5 m of medium- to coarse-grained epiclastic sandstone. The red tuff is a dark-red to lavender-gray, devitrified, densely welded, crystal-poor, generally pumice-rich rhyolite ash-flow tuff. It contains 1 to 7 percent phenocrysts of clear quartz, sanidine, and minor plagioclase (fig. 5; table 2). Pumice lapilli are strongly flattened (commonly 5 to 8 cm long and less than 5 mm thick) and locally show rheomorphic flow textures. The tuff locally contains white spherulites as much as 1 cm in diameter. The red tuff is more brittle than most other rocks and commonly is pervasively microbrecciated by faulting and partially silicified. This tuff commonly weathers into small chips and plates. The red tuff is as much as 150 m thick.

Gray-Green Tuff

The gray-green tuff is a thin ash-flow tuff unit that is very locally exposed between the red tuff and the blue-gray dacite breccia in the southwestern Paradise Range and near Goldyke. It is a white to light-green, devitrified crystal-poor, locally pumice-rich rhyolite(?) tuff that contains about 5 to 10 percent phenocrysts of quartz and plagioclase (fig. 5; table 2). This tuff generally is weakly to strongly argillically altered. It is as much as 50 m thick.

Blue-Gray Dacite Breccia

The blue-gray dacite breccia unit is a series of sparsely porphyritic to aphyric dacite and andesite lava flows and flow breccias that are present throughout most of the southwestern Paradise Range and northern Pactolus Hills. The most distinctive rocks in the unit are dark-blue-gray, finely brecciated dacite flow breccias that contain about 5 percent fine-grained phenocrysts of plagioclase, K-feldspar, and biotite in pilotaxitic groundmasses (fig. 5). The flow breccias locally are overlain by dark-gray to black, generally aphyric andesite flows. The total thickness of the unit is as much as 225 m in the southwestern Paradise Range and northern Pactolus Hills, but it pinches out along strike near the mouth of Sheep Canyon.

Upper White Tuff

The upper white tuff unit consists of three thin cooling units of crystal-poor ash-flow tuff that are present throughout most of the southwestern Paradise Range and northern Pactolus Hills. The lowest cooling unit has a prominent, greenish-black, lithic-rich basal vitrophyre that grades upward into devitrified, light-green-gray to purple, densely welded tuff containing about 5 percent phenocrysts of plagioclase and sanidine and trace amounts of biotite (table 2). The middle cooling unit is a devitrified, light-purple, densely welded, aphyric to sparsely porphyritic, pumice-poor ash-flow tuff containing less than 5 percent plagioclase phenocrysts. The upper part of the middle cooling unit commonly contains abundant white spherulites as much as 1 cm in diameter. The upper cooling unit is a white to pale green, unwelded to moderately welded, devitrified crystal-poor, locally lithic-rich tuff. The total thickness of these tuffs is as much as 150 m.

Red Rhyolite Tuff

The red rhyolite tuff consists of densely welded rhyolite ash-flow tuff that locally is overlain by dark-red epiclastic sandstone. The tuff is brick-red to light lavender-gray, devitrified, lithic- and pumice-poor, and contains 20 to 30 percent fine- to medium-grained phenocrysts of locally iridescent sanidine and bipyramidal smoky quartz (fig. 5; table 2). The tuff locally is overlain by as much as 10 m of irregularly crossbedded, fine- to medium-grained sandstone containing numerous coarser-grained crystals of sanidine and smoky quartz apparently derived from the underlying tuff. The total thickness of this unit is as much as 90 m, but thickness changes rapidly along strike, and this unit pinches out in many places. McKee and John (1987) reported a sanidine K-Ar age of 23.2±0.7 Ma on a sample of densely welded tuff (no. 24, table 3).

Tuff of Sheep Canyon

The tuff of Sheep Canyon forms the thickest and most complex ash-flow tuff unit in the southwestern Paradise Range. It is a compound ash-flow tuff consisting of as many as four cooling units, although the top and bottom cooling units commonly are absent. This tuff is white to light-pink to lavender-gray, crystal- and pumice-rich, devitrified, moderately to densely welded low-silica rhyolite and high-silica dacite and trachydacite tuff and lapilli tuff that contains 15 to 45 percent phenocrysts (average about 30 percent) consisting of medium-grained plagioclase, lesser quartz and sanidine, and 1 to 6 percent biotite (table 2; figs. 5, 8). There are notable vertical variations in modal mineralogy. The third cooling unit shows the greatest variability (fig. 8); within this cooling unit, plagioclase phenocrysts increase from about 20 to 30 volume percent from the base to the top of the unit, whereas the percentages of other phenocryst phases remain nearly constant or slightly decrease upward. The tuff characteristically contains abundant, strongly flattened, crystal-rich pumice fragments as much as 25 cm long. The lowest cooling unit locally is separated from the upper cooling units by about 10 to 15 m of fine- to coarse-grained epiclastic sandstone and pebble conglomerate. A thin airfall tuff zone is present locally at the base of the second cooling unit above the sedimentary rocks. The top of the second cooling unit commonly has undergone strong vapor-phase alteration and has distinctive gas escape structures. The tuff of Sheep Canyon reaches a maximum thickness of about 600 m but is exposed only for about 7 km along strike in the southwestern Paradise Range. McKee and John (1987) reported biotite K-Ar ages of 23.2±0.7 and 24.1±0.7 Ma on this tuff (nos. 25, 26, table 3).

Younger Andesite Sequence

Thick piles of intermediate to silicic lava flows and small intrusions unconformably overlie and intrude the ash-flow tuffs and the older andesites in the southwestern Paradise Range and in the northern Pactolus Hills. These rocks are part of a large early Miocene lava field that extends from the Gabbs Valley Range to the east side of the Paradise Range (fig. 6). The younger andesite

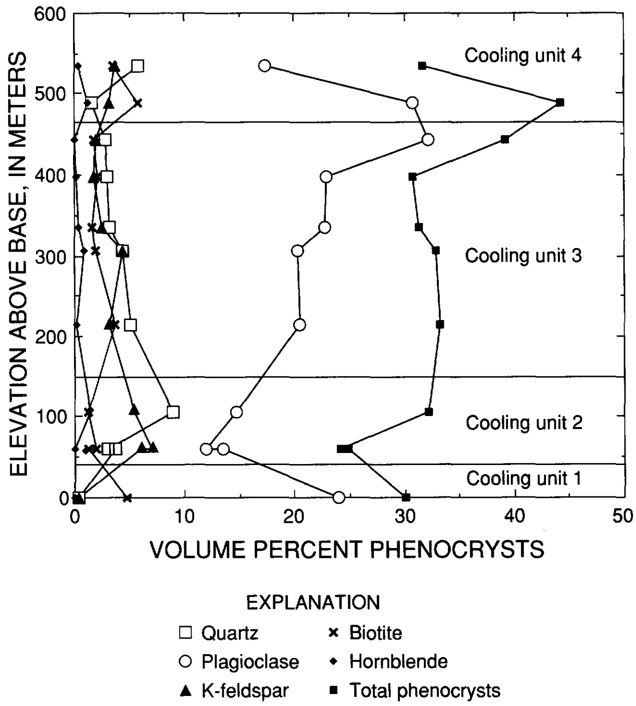


Figure 8. Variations in modal mineralogy of tuff of Sheep Canyon with increasing elevation above exposed base of tuff. Modes are from thin sections of samples collected in a traverse across thick section of densely welded tuff that contains parts of four cooling units. Section is located about 2 km southwest of Sheep Canyon (figs. 2 and 3) in SE¼ sec. 33 and SW¼ sec. 34, T.11 N., R. 36 E.

sequence is equivalent, in part, to the rocks of Mount Ferguson of Ekren and others (1980) and to the andesite and basaltic andesite unit on the east side of the Paradise Range. John (1988) and John and others (1989b) separated these younger lavas into two map units, hornblende andesite and porphyritic dacite units (figs. 4, 5). Many individual lava flows are present within each of these units. Dikes and small intrusions of hornblende andesite, that probably are feeders for the lavas, locally are present in Sheep Canyon. Small silicic intrusions and flow domes, that probably are silicic differentiates of the lavas based on chemical data and age equivalence, are common and intrude and overlie both the older rocks and the younger lavas.

Hornblende Andesite

Fine-grained porphyritic hornblende andesite lava flows crop out along the main part of the southwestern Paradise Range for about 6 km along strike. These unconformably overlie the tuff of Sheep Canyon, and a thin paleosol containing rounded granitic boulders is present locally along this contact. The lava flows are light greenish gray to black, commonly platy-weathering, and generally contain 5 to 20 percent fine- to medium-grained phenocrysts of acicular hornblende and plagioclase and sparse quartz xenocrysts in pilotaxitic groundmasses (fig. 5). Clinopyroxene locally is present as a groundmass phase. Thin beds of volcaniclastic sandstone and shale locally are interbedded within the lavas. This unit may be as much as 750 m thick in Sheep Canyon (John, 1988). Several dikes and small intrusions of fine-grained andesite that locally grade into the hornblende andesite lavas are present in the Sheep Canyon area and are interpreted as feeders for the lavas (John, 1988). John and others (1989b) reported a whole-rock K-Ar age of 20.1±0.6 Ma on a lava flow collected near the base of this unit (no. 14, table 3).

Porphyritic Dacite

The porphyritic dacite unit consists of numerous andesite to dacite lava flows, flow breccia, volcanic debris-flow deposits, and minor fine-grained volcaniclastic sedimentary rocks and block-and-ash flows. Several small intrusive plugs also have been identified about 1 km southwest of the Paradise Peak Mine (R.E. Thomason, oral commun., 1987). The most abundant rocks in the southwestern Paradise Range are gray to black to red, porphyritic lava flows and flow breccias that contain abundant medium- to coarse-grained phenocrysts of plagioclase, hornblende, and biotite or clinopyroxene in fine-grained to aphyric, pilotaxitic to hyalopilitic groundmasses. Plagioclase phenocrysts commonly are tabular and as much as 1 cm long. Biotite commonly forms coarse-grained books several millimeters thick. These porphyritic flows locally are overlain by black, sparsely porphyritic to aphyric andesite and dacite flows. In the northern Pactolus Hills, the basal flows in this sequence commonly are aphyric to sparsely porphyritic andesite with a trachytic groundmass that are overlain by porphyritic hornblende andesite and biotite-hornblende dacite lava flows and flow breccia.

Sections of the porphyritic dacite unit are best exposed in Finger Rock Wash about 8 km southwest of the Paradise Peak Mine (fig. 3). Here these lavas were mapped as the rocks of Mount Ferguson by Ekren and Byers (1985) and reach thicknesses of more than 500 m. These lavas thin to the northeast and, based on subsurface drilling, seldom exceed thicknesses of more than 200 m in the vicinity of the Paradise Peak Mine. In the northern Pactolus Hills, the porphyritic dacite unit may be as much as 400 m thick (John, 1988). West of the Paradise Range, the rocks of Mount Ferguson may reach thicknesses in excess of 2,000 m in the Gabbs Valley Range (Ekren and Byers, 1985). McKee and John (1987) and John and others (1989b) reported 11 K-Ar ages that range from 19.3 to 15.5 Ma on biotite, hornblende, and whole-rock samples of these lavas (nos. 5–13, table 3). The wide range in ages is believed to be real as it is similar to the range in ages obtained by Ekren and others (1980) on the rocks of Mount Ferguson (also see John and others, 1989b).

Silicic Dikes and Flow Domes

Small rhyolite dikes and flow domes are abundant in the Sheep Canyon area and in the northern Pactolus Hills, and a large rhyolite flow dome forms the ridge just west of the old workings at Goldyke (fig. 3). Three different compositional types of rhyolite are recognized based on phenocryst content: (1) biotite rhyolite, (2) quartz rhyolite, and (3) quartz-biotite-feldspar low-silica rhyolite. Biotite rhyolite commonly contains about 2 to 10 percent fine- to medium-grained phenocrysts of biotite with lesser plagioclase, K-feldspar, and quartz in cryptocrystalline groundmasses. Quartz rhyolite contains sparse, fine- to medium-grained, rounded quartz phenocrysts in aphanitic to cryptocrystalline groundmasses. The low-silica rhyolite contains about 10 percent fine- to medium-grained phenocrysts of plagioclase, biotite, rounded quartz, and local hornblende in cryptocrystalline groundmasses. Most intrusions are devitrified, although several glassy dikes and domes are present in the northern Pactolus Hills. Many of these rocks are strongly flow banded. Limited chemical analyses and K-Ar dating suggest that most of these rhyolites are silicic differentiates of the younger andesite sequence. McKee and John (1987) and John and others (1989b) reported three biotite K-Ar ages of 16.2±0.5, 16.3±0.5, and 19.2±0.6 Ma on dikes from the Sheep Canyon area (nos. 2–4, table 3).

Breccia and Conglomerate in the Southwestern Paradise Range

Poorly exposed, heterogeneous breccia and coarse-grained epiclastic sedimentary rocks cover about 4 square kilometers near Willow Spring in the southwestern Paradise Range (fig. 3). Breccia consists of a heterogeneous mixture of lithic-rich tuff breccia, rhyolitic flow breccia, blue-gray dacite flow breccia, coarse sedimentary breccia, and large (several hundred meters) blocks of the lower white tuff and blue-gray dacite breccia units. Clasts within sedimentary breccias are as much as several meters in diameter and include pre-Tertiary rocks, the older andesite, the blue-gray dacite breccia, the lower white, red, and red rhyolite tuffs, and several unidentified volcanic units. Breccia ranges from clast- to matrix-supported, is poorly bedded and sorted, and has a sand-sized matrix of volcanic debris. Beds of medium- to coarse-grained sandstone and conglomerate locally are interstratified(?) within the breccia. Blocks of chalcedonic sinter several meters in diameter also are locally present near the east edge of the breccia. Many breccia and conglomerate beds near the east edge of the exposures are silicified and locally heavily iron stained. Disseminated pyrite locally is present in the silicified rocks.

The breccia unit appears to unconformably overlie the older andesite unit and is faulted against pre-Tertiary rocks. Bedding generally dips at small to moderate angles into a major northeast-trending fault that truncates the Sheep Canyon detachment fault (fig. 3). The breccias cover an area about 1.5 by 3 km and are elongated parallel to this northeast-trending fault. Breccia fragments may slightly coarsen to the northeast. Breccia and associated sedimentary rocks are at least 250 m thick near their southwest end and probably thin to the north. The distribution, orientation, and lithologic characteristics of the breccia and interbedded conglomerate suggest that they formed by lithification of landslide debris and epiclastic sediments shed off the northeast-trending fault into a small basin or half-graben. The age of this fault is unknown, although it cuts the Sheep Canyon fault, which is younger than 16 Ma (John, 1988; John and others, 1989b).

Sedimentary Rocks of Stewart Valley

Thick sections of fine- to coarse-grained fluvial, lacustrine, and minor volcaniclastic sedimentary rocks are present in Stewart Valley between the southwest end of the Paradise Range and the north side of Cedar Mountain and from the Pactolus Hills on the east to the Gabbs Valley Range on the west (fig. 6). These rocks were deposited in a middle Miocene continental basin and subsequently were faulted, uplifted, and locally folded (Molinari, 1984). These rocks range in age from 15 to 11 Ma based on K-Ar dating of andesite flows that interfinger with the base of the sedimentary section, tuffs that are interbedded with the upper part of the section, and andesite lavas that overlie the sedimentary section (Evernden and others, 1964; Morton and others, 1977; Molinari, 1984; John and others, 1989b). Detailed descriptions of these rocks are given by Molinari (1984) and Ekren and Byers (1985, 1986).

Only small exposures of the sedimentary rocks in Stewart Valley are present in the area of this report. They consist of white, finely laminated siltstone, sandstone, and minor pebble conglomerate cropping out in the northern Pactolus Hills that John (1988) and John and Kelleher (1987) correlated with more extensive exposures of sedimentary rocks in Stewart Valley (younger sedimentary rocks unit of John and Kelleher, 1987). In the northern Pactolus Hills, the sedimentary rocks unconformably overlie ash-flow tuff units of the Sheep Canyon section and the older andesite unit and locally bury faults including low-angle normal faults that separate the older andesite unit from tuffs of the Sheep Canyon section. The sedimentary rocks appear to be interstratified with undated andesite and basaltic andesite flows that overlie the porphyritic dacite unit in the southern Pactolus Hills (John and Kelleher, 1987).

Andesite of Stewart Valley

The andesite of Stewart Valley locally overlies the sedimentary rocks of Stewart Valley, the porphyritic dacite unit, and older tuff units in the central and southern parts of the Pactolus Hills, at the north end of Stewart Valley, and on the southeast side of Finger Rock Wash. The lavas consist of black, aphyric to sparsely porphyritic andesite lava flows and flow breccias that contain 1 to 20 percent fine- to medium-grained phenocrysts of plagioclase, clinopyroxene, and olivine or hornblende set in pilotaxitic to hyalopilitic groundmasses. The flows in Finger Rock Wash previously were called latite by Ekren and Byers (1986) and John and others (1989b), but chemical analyses indicate that these rocks are normal calc-alkaline andesites. John and others (1989b) reported a whole-rock K-Ar age of 12.1±0.3 Ma (no. 1, table 3) for a hornblende andesite flow in Finger Rock Wash. The lavas in the Pactolus Hills and at the north end of Cedar Mountain are undated but probably younger than 11 Ma based on the age of the underlying sedimentary rocks. The lavas have a minimum thickness of about 100 m in the southern Pactolus Hills and are about 50 m thick in Finger Rock Wash. They are the youngest volcanic rocks exposed in the region.

REGIONAL DISTRIBUTION, SOURCES, AND VOLUMES OF MAJOR ASH-FLOW TUFF SHEETS

Five major ash-flow tuff units present in the Paradise Range and northern Pactolus Hills are widely distributed in adjacent ranges and have known or inferred sources outside of the Paradise Range. They are the tuffs of Pactolus and Davis Mine, both correlative with the Mission Spring Formation of Vitaliano and Vitaliano (1972), and the tuffs of Gabbs Valley, Arc Dome, and Toiyabe (fig. 6). A sixth unit, the tuff of Green Springs, may correlate with the Nine Hill Tuff, which is widely exposed in western Nevada and eastern California (Deino, 1985; Best and others, 1989b). Other ash-flow tuff units, such as the tuffs of Return Mine, Big Spring, Menter Canyon, and Camel Spring, are present locally in the southern Shoshone Mountains (Whitebread and others, 1988), but their complete extent is poorly known and therefore not discussed. Other ash-flow tuff units in the Paradise Range were not identified in adjacent ranges, and their sources remain unknown.

Volumes of regionally extensive ash-flow tuff units are estimated on the basis of their present distributions and thicknesses (table 9). These estimates are subject to large uncertainties due to several factors including amount of post-eruption crustal extension, large variations in thicknesses between intracaldera and extracaldera facies, effects of predeposition topography on distribution of the tuffs, relatively few stratigraphic sections where thicknesses of individual tuff units have been accurately measured, and probable erosion of poorly welded parts of these tuffs. Miocene and younger crustal extension is the largest source of uncertainty in these estimates. The amount of extension varies significantly across the area where these tuffs are exposed, probably ranging from less than 20 percent in the southern Toiyabe Range and southern Shoshone Mountains to as much as 200 percent in the Yerington district (Proffett, 1977; Stewart, 1978). Volume estimates in table 9 probably are minimum estimates, because the actual amount of extension may be less than that used in the calculations. Because of this uncertainty, volume estimates probably are no better than ±50 percent.

Tuffs of Pactolus and Davis Mine and the Mission Spring Formation

The tuffs of Pactolus and Davis Mine and the correlative Mission Spring Formation are exposed in the southern Paradise Range, Pactolus Hills, and southern Shoshone Mountains (fig. 6). Thick sections of the tuff of Davis Mine are exposed in the southwestern Paradise

Range and in northern and central Pactolus Hills. In the Pactolus Hills, the lithic-rich tuff of Davis Mine is underlain by the lithologically similar but lithic-poor tuff of Pactolus. This same tuff sequence also is exposed in the southern Shoshone Mountains between Spanish and Indian Canyons (fig. 6). The tuff sequence in the Shoshone Mountains was named the Mission Spring Formation by Vitaliano and Vitaliano (1972; also see Whitebread and others, 1988) and includes numerous altered rhyolite and rhyodacite lava flows. Based on mapping by Whitebread and others (1988), the Mission Spring Formation may be as much as 1,100 m thick in the southern Shoshone Mountains, whereas the combined thickness of the tuffs of Pactolus and Davis Mine are no more than 850 m in the central Pactolus Hills and 600 m in the vicinity of the Davis Mine in the southwestern Paradise Range (fig. 6). Increasing thickness and the presence of abundant silicic lava flows in the southern Shoshone Mountains suggest that these tuffs had a source in or near the southern Shoshone Mountains, although existing mapping does not allow a more precise location of the source.

The Mission Spring Formation and the tuffs of Pactolus and Davis Mine presently are exposed over an area covering about 475 km^2. Assuming an average thickness of 800 m and an average of 50 percent posteruption extension, the approximate volume of these tuffs is 250 km^3. This is a conservative estimate, because average extension may have been less than 50 percent and the possibility that these tuffs continue east of the Shoshone Mountains beneath younger volcanic rocks is ignored.

Tuff of Gabbs Valley

The tuff of Gabbs Valley is irregularly exposed in an east-west belt approximately 140 km long and 15–30 km wide (fig. 6), based on geochemical data for the Bluestone Mine Tuff and the tuff of Gabbs Valley contained in Deino (1985) to outline the west limit of the tuff of Gabbs Valley, and ignoring exposures of the correlative(?), but poorly known, tuff of Hackett Canyon in the Virginia Range. In the Gabbs Valley Range, the tuff of Gabbs Valley consists of three cooling units of densely welded rhyolitic ash-flow tuff with a maximum exposed thickness of 630 m (Ekren and others, 1980; Ekren and Byers, 1986). On the east side of the Paradise Range and in the southern Shoshone Mountains, only the lowest cooling unit is exposed. Here, the tuff is as much as 350 m thick. At least two cooling units of the tuff of Gabbs Valley are present northwest of Gabbs Valley at the south end of the Sand Springs Range near Scheelite, where the tuff may be several hundred meters thick (fig. 6). On the east side of the Yerington district, exposures of the Bluestone Mine Tuff tentatively correlated with the tuff of Gabbs Valley are as much as 300 m thick. Assuming an average thickness of 350 m and an average of 100 percent extension, the volume of tuff of Gabbs Valley is approximately 420 km^3. This estimate is conservative, because the thickness commonly is greater than 350 m and the average amount of extension may be considerably less than 100 percent.

Ekren and Byers (1976) and Ekren and others (1980) postulated that the tuff of Gabbs Valley was erupted from a volcanic center located in Gabbs Valley and the southern Monte Cristo Range that is near the approximate center of the tuff of Gabbs Valley (fig. 6). Ekren and Byers (1976) described a fissure vent from which the upper cooling unit of these tuffs was erupted, and Ekren and Byers (1986) showed part of an inferred cauldron margin at the northern end of Gabbs Valley (fig. 6). The total thickness of the tuff of Gabbs Valley also is greatest near this inferred cauldron. Thus, although a well-preserved caldera is not present, it is probable that the source of the tuff of Gabbs Valley is in Gabbs Valley.

Tuff of Arc Dome

The tuff of Arc Dome is widely exposed in the Paradise Range, the southern Shoshone Mountains, the southern Toiyabe Range, the southern Sand Springs Range, and possibly on the east side of the Toquima Range (fig. 6). Ignoring small outcrops of tuff on the east side of the Toquima Range that are possibly correlative, the tuff of Arc Dome presently is exposed over an area covering about 3,350 km^2. In the Paradise Range, the tuff of Arc Dome crops out for about 15 km between Ellsworth Canyon on the north and the pediment surface south of Brunton Pass (fig. 3) on the south and has a minimum thickness of 400 m. In the Shoshone Mountains, the tuff of Arc Dome crops out discontinuously from near Peterson Station on old U.S. Highway 50 to Union Canyon about 40 km to the south and has a minimum thickness of about 450 m near North Shoshone Peak (Bonham, 1970). In the Toiyabe Range, the tuff of Arc Dome is exposed for about 35 km between the mouth of San Juan Creek and Arc Dome, where it may be more than 1 km thick. On the east side of the Toquima Range, the tuff of Ryecroft Canyon has strikingly similar textures, modal compositions, and an identical K-Ar age to the tuff of Arc Dome (fig. 6; Boden, 1986; D.R. Boden, oral commun., 1984). In the southern Sand Springs Range, the tuff of Arc Dome is exposed from Rawhide to the vicinity of Eagleville (fig. 6), where it is as much as 250 m thick (M.L. Sorensen, oral commun., 1989). A conservative estimate of the volume of this tuff is approximately 880 km^3, assuming an average thickness of 500 m and 25 percent extension for the east half of its exposures and 100 m thickness and 100 percent extension for the west half of its exposures.

The source of the tuff of Arc·Dome is not precisely known. G.F. Brem (oral and written communs., 1985, 1986; Brem and others, 1991) suggested that increasing thickness of the tuff, increasing complexity of volcanic units within the tuff, and the presence of intrusive rocks similar to the tuff all indicate that the source of the tuff of Arc Dome is probably located in the southern Reese River Valley near Stewart Creek (fig. 6). Based on these relations and on a large gravity low centered in this area (Healey and others, 1981; Snyder and Healey, 1984), Brem and others (1991) inferred that a caldera probably is buried in the southern Reese River Valley.

Tuff of Toiyabe and Tuff of Copper Mountain

The tuff of Toiyabe is widely distributed in the southern Toiyabe and Paradise Ranges, southern Shoshone Mountains, Pactolus Hills, northern Royston Hills, and north Cedar Mountain (Simon area) (fig. 6). The south boundary of this tuff is well defined and trends nearly east-west across three ranges at approximately lat 38°30' N. West of long 118° W. the tuff of Copper Mountain is believed to be correlative with the tuff of Toiyabe. The tuff of Copper Mountain is a rhyolitic tuff named and described by Ekren and others (1980) for exposures in the northeastern Gabbs Valley Range (fig. 6). The tuff of Copper Mountain is megascopically, microscopically, and modally similar to the tuff of Toiyabe and has a major-element composition comparable to the tuff of Toiyabe (R.F. Hardyman, written commun., 1989). Although it has not been directly dated, limiting ages based on stratigraphy indicate that it is nearly the same age (23–22 Ma, Ekren and others, 1980, p. 43) as the tuff of Toiyabe (22.9–21.4 Ma, table 3).

The undivided tuff of Toiyabe and tuff of Copper Mountain presently are exposed over an approximate area of 4,150 km^2. Thicknesses range from more than 1 km near the source of the tuff of Toiyabe in the southern Toiyabe Range, to about 600 m at north Cedar Mountain, 400 m on the east side of the Paradise Range, and about 100 m near Copper Mountain. A conservative estimate of the volume of these tuffs is approximately 1,100 km^3, assuming an average thickness of 700 m and 25 percent extension in the Shoshone Mountains and Toiyabe Range, an average thickness of 400 m and 50 percent extension in the Paradise Range, north Cedar Mountain, and Pactolus Hills, and an average thickness of 100 m and 100 percent extension further west.

Assuming that the tuff of Toiyabe and the tuff of Copper Mountain are correlative, their present distribution allows estimation of offset on the Petrified Spring fault, the easternmost of four late Cenozoic right-lateral strike-slip faults mapped by Ekren and Byers (1984) in the eastern Walker Lane west of the Paradise Range (fig. 6). Offset along the Petrified Spring fault is approximately 35 km based on apparent offset of the south margin of the undivided tuff of Toiyabe and tuff of Copper Mountain. In contrast, the tuff of Gabbs Valley, which is several million years older than the undivided tuff of Toiyabe and tuff of Copper Mountain, shows no discernible offset by this fault, although the tuff of Gabbs Valley primarily crops out north of the mapped trace of this fault and the distributions of individual cooling units are poorly known (fig. 6). Other Oligocene or early Miocene ash-flow tuff units are not present on both sides of the fault and cannot be used for estimating offset. The present distribution of 22- to 15-Ma intermediate lavas in the Gabbs Valley Range (rocks of Mount Ferguson) suggest somewhat less offset along this fault (approx. 10 km, fig. 6), possibly indicating movement on this fault before or during the prolonged eruption of the rocks of Mount Ferguson. Synvolcanic movement along this fault also is suggested by the presence of landslipped debris interbedded in the rocks of Mount Ferguson (Ekren and others, 1980). Total late Cenozoic right-lateral offset on the Petrified Spring fault probably is about 35 km; the apparent lack of offset on this fault shown by the tuff of Gabbs Valley is believed to reflect poor understanding of the distribution of cooling units in the tuff of Gabbs Valley.

The source of the tuff of Toiyabe has long been postulated to be in the southern Toiyabe Range (Ferguson and Cathcart, 1954; Kleinhampl and Ziony, 1967, 1985). Recent mapping by G. F. Brem (oral and written communs., 1986; also see Brem and others, 1985, 1991) has identified several vents for the tuff of Toiyabe and a partial caldera wall in the southern Toiyabe Range and southeastern Shoshone Mountains (fig. 6).

Tuff of Green Springs

The tuff of Green Springs is megascopically, petrographically, and chemically similar to the Nine Hill Tuff, which is widely distributed in western Nevada and eastern California (Deino, 1985; Best and others, 1989b). Apparent discrepancies in radiometric age data, however, do not permit correlation of these units at the present time; the Nine Hill Tuff has a very precise ^{40}Ar-^{39}Ar age of 25.11±0.017 Ma (Deino, 1989), whereas the tuff of Green Springs is older than the tuff of Gabbs Valley, which has K-Ar ages of 25.0–26.1 Ma (table 3; Ekren and others, 1980). Moreover, the tuff of Green Springs lies southeast of the known distribution of the Nine Hill Tuff (Deino, 1985), and the apparent thickness of the tuff of Green Springs (as much as 300 m) is considerably greater than most sections of the Nine Hill Tuff, which generally are less than 100 m thick and reach a maximum thickness of about 250 m (Deino, 1985; Best and others, 1989b). The source of the Nine Hill Tuff is unknown, although Best and others (1989b, fig. 7) inferred that the source may a caldera buried in Carson Sink about 100 km northwest of the Paradise Range.

Sources of Other Ash-Flow Tuff Units in the Paradise Range

Most ash-flow tuff units in the Paradise Range do not have readily identifiable sources. Ekren and others (1980) discussed the lack of known sources, specifically calderas, for several voluminous, widely distributed ash-flow tuffs within the Walker Lane in west-central Nevada. They suggested several possible reasons for caldera sources not having been identified for these tuffs: (1) eruptions of these tuffs did not lead to formation of calderas; (2) calderas were structurally dismembered by later faulting; (3) calderas were buried beneath younger deposits; or (4) caldera structures have not been recognized. They suggested that a broad structural volcano-tectonic depression rather than fault-bounded caldera(s) may have developed, possibly because the magma chamber(s) were at too great depths to allow formation of fault-bounded calderas. They speculated that reverse compositional zoning and strong resorption of quartz phenocrysts in the Mickey Pass and Singatse Tuffs are indicative of deep magma chambers. They also noted that lacustrine sediments locally are interbedded in these tuffs and possibly indicate local structural sags resulting from deep eruptions of the tuffs.

In the Paradise Range, many of the ash-flow tuffs appear to represent small-volume localized units that may not have formed calderas and whose vents could easily be concealed beneath basin-filling alluvium. Many of the tuffs appear to be distal outflow sheets; pyroclastic textures suggestive of near-vent facies or intracaldera rocks, megabreccias, and dikes and lava flows genetically related to the tuffs are not apparent. These relations suggest that caldera sources for most of these tuffs are not present in the Paradise Range. An exception may be the tuff of Sheep Canyon, which contains as many as four cooling units, reaches thicknesses in excess of 600 m, and locally contains very coarse pumice fragments. However, this tuff is exposed only for about 7 km along strike in the southwestern Paradise Range, has not been recognized in adjacent ranges, and also may be a relatively small volume, albeit very thick, ash-flow tuff unit.

In the Paradise Range, most of the tuffs present in the Sheep Canyon section represent a relatively short time period (less than 2 m.y.), and many features are common to different ash-flow tuff units, which suggests that several of these tuffs may have had common sources. For example, the lower white, red, gray-green, and upper white tuffs are all relatively thin, crystal-poor rhyolitic(?) tuffs that have very similar textural and petrographic characteristics and could have a common source. The tuffs of Goldyke and Sheep Canyon also share many characteristics and possibly have a common source. Additional petrologic, geochemical, and geochronologic data are required to test these hypotheses, but the actual number of sources for the ash-flow tuffs in the Paradise Range may be far fewer than suggested by the number of mappable ash-flow tuff units.

Ekren and others (1980) noted several features that are present in the Gabbs Valley and Gillis Ranges, including reverse compositional zoning and resorption of quartz phenocrysts, which they inferred were indicative of deep magma chambers. These features are not present in the Paradise Range. Reverse compositional zoning is not obvious in ash-flow tuff in the Paradise Range. The only tuffs showing substantial compositional zoning are the tuffs of Arc Dome and Sheep Canyon. The tuff of Arc Dome shows normal (felsic to mafic) zoning (figs. 5, 7; see below). Zoning in the tuff of Sheep Canyon is less well defined, but most zoning may occur between different cooling units rather than within individual cooling units (fig. 8; see below). In addition, strong resorption of quartz phenocrysts is only evident in one ash-flow unit (the tuff of Goldyke).

Sources for many of the ash-flow tuff units in the Paradise Range remain unidentified. Problems in identifying sources for the tuffs include the lack of depositional contacts between pre-Tertiary and Tertiary rocks, the complex faulting history, and locally strong hydrothermal alteration of the tuffs. However, extensive K-Ar dating of fresh rocks (table 3), modal data (fig. 5; table 2), and geochemical data (see below) indicate that most tuffs in the Paradise Range, whose sources are not known, are not correlated with tuffs in adjacent ranges. For example, most of the tuffs in the Sheep Canyon section are substantially younger and less mafic than tuffs in the Gabbs Valley and Gillis Ranges. Similarly, tuffs in the lower part of the Menter Canyon section and in the Ellsworth section are much less mafic than age-equivalent tuffs in the Gabbs Valley and Gillis Ranges. The inability to correlate many tuff units in the Paradise Range with units in adjacent ranges and the absence of rocks with textures indicative of near-vent facies in the Paradise Range indicate that it is highly unlikely that sources for the tuffs are exposed in the Paradise Range.

DISTRIBUTION AND SIGNIFICANCE OF THE YOUNGER ANDESITE SEQUENCE

The younger andesite sequence (20- to 15-Ma intermediate lavas) in the Paradise Range and Pactolus Hills is part of an early Miocene volcanic field that may have covered more than 1,000 km² in the Gabbs Valley and Paradise Ranges (fig. 6). These lavas include the rocks of Mount Ferguson in the Gabbs Valley Range and the hornblende andesite, porphyritic dacite, and andesite and basaltic andesite units in the Paradise Range. These lavas were erupted during or shortly after a brief period of early Miocene normal faulting and, at least locally, extreme crustal extension (John and others, 1989a, b). In the Paradise Range, this episode of faulting is marked by major angular unconformities between earliest Miocene ash-flow tuff units and the overlying younger andesite sequence (as much as 75° in the northern Pactolus Hills) and changes in the orientation and abundance of faults cutting the older rocks and the younger andesites (John, 1988). Similar field relations were described by Ekren and Byers (1984) in the Gabbs Valley Range and appear to be widespread throughout west-central Nevada (fig. 6; see data compilation in John and others, 1989b).

There are several other early Miocene (approximately 22 to 18 Ma) volcanic centers composed dominantly of intermediate lavas in west-central Nevada including Goldfield, Tonopah-San Antonio Mountains, Candelaria Hills-Monte Cristo Range, Terrill Mountains, southern Cocoon Mountains, and the northern Yerington district (Lincoln Flat area) (fig. 6; John and others, 1989b). There is a good correlation between areas of early Miocene faulting and the distribution of early Miocene intermediate lavas; intermediate lavas are mostly restricted to regions that underwent extensive normal faulting (fig. 6). Early Miocene andesite in the Paradise Range is chemically distinct from the older andesite (fig. 9*A*), which appears to be genetically related to the ash-flow tuffs (fig. 9*B*).

Early Miocene intermediate magmatism and the plumbing system provided by extensive high-angle faults played important roles in the genesis of several major, early Miocene, epithermal gold-silver deposits including the Tonopah, Goldfield, and Paradise Peak deposits (John and others, 1989a, b, 1991). In particular, the deposits formed during or just after a period of early Miocene normal faulting and are spatially, temporally, and probably genetically related to intermediate magmatism.

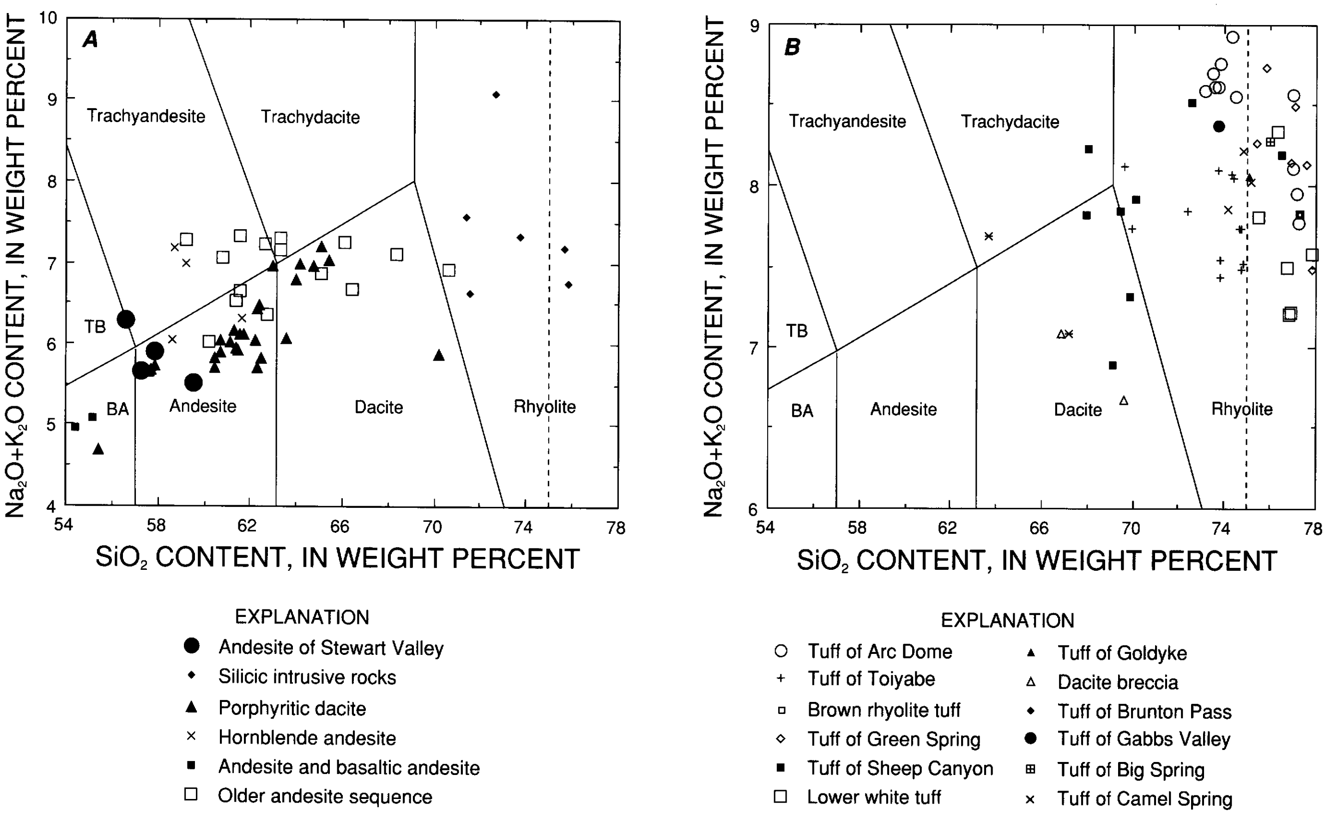


Figure 9. Total alkali-silica diagrams for Tertiary volcanic rocks in Paradise Range. All analyses recalculated to 100 percent on volatile-free basis. Analyses of samples that have undergone obvious hydrothermal alteration (SiO_2>78 weight percent, high K_2O, low Na_2O, or low Al_2O_3) are not plotted. Rock names are I.U.G.S. classification (Le Bas and others, 1986) except for dashed line at SiO_2=75 percent separating high-silica rhyolite (>75 percent SiO_2) from rhyolite. BA, basaltic andesite; TB, trachybasalt. *A*, Older andesite sequence from the Sheep Canyon section, younger andesite sequence from throughout the Paradise Range and northern Pactolus Hills (hornblende andesite, porphyritic dacite, and andesite and basaltic andesite units), silicic intrusive rocks from southwestern Paradise Range and northern Pactolus Hills, and andesite of Stewart Valley. *B*, Ash-flow tuffs and interbedded lavas from Menter Canyon, Ellsworth and Sheep Canyon sections.

GEOCHEMICAL STUDIES

Approximately 120 whole-rock chemical analyses were obtained for volcanic rocks in the Paradise Range. These samples represent most major volcanic units, except those pervasively hydrothermally altered. Most ash-flow tuff samples were densely welded and devitrified, and no attempt was made to separate the strongly flattened, devitrified pumice blobs from matrix material. Many samples were weakly altered (generally deuteric or propylitic alteration). Glass in vitrophyric samples was hydrated, and irregular and low sodium contents of many hydrated glasses suggest that partial sodium loss occurred during hydration (Noble, 1970). In addition, several ash-flow tuff samples that megascopically appear unaltered showed alkali metasomatism, probably due to vapor-phase alteration. Because of these limitations, detailed petrochemical discussion of volcanic rocks in the Paradise Range is not warranted, and chemical analyses are used only to define general trends and as an aid in correlation of rock units.

Major elements in most samples were analyzed by wavelength-dispersive X-ray fluorescence spectroscopy (Taggert and others, 1987), and minor elements (Nb, Rb, Sr, Zr, Y, Ba, Ce, La, Cu, Ni, Zn, and Cr) were analyzed by energy-dispersive X-ray fluorescence spectroscopy (Johnson and King, 1987). FeO, H_2O^+, H_2O^-, CO_2, and F were determined by conventional wet chemical methods (Jackson and others, 1987). Major elements for a few samples were determined by single-solution rapid rock analysis (Shapiro, 1975). Sr-isotopes were measured for about 25 samples using standard mass spectrometry techniques (see Kistler and others (1986) for a description of analytical procedures). Geochemical data are presented in tables 4, 5, 6, 10, 11, 12, 13, 14, 15, 16, and 17.

Older and Younger Andesite Sequences and the Andesite of Stewart Valley

Analyses of the older and younger andesite sequences and the andesite of Stewart Valley are given in tables 6, 10, and 11. Rocks in the older andesite sequence range in composition from 59 to 70 weight percent SiO_2 (major elements are recalculated to 100 percent on a volatile-free basis), have fairly high total alkali contents (6.0 to 7.3 weight percent $Na_2O + K_2O$), and are andesites, trachyandesites, dacites, trachydacites, and rhyolites using the I.U.G.S. chemical classification (fig. 9*A*; Le Bas and others, 1986). They have an alkali-lime index of about 55 (fig. 10*C*) and thus are alkali-calcic (Peacock, 1931). They form a high-K series using Gill's (1981) classification of orogenic andesites (fig. 11). Lava flows intercalated in the tuffs in the Sheep Canyon and Ellsworth sections (andesite and rhyodacite to andesite units) are andesite and dacite compositionally similar to the older andesite sequence (figs. 9–11, tables 14, 15).

Silica content in the younger andesite sequence ranges widely from 54 to 70 weight percent. Using the I.U.G.S. classification, these rocks range from basaltic andesite to high-silica dacite (fig. 9*A*). They have an alkali-lime index of about 60 and are calc-alkalic using Peacock's (1931) classification. Using Gill's (1981) classification these rocks straddle the medium- and high-K series boundary and generally have notably lower K_2O contents than the older andesites (fig. 11).

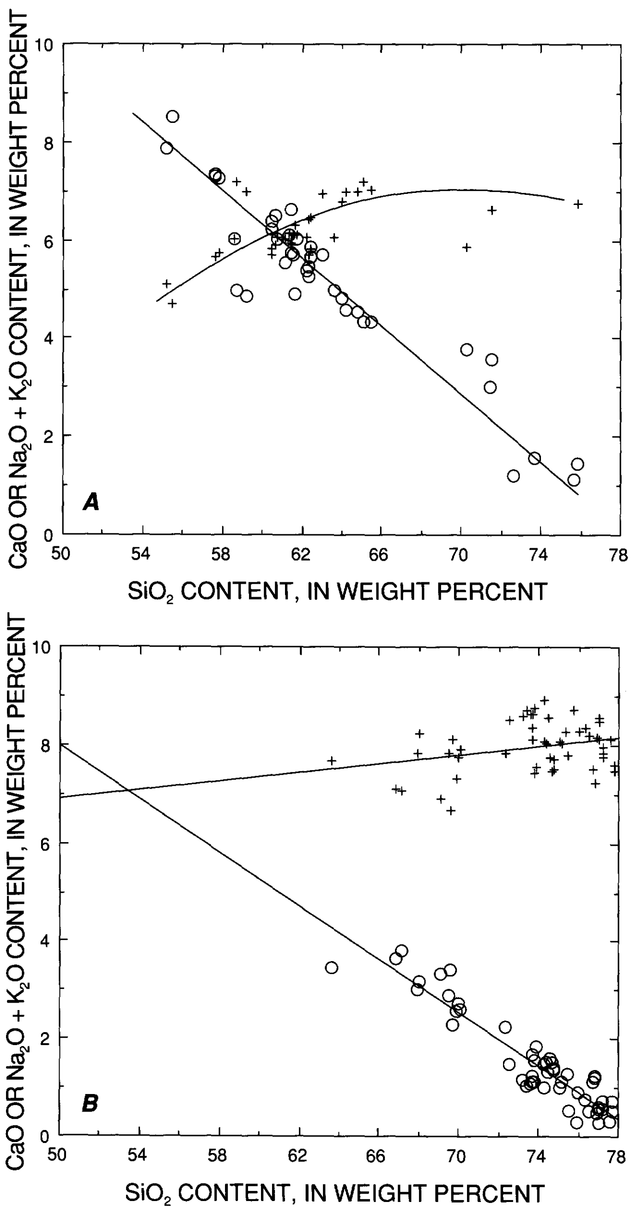
Limited chemical data for the silicic intrusive rocks that are equivalent in age to the younger andesite sequence suggest that the silicic intrusive rocks probably are silicic differentiates of the younger andesite sequence (figs. 9–12, tables 12, 13). In particular, the relatively low Rb and K_2O contents and initial strontium ratio and relatively high K/Rb and Sr/Rb ratios are generally similar to the younger andesites and dissimilar to the older andesites.

Four analyses of the andesite of Stewart Valley range from 56.6 to 59.7 weight percent SiO_2 (table 11) and are andesites and basaltic trachyandesites using the I.U.G.S. classification (fig. 9*A*). Their compositions are very similar to the younger andesite sequence (figs. 9–11), and they also have relatively low initial strontium ratios similar to the younger andesites ($^{87}Sr/^{86}Sr_i$=0.7047; table 13; fig. 12).

Although the range of silica contents of the older and younger andesite sequences are broadly similar, there are many compositional differences between these lava sequences (figs. 9–11). The older andesites tend to have higher K_2O, MgO, Rb, and Rb/Sr contents at a given SiO_2 value than the younger andesites, whereas the younger andesites generally have higher CaO, P_2O_5, Sr, K/Rb, and FeO*/MgO than the older andesites. Initial strontium ratios generally are higher for the older andesites ($^{87}Sr/^{86}Sr_i$=0.7049–0.7054) than for the younger andesites ($^{87}Sr/^{86}Sr_i$=0.7042–0.7051) and are comparable to those of the ash-flow tuffs ($^{87}Sr/^{86}Sr_i$=0.7050–0.7055) (table 13; fig. 12).

Compositional differences between the two groups of andesites in the Paradise Range are very similar to chemical variations between different ages of andesites elsewhere in the Walker Lane (Silberman and others, 1976) and are similar to differences described in detail by Mellot and Hart (1987) for two series of Miocene andesitic lavas in the northern Basin and Range in Nevada. Mellot and Hart (1987) suggested that these compositional differences arise from a complex tectonic history involving magmas from multiple or heterogeneous sources and variable interaction of these magmas with evolved subcontinental mantle or heterogeneous crust. Similar complex magmatic histories may have occurred in the Paradise Range, although a lack of Pb and Nd isotopic data and rare-earth element data preclude formulation of a detailed model for generation of the andesitic magmas. However, the chemical data and the different tectonic settings of the two groups of andesites in the Paradise Range suggest that their magmas had different origins. In particular, lower K and Rb contents and initial strontium ratios and higher Ca, Sr, and P contents and K/Rb and Sr/Rb ratios of the younger andesite sequence and the silicic intrusive rocks indicate that they are less highly evolved than the older andesite sequence and suggest that they have a more primitive source (possibly a larger component of mantle or subducted oceanic crust) or have undergone less interaction with continental crust during ascent than the older andesites. The lack of correlation between silica content and initial strontium ratio (fig. 11) indicates that simple mixing of melts derived from the continental crust and from the upper mantle is not a reasonable mechanism to explain the compositional variation seen in the Paradise Range (compare to figure 14 of Gans and others, 1989).

There are relatively few chemical data for late Oligocene and early Miocene intermediate lavas from adjacent areas. Intermediate lavas in the Mizpah Trachyte (24–23 Ma) in the Tonopah district are trachyandesites that have major-element compositions very similar to the older andesites (Bonham and Garside, 1979). Early Miocene (mostly 22–20.5 Ma) lavas from the Goldfield district dominantly have intermediate compositions with calc-alkaline affinities that also appear similar to the older andesites in the Paradise Range (Ashley, 1979; R.P. Ashley, written commun., 1989). In contrast, the andesite of Lincoln Flat (19–18 Ma) in the northern Yerington district consists of



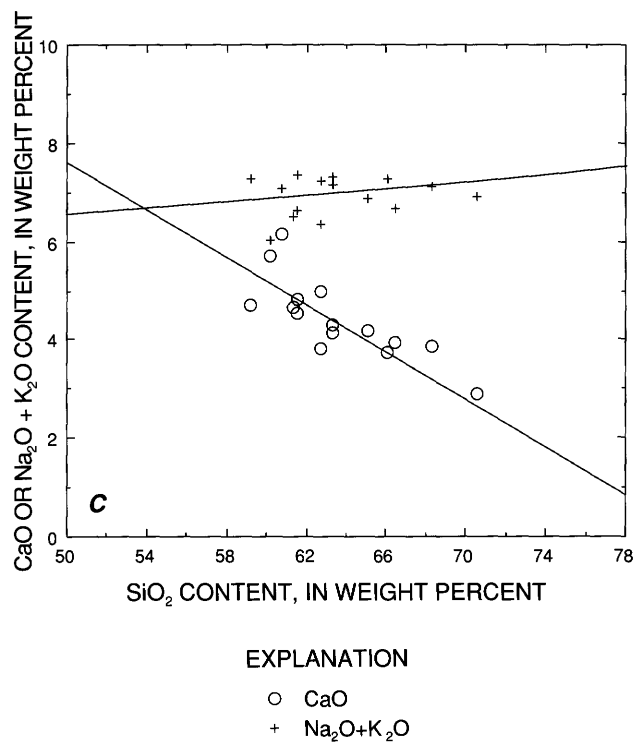


Figure 10. Peacock (1931) diagrams (CaO versus SiO_2 and Na_2O+K_2O versus SiO_2) for Tertiary volcanic rocks in the Paradise Range. All analyses recalculated to 100 percent on volatile-free basis. Analyses of samples that have undergone obvious hydrothermal alteration are not plotted. Peacock index is silica content where lines through CaO and Na_2O+K_2O intersect. *A*, Younger andesite sequence, silicic intrusive rocks, and andesite of Stewart Valley. *B*, Ash-flow tuffs and interbedded lavas from Menter Canyon, Ellsworth, and Sheep Canyon sections. *C*, Older andesite sequence.

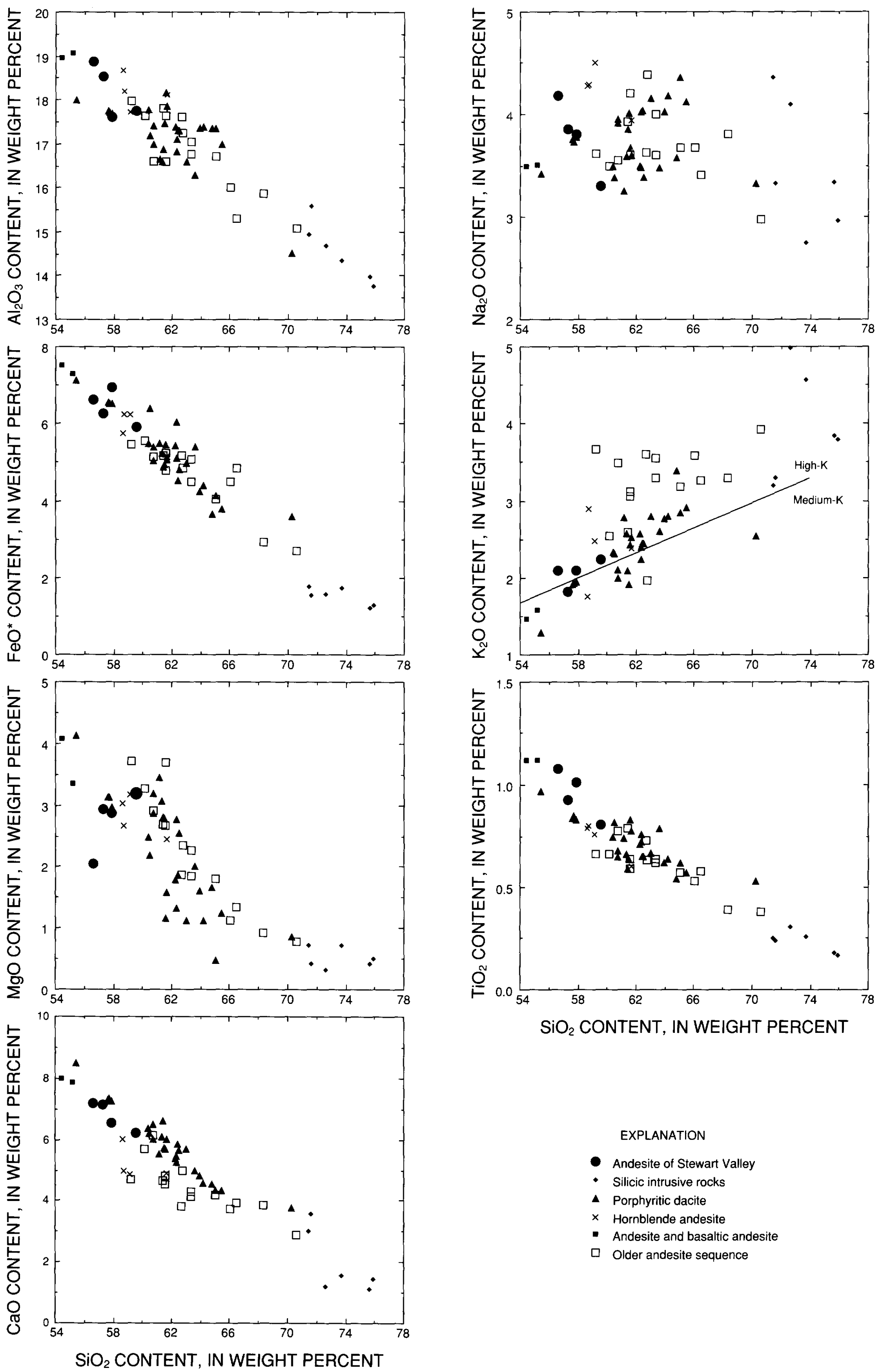


Figure 11. Silica variation diagrams for the older and younger andesite sequences in Paradise Range and northern Pactolus Hills, silicic intrusive rocks, and andesite of Stewart Valley. All analyses recalculated to 100 percent on volatile-free basis. Samples that have undergone obvious hydrothermal alteration are not plotted. Line separating high-K and medium-K series from Gill (1981).

andesite, trachyandesite, and trachydacite with alkali contents between those of the older and younger andesite sequences, but with Rb and Sr concentrations and Sr/Rb and K/Rb ratios similar to the younger andesite sequence (Proffett and Proffett, 1976). Lavas in the Alta Formation (approx. 20–14.5 Ma; Vikre and others, 1988) in the Virginia City area about 150 km northwest of the Paradise Range mostly are andesite with major- and trace-element compositions similar to the younger andesite sequence (Whitebread, 1976; M.L. Silberman, written commun., 1990). These data suggest that compositional changes seen in intermediate lavas in the Paradise Range occurred regionally and that major changes in andesite chemistry, and presumably magma genesis, occurred at about 20 Ma in the west-central Great Basin. Notably, this change in magma chemistry occurred during an episode of widespread crustal extension, and the compositional changes are consistent with a larger component of mantle source material in the early Miocene magmas.

Numerous authors have noted that the tectonic environment of the Great Basin changed across the region during the early to middle Miocene (approximately 20 to 17 Ma) from subduction-related, dominantly andesitic magmatism, generally occurring in areas of intra- and back-arc extension, to fundamentally bimodal basalt-rhyolite magmatism associated with oblique extension east of the San Andreas transform and its result, modern Basin and Range faulting (see for example McKee, 1971; Christiansen and Lipman, 1972; Silberman and others, 1976; Snyder and others, 1976). The Walker Lane area in the western Great Basin is anomalous, however, because it is characterized throughout the Miocene by intermediate calc-alkaline volcanism that may be the southward continuation of the Cascade volcanic arc, and the transition to bimodal magmatism occurred much later than in most other areas of the Great Basin (see for example Silberman and others, 1976; Snyder and others, 1976). The Paradise Range lies along the east side of the Walker Lane, and compositional changes seen in early Miocene intermediate magmatism in the Paradise Range and nearby ranges to the west apparently reflect the change from andesitic magmatism associated with back-arc extension to andesitic magmatism related to the Cascade arc (for example, Silberman and others, 1976). However, the role of crustal extension played in the genesis of these magmas and how early Miocene extension fits into tectonic models for the western Great Basin remain unclear.

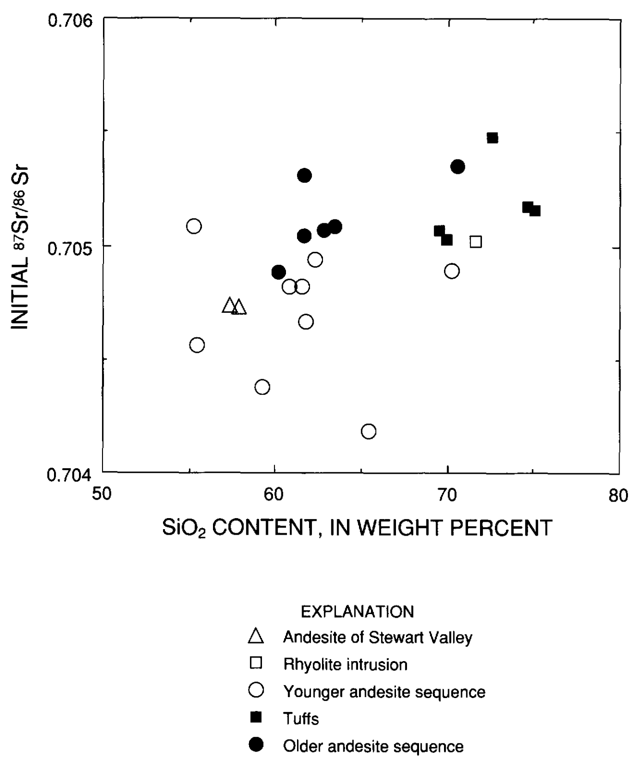


Figure 12. Plot of initial $^{87}Sr/^{86}Sr$ ratio versus silica content for Tertiary volcanic rocks in Paradise Range and northern Pactolus Hills. See table 13 for Sr-isotope data.

Tuffs in the Menter Canyon and Ellsworth Sections

With the exception of the more mafic Cloverdale Ranch unit of the tuff of Toiyabe, all analyzed tuffs in the Menter Canyon and Ellsworth sections are rhyolites or high-silica rhyolites (tables 4, 5, and 14; fig. 13). Most of these tuffs have unremarkable major- and trace-element compositions and trends that are similar to other Oligocene and early Miocene, broadly calc-alkaline ash-flow tuff sheets in the Great Basin (for example, Ekren and others, 1974; Bonham and Garside, 1979; Boden, 1986, 1989; Gans and others, 1989; Best and others, 1989a, b) and dissimilar to Oligocene trachytic tuffs in the central Great Basin (for example, Isom Formation, Best and others, 1989a, b) and peralkaline rhyolitic ash-flow tuffs associated with middle and late Miocene magmatism in the northern and southern Great Basin (for example, Noble and Christiansen, 1974; Christiansen and others, 1977; Rytuba and McKee, 1984; Conrad, 1984). Tuffs on the east side of the Paradise Range are in general more siliceous than age-equivalent tuffs in the Gabbs Valley, Gillis, and Singatse Ranges to the west (Proffett and Proffett, 1976; Ekren and others, 1980). Notably absent are the "monotonous intermediates" (dacitic tuffs) of Hildreth (1981) that characterize many Oligocene and early Miocene ash-flow tuff sequences elsewhere in the Great Basin (for example, Gans and others, 1989; Best and others, 1989a, b).

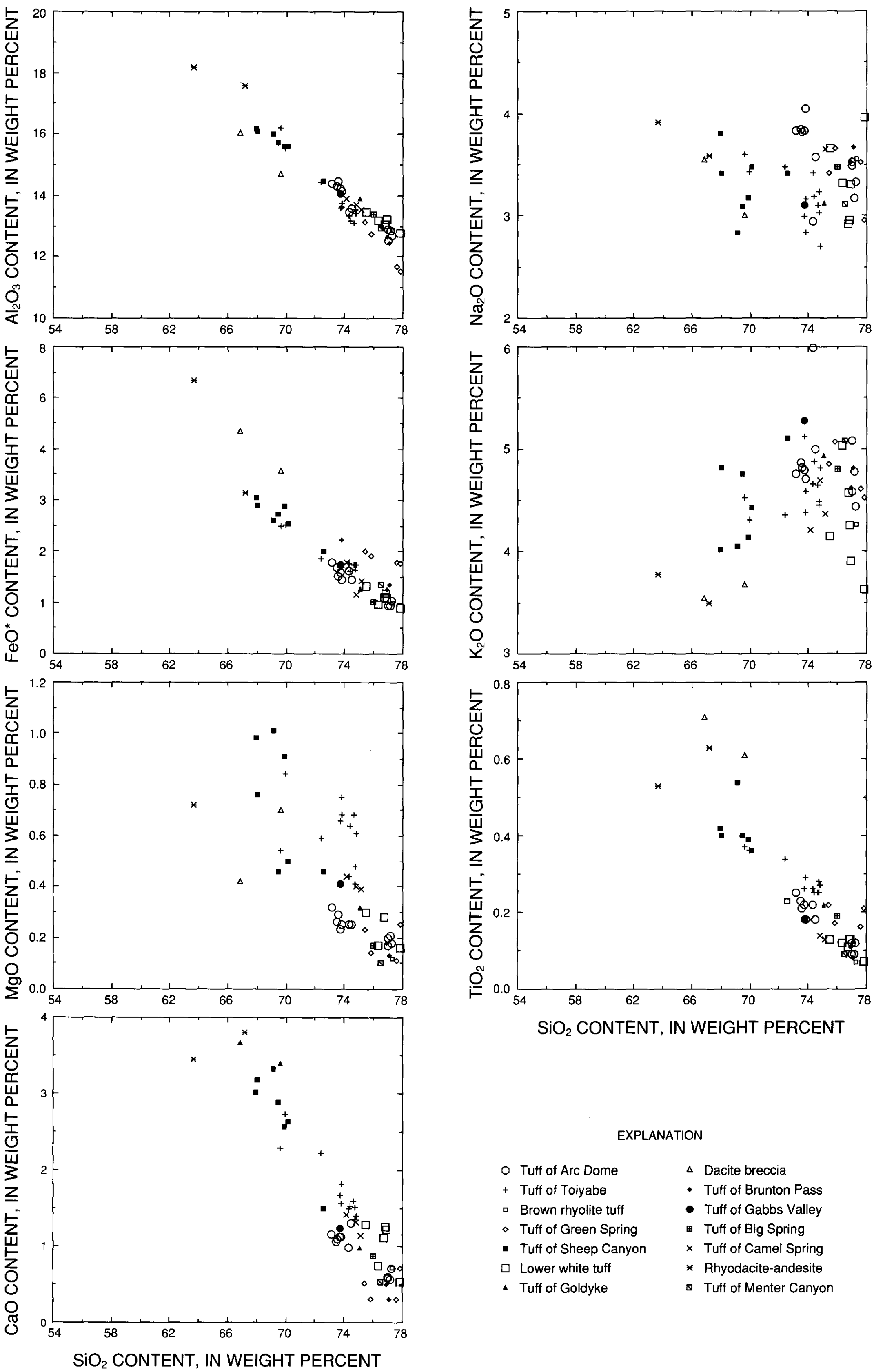
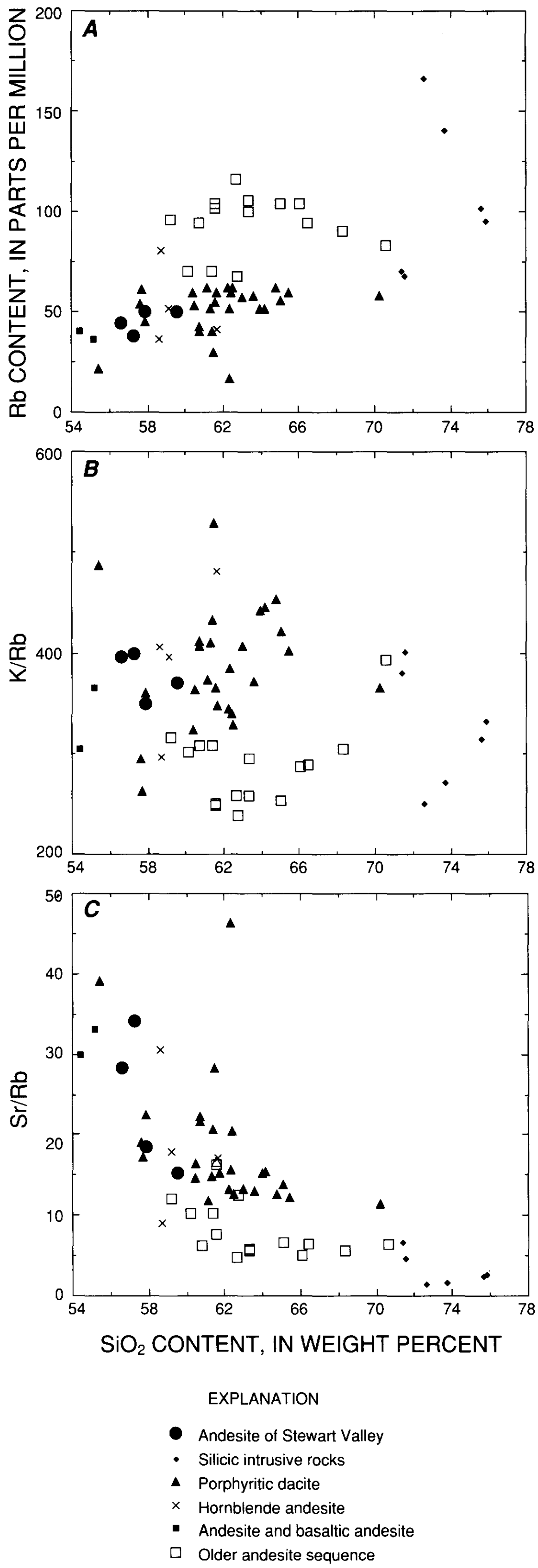


Figure 13. Silica variation diagrams for ash-flow tuffs and interbedded lavas in Paradise Range and northern Pactolus Hills. All analyses recalculated to 100 percent on volatile-free basis. Analyses of samples that have undergone obvious hydrothermal alteration are not plotted.

The tuff of Green Springs is a high-silica rhyolite (75–77 weight percent SiO_2) that is highly enriched in Ce, La, Nb, Zn, and Zr relative to other tuffs in the Paradise Range (table 14; fig. 14) and is compositionally comparable to the Nine Hill Tuff (fig. 14; Deino, 1985). Analyses of samples from both cooling units of the tuff of Green Springs from two localities indicate that the lower cooling unit is more highly evolved than the upper cooling unit as it is enriched in SiO_2, K_2O, Ce, Nb, Rb, Y, Zn, and Zr relative to the upper cooling unit, which is enriched in all other elements (table 14). The high Zr content, low phenocryst content, and secondary flowage textures of the tuff of Green Springs suggest that it erupted at relatively high temperatures as did the Nine Hill Tuff, which also has these features (Deino, 1985).

Trace-element analyses of samples of the lower cooling unit of the tuff of Gabbs Valley collected in the Paradise Range are similar to analyses obtained by Deino (1985) for other exposures of the tuff of Gabbs Valley. The relatively low Zr and Nb contents of the tuff



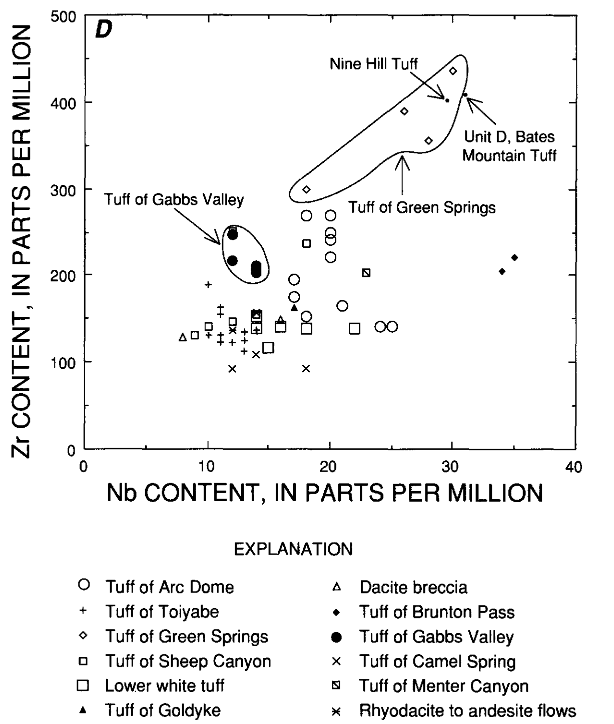


Figure 14. Plots of trace-element data for Tertiary volcanic rocks in Paradise Range and northern Pactolus Hills. *A*, Rb versus SiO_2 for older and younger andesite sequences. *B*, K/Rb versus SiO_2 for older and younger andesite sequences. *C*, Sr/Rb versus SiO_2 for older and younger andesite sequences. *D*, Zr versus Nb for ash-flow tuffs from Menter Canyon, Ellsworth, and Sheep Canyon sections. Also shown are average compositions for the Nine Hill Tuff and Unit D of the Bates Mountain Tuff from Deino (1985). Note that analyses of tuff of Green Springs are similar to the Nine Hill Tuff and Unit D of the Bates Mountain Tuff and that analyses of tuff of Gabbs Valley from the Paradise Range are distinct from the Nine Hill Tuff and Unit D of the Bates Mountain Tuff.

of Gabbs Valley clearly indicate that the tuff exposed in the Paradise Range and elsewhere is not correlative with the Nine Hill Tuff (fig. 14; Deino, 1985), despite their strikingly similar and distinctive megascopic textures.

Tuff of Arc Dome

The tuff of Arc Dome shows pronounced normal compositional zoning with the basal 50 m of the tuff enriched in SiO_2, Rb, Nb, and Zn relative to the fairly homogeneous upper 300+ m of the tuff, which has higher concentrations of most other elements (fig. 15; table 4). Changes in bulk composition are reflected in phenocryst mineralogy: the basal zone contains more quartz and sanidine relative to the upper parts of the tuff, which have greater plagioclase and mafic mineral contents (fig. 7). As noted above, no cooling break has been observed between the basal, black fiamme-rich part of the tuff and the homogeneous upper part of the tuff. These trends probably reflect compositional zoning in the magma chamber.

Compositional and mineralogical trends in the tuff of Arc Dome are similar to trends reported for other large-volume, middle Tertiary ash-flow tuff sheets in the western Great Basin (for example, the Windous Butte Formation and the tuffs of Williams Ridge and Morey Peak, Ekren and others, 1974; tuff of Mount Jefferson, Boden, 1986, 1989). However, the upper parts of many other tuffs are much more mafic than the exposed top of the tuff of Arc Dome. The lack of more mafic ash flows in exposures of outflow-facies rocks of the tuff of Arc Dome in the Paradise Range and southern Shoshone Mountains may reflect differences between outflow-facies and intracaldera-facies rocks, with only the more

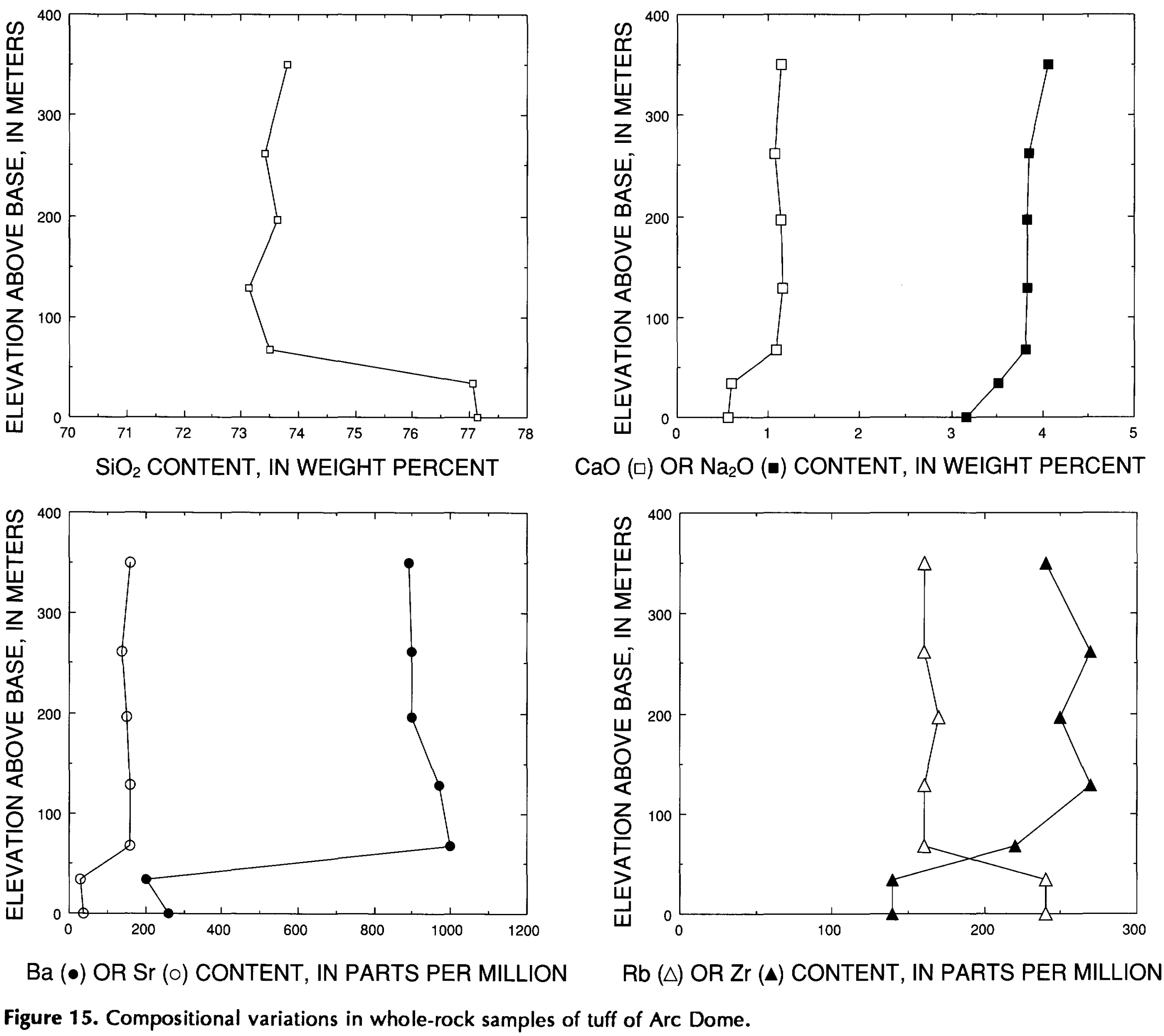


Figure 15. Compositional variations in whole-rock samples of tuff of Arc Dome.

siliceous upper part of the magma chamber represented in the outflow facies tuff.

Tuff of Toiyabe

Although a detailed sampling traverse across the tuff of Toiyabe was not made, there is little evidence for significant compositional zoning within the part of the tuff of Toiyabe exposed in the eastern Paradise Range (compare analyses of the basal part of the tuff (nos. 1–3, table 5) to the other analyses (nos. 4–6)). The tuff of Toiyabe has notably higher CaO, Sr, and Sr/Rb and lower total alkalis, Zr, Ba, Ce, and La than the upper part of tuff of Arc Dome, although they have similar silica contents (tables 4, 5). The tuff of Toiyabe exposed in the Simon area at the north end of Cedar Mountain is slightly more mafic than the tuff exposed on the east side of the Paradise Range (nos. 7, 8, table 5) but is considerably less mafic than its Cloverdale Ranch unit exposed in the northern Pactolus Hills (nos. 9, 10, table 5). Major-element analyses of the probably correlative tuff of Copper Mountain from the Gabbs Valley Range and Barnett Hills are nearly identical to analyses of the tuff of Toiyabe from the east side of the Paradise Range (R.F. Hardyman, written commun., 1989).

Tuffs in the Sheep Canyon Section

Ash-flow tuffs in the Sheep Canyon section show more compositional variation than tuffs on the east side of the Paradise Range ranging from trachydacite to high-silica rhyolite, although all of the analyzed units except the tuff of Sheep Canyon are rhyolite or high-silica rhyolite. Many tuffs are weakly to strongly altered (notably the lower white tuff, red tuff, and red rhyolite tuff units). Altered tuffs commonly have high K_2O and SiO_2 and low Na_2O (nos. 4–6, table 14, and nos. 2 and 7–11, table 16). This alteration probably reflects vapor-phase alteration as the tuffs cooled, because it does not affect underlying units or the hydrated basal vitrophyre of the lower white tuff (compare nos. 1 and 2, table 16) and it does not appear to be structurally controlled as is potassium metasomatism, which results in similar chemical changes (Brooks, 1986; Glazner, 1988). Some alteration of the red tuff may be due to partial silicification during tectonic brecciation, because it has relatively normal K_2O and Na_2O but very high SiO_2 and very low Al_2O_3 (no. 4, table 15).

The tuff of Sheep Canyon shows the most compositional variation and is the most mafic tuff analyzed in the southwestern Paradise Range (68 to 72.5 weight percent SiO_2), which is consistent with its phenocryst mineralogy (table 2; figs. 5, 8). As noted above, there are substantial variations in modal mineralogy of samples collected along a detailed traverse across the four cooling units in this tuff (fig. 8). Because of strong deuteric or propylitic alteration of this tuff, chemical analyses of most samples collected in this traverse were not made, and the total compositional variation of this tuff is unknown. Modal data suggest that compositional zoning is normal (felsic to mafic) in the thickest (third) cooling unit (fig. 8). Comparison of modal data of chemically analyzed samples with modal data from samples in this traverse suggests that greater compositional variation occurs between cooling units than within individual cooling units.

SUMMARY OF LATE CENOZOIC VOLCANIC AND TECTONIC HISTORY OF THE PARADISE RANGE

Tertiary volcanic rocks exposed in the Paradise Range and northern Pactolus Hills record a complex history of late Cenozoic volcanism and tectonism that is summarized in figure 16. The earliest Tertiary volcanic eruptions preserved in the Paradise Range are the tuffs of Davis Mine and Pactolus in the southwestern part of the range and in the Pactolus Hills, the tuff of Return Mine at the north end of the range, and the lower part of the Menter Canyon section (tuffs of Green Springs and Menter Canyon) on the east side of the range. The tuffs of Davis Mine and Return Mine both locally contain abundant lithic fragments of pre-Tertiary rocks, indicating that they were erupted through or traveled across areas containing exposed pre-Tertiary rocks. They also contain clasts of Tertiary(?) intermediate lavas. These relations suggest that the tuffs of Davis Mine and Return Mine are some of the earliest Tertiary units in the region. In contrast, most other ash-flow tuff units lack abundant pre-Tertiary lithic components (the tuffs of Menter Canyon and Gabbs Valley are exceptions). The tuffs of Pactolus and Davis Mine may have been erupted from the southern Shoshone Mountains and may date from about 34 Ma. The tuff of Return Mine and tuffs in the lower part of the Menter Canyon section are undated but probably date from 30 to 26 Ma. Sources for these latter tuffs have not been identified. Compositions of the tuffs of Pactolus, Davis Mine, and Return Mine are unknown due to extensive hydrothermal alteration, but modal analyses suggest that they are rhyolites similar to other Oligocene calc-alkaline ash-flow tuffs exposed throughout the Great Basin (for example, Best and others, 1989a, b; Gans and others, 1989).

In the southern part of the Paradise Range and in the Pactolus Hills, eruption of the tuffs of Pactolus and Davis Mine may have been followed by a period of normal faulting and tilting. These tuffs, particularly the tuff of Davis Mine, have a different structural orientation

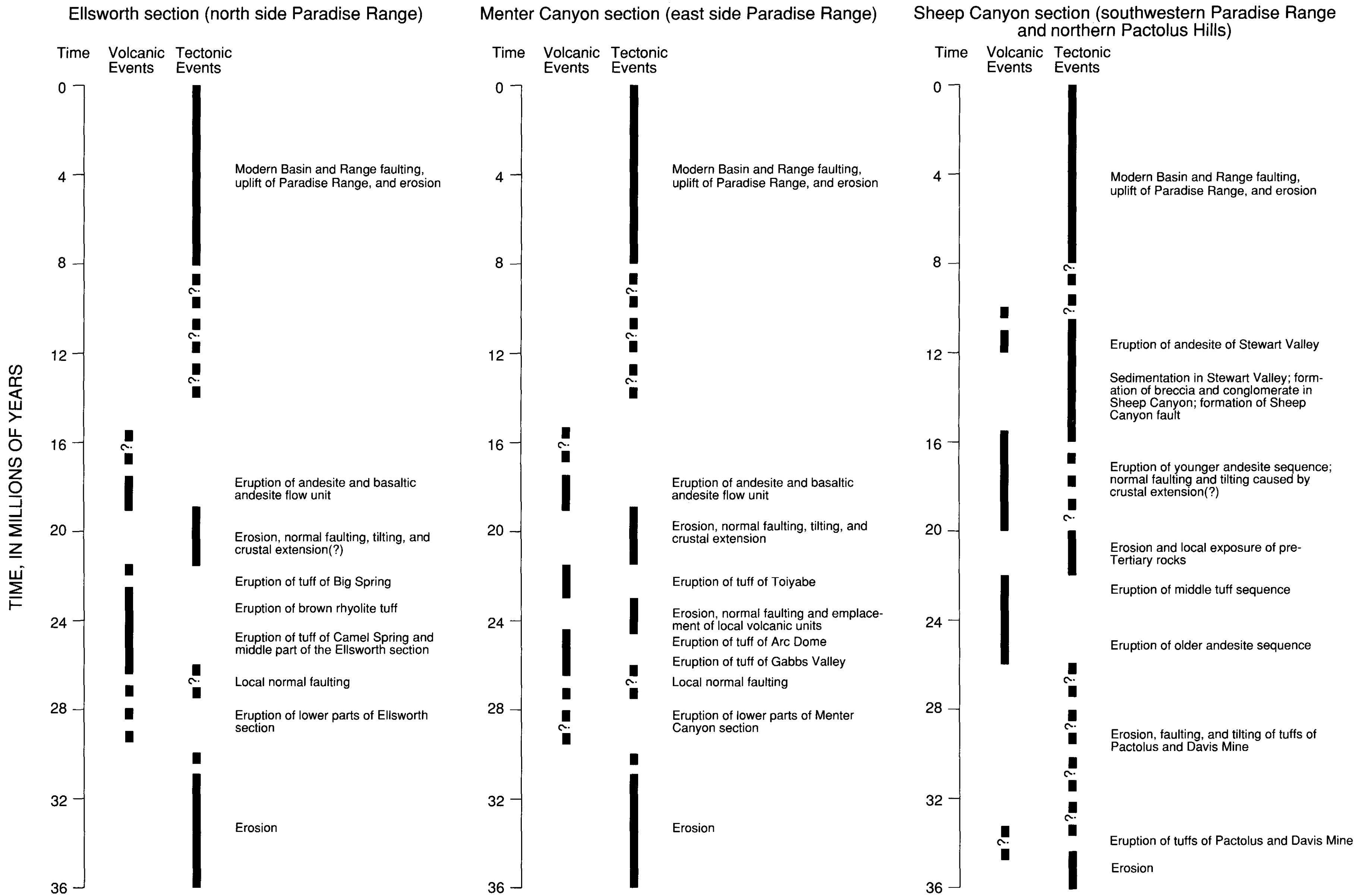


Figure 16. Schematic summary of late Cenozoic volcanic-tectonic history of Paradise Range and northern Pactolus Hills.

compared to younger rocks in the same area, suggesting that the older tuffs may have undergone a period of faulting and tilting prior to eruption of the younger rocks.

Oligocene faulting and extension also have been suggested for several areas near the Paradise Range. Boden (1986) and Mills and others (1988) presented data on the orientation of Oligocene faults and dikes near Round Mountain in the southern Toquima Range and suggested that the orientation of these features indicates a period of Oligocene normal faulting and extension(?). R.F. Hardyman (written commun., 1987) described a major angular unconformity between Oligocene ash-flow tuff units in the Dicalite Summit area at South Cedar Mountain. Seedorff (1981, 1991) also described a major angular unconformity between Oligocene ash-flow tuff units in the Royston area and suggested that a widespread episode of crustal extension occurred about 27 Ma.

In the southwestern Paradise Range and in northern Pactolus Hills, voluminous eruptions of an older sequence of intermediate to silicic lavas occurred between about 26 and 24 Ma. The lavas are not widespread in adjacent ranges and therefore probably had fairly local sources. However, most contacts with pre-Tertiary rocks are faults whose displacement are unknown, which precludes accurate reconstruction of the original distribution of these lavas. These lavas were conformably(?) overlain by a thick sequence of silicic ash-flow tuff and less abundant intermediate to felsic lava that erupted during a short period of time about 23 Ma. Differences in chemistry and petrography suggest at least three sources for the tuffs, but vents have not been identified. The older andesite sequence and ash-flow tuffs form a broadly calc-alkalic, high-K series that is petrochemically similar to other calc-alkaline sequences erupted throughout much of the Great Basin during the Oligocene and earliest Miocene (approx 36 to 22 Ma).

On the east side of the Paradise Range, ash-flow tuff erupted from several major sources was deposited between about 26 and 24.5 Ma. These tuffs were erupted from Gabbs Valley (tuff of Gabbs Valley) and from the west side of the Toiyabe Range (tuff of Arc Dome). Following eruption of the tuff of Arc Dome, there was a major period of erosion lasting until about 22 to 23 Ma. Erosion may have resulted from local uplift due to faulting as suggested by the local preservation of small exposures of tuffs overlying the tuff of Arc Dome near Brunton Pass and the formation of a volcanic-tectonic trough in the southern Toiyabe Range at this time (Brem and others, 1985, 1991). About 22 to 23 Ma, eruptions of the tuff of Toiyabe covered most of the east side of the Paradise Range and the Pactolus Hills. Although exposed far west and south of the Paradise Range, this tuff is not present in the southwestern Paradise Range, possibly because that part of the range was a topographic high.

Following eruption of the tuff of Toiyabe and the tuffs in the Sheep Canyon section at about 22 Ma, there was a hiatus in volcanic activity that lasted about 2 m.y. in the southwestern Paradise Range and about 3 m.y. in the northern Pactolus Hills and on the east side of the Paradise Range. A similar hiatus in volcanic activity is widespread in west-central Nevada and generally marks the end of voluminous silicic ash-flow tuff eruptions at this latitude (see discussion and references in John and others, 1989b).

In the Paradise Range, and in most ranges to the west where the Oligocene and early Miocene tuff is preserved, there is evidence for a major period of normal faulting and, locally, extreme crustal extension that began during or shortly after the early Miocene hiatus in volcanic activity. In the Paradise Range, this faulting event is marked by major unconformities between Oligocene to early Miocene tuffs and the younger andesite sequence and changes in the abundance and orientation of faults. The tuff of Toiyabe and overlying basaltic andesite lavas are separated by a 10°–25° angular unconformity on the east side of the range. In the northern Pactolus Hills, there is as much as a 75° angular unconformity between the Cloverdale Ranch unit of the tuff of Toiyabe and overlying hornblende andesite lava flows and flow breccias.

Normal faulting and intermediate to felsic volcanism occurred simultaneously in the southwestern Paradise Range during the early Miocene. Numerous low-angle faults, which may have originated as high-angle faults, formed at this time. There is a pronounced unconformity between the tuffs and overlying hornblende andesite and porphyritic dacite units, and a paleosol containing rounded granitic boulders locally separates the tuff of Sheep Canyon from the overlying hornblende andesite unit, suggesting uplift of the range and exposure of the pre-Tertiary basement prior to eruption of the hornblende andesite unit. Andesite dikes, interpreted as feeders for the upper part of the hornblende andesite unit, cross-cut low-angle faults between the older andesites and tuffs. Preliminary paleomagnetic data suggest that these dikes are untilted (M.R. Hudson, oral commun., 1989). Rhyolite dikes, interpreted as silicic differentiates of the younger andesites, also cross-cut low-angle faults. Elsewhere in the southwestern Paradise Range, lava flows in the hornblende andesite unit are steeply tilted and are in low-angle fault contact with the tuff sequence.

Near the end of eruption of the younger sequence of intermediate lavas, a large basin formed in Stewart Valley. Subsidence and sedimentation in this basin lasted from about 15 to 12–11 Ma. Sedimentary rocks in Stewart Valley are at least 445 m thick (Molinari, 1984).

In the southwestern Paradise Range and in the northern Pactolus Hills, these sedimentary rocks locally lap up against the older rocks and cover older faults. The Sheep Canyon detachment fault in the southwestern Paradise Range may have formed at this time, perhaps as a large gravity slide, as this fault cuts rhyolite dikes dated at 19 to 16 Ma and the hornblende andesite unit (20 to >16 Ma). The breccia and conglomerate unit exposed near Willow Spring in the southwestern Paradise Range also may have formed during this time from landslide debris shed into a small half-graben that formed either along a northeast-trending fault that cuts the Sheep Canyon fault or along the Sheep Canyon fault. Blocks of sinter in the breccia and conglomerate unit, and local silicification and pyritic alteration along the margin of these rocks where they were deposited against a northeast-trending fault, suggest that hydrothermal activity occurred during formation of these rocks and that they probably are not much younger than the youngest volcanic rocks in the area (approximately 15.5 Ma in the southwestern Paradise Range).

The latest volcanic activity in the area occurred south of the Paradise Range at the north end of Stewart Valley, in the southern Pactolus Hills, and at the north end of Cedar Mountain, where 50–100 m of andesite lava and lahars locally cap the sedimentary rocks. These rocks are about 12 Ma at the north end of Stewart Valley (John and others, 1989b), but rocks further south are undated and may be slightly younger.

The present physiography of the Paradise Range and northern Pactolus Hills is mainly controlled by north- to north-northeast-trending high-angle normal faults that are modern Basin and Range structures. These faults resulted in the uplift of the Paradise Range and Pactolus Hills relative to Gabbs, Lodi, and Stewart Valleys (fig. 2). It is unknown when movement on these faults began, but movement probably has continued into the Quaternary (J.C. Dohrenwend, oral commun., 1989).

COMPARISON OF THE PARADISE RANGE TO OTHER HIGHLY EXTENDED TERRANES IN THE BASIN AND RANGE PROVINCE

Gans and others (1989) described early Oligocene synextensional magmatism in eastern Nevada and summarized tectonic and volcanic features of other highly extended terranes in the Basin and Range province. They recognized six features that are common to most highly extended terranes: (1) multiple generations of imbricated normal faults with older faults cut and rotated to low angles by younger high-angle normal faults; (2) volcanic sequences that show broad compositional zonation upward from intermediate composition at the base to more silicic composition at the top (andesite or basaltic andesite at the base to dacite or rhyolite at the top); (3) relatively short duration of volcanism (several million years) and high rate of volcanic eruption; (4) beginning of extension either synchronous with, or immediately after, peak magmatic activity; (5) a marked decrease or cessation of volcanic eruption shortly after initiation of extension with deposition of thick sections of coarse sedimentary rocks during extension; and (6) local presence of gently dipping sequences of basalt (±rhyolite) interstratified with fanglomerates. These capping sequences overlie older volcanic rocks along an angular unconformity. Several of these features are present in the Paradise Range, although there are notable differences.

Oligocene and early Miocene rocks in the Paradise Range show evidence for multiple generations of normal faults formed during a period of early Miocene faulting; the oldest faults now dip at low angles and are cut by younger normal and strike-slip faults. Upper plate rocks generally dip at moderate to high angles into the fault planes suggesting that the low-angle faults may be rotated high-angle faults. The oldest faults generally trend northwest, whereas the youngest faults generally trend north-northeast to northeast. The origin of many of the low-angle faults remains unclear. The amount of stratal rotation of lower plate rocks for many of the low-angle faults is indeterminate. Preliminary paleomagnetic studies of rocks beneath the Sheep Canyon fault suggest that the lower plate rocks of this fault have not been tilted as much as upper plate rocks (John and Hudson, 1990; M.R. Hudson, oral commun., 1989). Thus, the Sheep Canyon fault may have originated as a low-angle structure. In addition, depositional contacts between pre-Tertiary and Tertiary rocks are absent in the Paradise Range, and therefore restored cross sections showing pre-Cenozoic faulting cannot be constructed. These relations preclude a unique interpretation of the faulting history in the Paradise Range, but it is likely that at least some low-angle normal faults are rotated high-angle faults.

Synextensional magmatic rocks in the Paradise Range may show gross overall compositional zonation from intermediate to more silicic compositions with decreasing age, although the volume of siliceous rocks is small and mostly consists of small rhyolitic intrusions. Compositions of syn- to post-extensional intermediate lavas do not appear to change systematically with time. The oldest lavas in the southwestern part of the Paradise Range, the hornblende andesite unit, are compositionally similar to many of the younger lavas (approximately 58.7–61.7 weight percent SiO_2; table 6). Lavas in a well-exposed, 500+m-thick section of intermediate lavas in Finger Rock Wash range from about 55 to 63 weight percent SiO_2, although there is almost no variation between the lowest and uppermost exposures that contain approximately 61 weight percent SiO_2. In a 200-m-thick section of the youngest part of the younger andesite sequence exposed about 2 km southwest of the Paradise Peak Mine, lavas decrease from about 70 weight percent SiO_2 at the base of the section to about 64 weight percent SiO_2 at the top of the section. In the Pactolus Hills, SiO_2 increases from about 58 to 62.5 weight percent from the base to the middle of the section. However, many of the youngest rocks in the southwestern Paradise Range are small rhyolitic intrusions that are distinctly more siliceous than the lavas (SiO_2 content of the intrusions is 71.5–76 weight percent), suggesting that there may be a general tendency toward more siliceous compositions with decreasing age.

Synextensional volcanism in the southwestern Paradise Range lasted about 4.5 m.y., somewhat longer than in most areas discussed by Gans and others (1989). In other parts of the Paradise Range and in the northern Pactolus Hills, the duration of volcanism is unknown. In comparison to the southwestern Paradise Range, most of the synextensional volcanic rocks in the Yerington district were erupted in about 2 m.y. (between 19 and 17 Ma) (Proffett, 1977; Proffett and Proffett, 1976), and in eastern Nevada most of the synextensional rocks were erupted in 1–2 m.y. (Gans and others, 1989).

Early Miocene normal faulting and extension occurred during a hiatus in magmatic activity and prior to onset of large-volume intermediate volcanism on the east side of the Paradise Range and in the Pactolus Hills. Major angular unconformities separate Oligocene to earliest Miocene tuff from overlying early Miocene lavas. The early Miocene lavas generally are tilted less than 15–20°, in contrast to the underlying tuffs that locally are tilted as much as 75°. In the southwestern Paradise Range, relative timing between faulting and intermediate volcanism is less well constrained, but the lower part of the younger andesite sequence is tilted as much as the ash-flow tuffs, and thus large-volume, intermediate volcanism began prior to extensional faulting.

In the Paradise Range, intermediate-composition magmatism continued well after extension started, and synextensional sedimentary rocks are absent. These relations are well exposed on the east side of the range and in the northern Pactolus Hills, where thick sequences of intermediate lava appear to entirely postdate early Miocene extensional faulting, and sedimentary horizons are virtually absent. Gently dipping sedimentary horizons in the central and southern Pactolus Hills grade laterally into thick sequences of sedimentary rocks in Stewart Valley. The sedimentary rocks of Stewart Valley lap over low-angle faults and steeply tilted tuffs and appear to entirely postdate early Miocene faulting. Farther west on the east side of the Gabbs Valley Range, the base of the sedimentary rocks section has been dated at about 15 Ma, whereas faulting occurred between 22 and 19 Ma. In the southwestern Paradise Range, coarse sedimentary breccia locally is present, but its age and origin are unclear. The breccia probably is younger than the major period of early Miocene faulting as it appears to lap over low-angle faults and steeply tilted tuffs and is inferred to have filled a half-graben formed by a fault that cuts the Sheep Canyon fault.

In summary, the late Cenozoic volcanic-tectonic history of Paradise Range differs from that of other highly extended terranes in the Basin and Range province. Much extensional faulting occurred during a hiatus in magmatic activity in the early Miocene. Extension was followed by a relatively long episode of dominantly intermediate composition magmatism that is geochemically distinct from earlier, dominantly silicic magmatism common throughout west-central Nevada during the Oligocene and early Miocene. There is little systematic compositional variation in intermediate lavas erupted during or just after extensional faulting, and true basalts are absent in the Paradise Range. Major horizons of synextensional sedimentary rocks also are absent in the Paradise Range. It is not clear whether these differences between the Paradise Range and highly extended terranes in the Basin and Range province represent local variations or fundamentally different styles of crustal extension and volcanism.

REFERENCES CITED

Armstrong, R.L., 1970, Geochronology of Tertiary igneous rocks, eastern Basin and Range Province, western Utah, eastern Nevada, and vicinity, U.S.A.: Geochimica et Cosmochimica Acta, v. 34, p. 203–232.

Ashley, R.P., 1979, Relation between volcanism and ore deposition at Goldfield, Nevada: Nevada Bureau of Mines and Geology Report 33, p. 77–86.

Best, M.G., Christiansen, E.H., and Blank, R.H., Jr., 1989a, Oligocene caldera complex and calc-alkaline tuffs and lavas of the Indian Peak volcanic field, Nevada and Utah: Geological Society of America Bulletin, v. 101, p. 1076–1090.

Best, M.G., Christiansen, E.H., Deino, A.L., Grommé, C.S., McKee, E.H., and Noble, D.C., 1989b, Excursion 3A: Eocene through Miocene volcanism in the Great Basin of the Western United States: New Mexico Bureau of Mines and Geology Resources Memoir 47, p. 91–133.

Bingler, E.C., 1978, Abandonment of the name Hartford Hill Rhyolite Tuff and adoption of new formation names for middle Tertiary ash-flow tuffs in the Carson City-Silver City area, Nevada: U.S. Geological Survey Bulletin 1457-D, 19 p.

Boden, D.R., 1986, Eruptive history and structural development of the Toquima caldera complex, central Nevada: Geological Society of America Bulletin, v. 97, p. 61–74.

———1989, Evidence for step-function zoning of magma and eruptive dynamics, Toquima caldera complex, Nevada: Journal of Volcanology and Geothermal Research, v. 37, p. 39–57.

Bonham, H.F., Jr., 1970, Geologic map and sections of a part of the Shoshone Mountains, Lander and Nye Counties, Nevada: Nevada Bureau of Mines and Geology Map 32, scale 1:62,500.

Bonham, H.F., Jr., and Garside, L.J., 1979, Geology of the Tonopah, Lone Mountain, Klondike, and northern Mud Lake quadrangles, Nevada: Nevada Bureau of Mines and Geology Bulletin 92, 142 p.

Brem, G.F., John, D.A., Nash, J.T., Poole, F.G., and Synder, D.B., 1991, Mineral resources of the Arc Dome Wilderness Recommendation Area, Nye County, Nevada: U.S. Geological Survey Bulletin 1961, 21 p.

Brem, G.F., Purdy, T.L., and Snyder, D.B., 1985, Oligocene and Miocene volcanic-tectonic history of the southern Toiyabe and Shoshone Mountains [abs.]: Geological Society of America Abstracts with Programs, v. 17, p. 343.

Brooks, W.E., 1986, Distribution of anomalously high K_2O volcanic rocks in Arizona: Metasomatism at the Picacho Peak detachment fault: Geology, v. 14, p. 339–342.

Christiansen, R.L., and Lipman, P.W., 1972, Cenozoic volcanism and plate-tectonic evolution of the Western United States—Part II—Late Cenozoic: Philosophical Transactions of the Royal Society of London, v. 271, p. 249–284.

Christiansen, R.L., Lipman, P.W., Carr, W.J., Byers, F.M., Jr., Orkild, P.P., and Sargent, K.A., 1977, Timber Mountain-Oasis Valley caldera complex of southern Nevada: Geological Society of America Bulletin, v. 88, p. 943–959.

Conrad, W.K., 1984, The mineralogy and petrology of compositionally zoned ash flow tuffs, and related silicic volcanic rocks, from the McDermitt caldera complex, Nevada-Oregon: Journal of Geophysical Research, v. 89, no. B10, p. 8639–8664.

Deino, A.L., 1985, Stratigraphy, chemistry, K-Ar dating, and paleomagnetism of the Nine Hill Tuff, California-Nevada: Part 1: Berkeley, University of California, Ph.D. thesis, 338 p.

———1989, Single-crystal $^{40}Ar/^{39}Ar$ dating as an aide in correlation of ash flows: Examples from the Chimney Spring/New Pass Tuffs and the Nine Hill/Bates Mountain Tuffs of California and Nevada [abs.]: New Mexico Bureau of Mines and Mineral Resources Bulletin 131, p. 70.

Ekren, E.B., and Byers, F.M., Jr., 1976, Ash-flow fissure vent in west-central Nevada: Geology, v. 4, p. 247–251.

———1984, The Gabbs Valley Range—A well exposed segment of the Walker Lane in west-central Nevada, *in* Lintz, Joseph, Jr., ed., Western geological excursions, volume 4, 1984, Annual Meeting of the Geological Society of America: Boulder, Geological Society of America, p. 203–215.

———1985, Geologic map of the Gabbs Mountain, Mount Ferguson, Luning and Sunrise Flat quadrangles, Mineral and Nye Counties, Nevada: U.S. Geological Survey Miscellaneous Investigations Map Series I–1577, scale 1:48,000.

———1986, Geologic map of the Mount Annie NE, Mount Annie, Ramsey Spring, and Mount Annie SE quadrangles, Mineral and Nye Counties, Nevada: U.S. Geological Survey Miscellaneous Investigations Map Series I–1579, scale 1:48,000.

Ekren, E.B., Byers, F.M., Jr., Hardyman, R.F., Marvin, R.F., and Silberman, M.L., 1980, Stratigraphy, preliminary petrology, and some structural features of Tertiary volcanic rocks in the Gabbs Valley and Gillis Ranges, Mineral County, Nevada: U.S. Geological Survey Bulletin 1464, 54 p.

Ekren, E.B., Quinlivan, W.D., Snyder, R.P., and Kleinhampl, F.J., 1974, Stratigraphy, structure, and geologic history of the Lunar Lake caldera of northern Nye County, Nevada: U.S. Geological Survey Journal of Research, v. 2, p. 599–608.

Evernden, J.F., Savage, D.E., Curtis, G.H., and James, G.T., 1964, Potassium-argon dates and the Cenozoic mammalian chronology of North America: American Journal of Science, v. 262, p. 145–198.

Ferguson, H.G., and Cathcart, S.H., 1954, Geologic map of the Round Mountain quadrangle, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ–40, scale 1:125,000.

Gans, P.B., Mahood, G.A., and Schermer, Elizabeth, 1989, Synextensional magmatism in the Basin and Range Province; a case study from the eastern Great Basin: Geological Society of America Special Paper 233, 53 p.

Gill, J.B., 1981, Orogenic andesites and plate tectonics: New York, Springer-Verlag, 385 p.

Glazner, A.F., 1988, Stratigraphy, structure, and potassic alteration of Miocene volcanic rocks in the Sleeping Beauty area, central Mojave Desert, California: Geological Society of America Bulletin, v. 100, p. 424–435.

Hardyman, R.F., 1980, Geologic map of the Gillis Canyon quadrangle, Mineral County, Nevada: U.S. Geological Survey Miscellaneous Investigations Series Map I–1237, scale 1:48,000.

Healey, D L., Snyder, D.B., and Wahl, R.R., 1981, Bouguer gravity map of Nevada: Tonopah sheet: Nevada Bureau of Mines and Geology Map 73, scale 1:250,000.

Hildreth, Wes, 1981, Gradients in silicic magma chambers: Implications for lithospheric magmatism: Journal of Geophysical Research, v. 86, p. 10,153–10,192.

Jackson, L.L., Brown, F.W., and Neil, Sarah, 1987, Major and minor elements requiring individual determination, classical whole rock analysis, and rapid rock analysis, *in* Baedecker, P.A., ed., Methods for geochemical analysis: U.S. Geological Survey Bulletin 1770, p. G1–G23.

John, D.A., 1986, Geology of Tertiary volcanic rocks in the Paradise Range and northern Pactolus Hills, Nye County, Nevada [abs.]: U.S. Geological Survey Open-File Report 86–467, p. 13.

———1987, Map showing the distribution and characteristics of plutonic rocks in the Tonopah 1° by 2° quadrangle, central Nevada: U.S. Geological Survey Miscellaneous Field Studies Map MF–1877–J, scale 1:250,000.

———1988, Geologic map of Oligocene and Miocene volcanic rocks in the Paradise Peak and western part of the Ione quadrangles, Nye County, Nevada: U.S. Geological Survey Miscellaneous Field Studies Map MF–2025, scale 1:24,000, 2 sheets.

John, D.A., and Hudson, M.L., 1990, Paleomagnetic evidence for the geometry and chronology of Tertiary tectonic rotations, Paradise Range, western Nevada [abs.]: Eos, v. 71, no. 43, p. 1295.

John, D.A., and Kelleher, P.L., 1987, Bedrock geologic map of the Goldyke quadrangle, Nye County, Nevada: U. S. Geological Survey Miscellaneous Field Studies Map MF–1963, scale 1:24,000.

John, D.A., and McKee, E.H., 1987, K-Ar ages of granitic plutonism and hydrothermal alteration in the western part of the Tonopah 1° by 2° quadrangle, Nevada: Isochron/West, no. 48, p. 16–18.

John, D.A., Nash, J.T., Clark, C.W., and Wulftange, W.H., 1991, Geology, hydrothermal alteration, and mineralization at the Paradise Peak gold-silver-mercury deposit, Nye County, Nevada, *in* Raines, G.L., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., eds., Symposium on the geology and ore deposits of the Great Basin, symposium proceedings: Reno, Geological Society of Nevada and U.S. Geological Survey, p. 1020–1050.

John, D.A., Thomason, R.E., Clark, C.W., and McKee, E.H., 1989a, Volcanic-tectonic setting and geology of the Paradise Peak gold-silver-mercury deposit, Nye County, Nevada [abs.], *in* Schindler, K.S., ed., USGS research on mineral resources—1989 program and abstracts: U.S. Geological Survey Circular 1035, p. 37–38.

John, D.A., Thomason, R.E., and McKee, E.H., 1989b, Geology and K-Ar geochronology of the Paradise Peak Mine and the relationship of pre-Basin and Range extension to early Miocene precious-metal mineralization in west-central Nevada: Economic Geology, v. 84, p. 631–649.

Johnson, R.G., and King, B.S.L., 1987, Energy-dispersive x-ray fluorescence spectrometry, *in* Baedecker, P.A., ed., Methods for geochemical analysis: U.S. Geological Survey Bulletin 1770, p. F1–F5.

Kistler, R.W., Chappell, B.W., Peck, D.L., and Bateman, P.C., 1986, Isotopic variation in the Tuolumne Intrusive Suite, central Sierra Nevada, California: Contributions to Mineralogy and Petrology, v. 94, p. 205–220.

Kleinhampl, F.J., and Ziony, J.I., 1967, Preliminary geologic map of northern Nye County, Nevada: U.S. Geological Survey Open-File Map, scale 1:200,000.

———1984, Mineral resources of northern Nye County: Nevada Bureau of Mines and Geology Bulletin 99B, 241 p.

———1985, Geology of northern Nye County, Nevada: Nevada Bureau of Mines and Geology Bulletin 99A, 172 p.

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

Lipman, P.W., Christiansen, R.L., and O'Connor, T.J., 1966, A compositionally zoned ash-flow sheet in southern Nevada: U.S. Geological Survey Professional Paper 524–F, 47 p.

Locke, Augustus, Billingsley, P.R., and Mayo, E.B., 1940, Sierra Nevada tectonic patterns: Geological Society of America Bulletin, v. 51, p. 513–540.

Ludwig, K.R., 1987, Isoplot200, a plotting and regression program for isotope geochemists, for use with HP Series 200 computers: U.S. Geological Survey Open-File Report 85–513, 102 p.

McKee, E.H., 1971, Tertiary igneous chronology of the Great Basin of the western United States: Implications for tectonic models: Geological Society of America Bulletin, v. 82, p. 3497–3502.

McKee, E.H., and John, D.A., 1987, Sample locality map and potassium-argon ages and data for Cenozoic igneous rocks in the Tonopah 1° x 2° quadrangle, central Nevada: U.S. Geological Survey Miscellaneous Field Studies Map MF–1877–I, scale 1:250,000.

McKee, E.H., Silberman, M.L., Marvin, R.E., and Obradovich, J.D., 1971, A summary of radiometric ages of Tertiary volcanic rocks in Nevada and eastern California, Part 1: Central Nevada: Isochron/West, no. 2, p. 21–42.

Mellot, M.G., and Hart, W.K., 1987, Petrogenesis and tectonic significance of andesites from the northern Basin and Range, Nevada [abs.]: Geological Society of America Abstracts with Programs, v. 19, p. 770.

Mills, B.A., Boden, D.R., and Sander, M.V., 1988, Alteration and precious metal mineralization associated with the Toquima caldera complex, Nye County, Nevada, *in* Schafer, R.W., Cooper, J.J., and Vikre, P.G., eds., Bulk mineable precious metal deposits of the Western United States, symposium proceedings: Reno, Geological Society of Nevada, p. 303–331.

Molinari, M.P., 1984, Late Cenozoic structural geology of Stewart and Monte Cristo Valleys, Walker Lane of west central Nevada, *in* Lintz, Joseph, Jr., ed., Western geological excursions, volume 4, 1984 Annual Meeting of the Geological Society of America: Boulder, Geological Society of America, p. 219–231.

Morton, J.L., Silberman, M.L., Bonham, H.F., Jr., Garside, L.J., and Noble, D.C., 1977, K-Ar ages of volcanic rocks, plutonic rocks, and ore deposits in Nevada and eastern California: Isochron/West, no. 20, p. 19–29.

Noble, D.C., 1970, Loss of sodium from crystallized comendite welded tuffs of the Miocene Grouse Canyon member of the Belted Range Tuff, Nevada: Geological Society of America Bulletin, v. 81, p. 2677–2688.

Noble, D.C., and Christiansen, R.L., 1974, Black Mountain volcanic center, *in* Guidebook to the geology of four Tertiary volcanic centers in central Nevada: Nevada Bureau of Mines and Geology Report 19, p. 22–34.

Oldow, J.S., 1984, Evolution of a late Mesozoic back-arc fold and thrust belt, northwestern Great Basin, U.S.A.: Tectonophysics, v. 102, p. 245–274.

Palmer, A.R., compiler, 1983, The Decade of North American Geology 1983 time scale: Geology, v. 11, p. 503–504.

Peacock, M.A., 1931, Classification of igneous rock series: Journal of Geology, v. 39, p. 54–67.

Proffett, J.M., Jr., 1977, Cenozoic geology of the Yerington district, Nevada and implications for the nature and origin of basin and range faulting: Geological Society of America Bulletin, v. 88, p. 247–266.

Proffett, J.M., Jr., and Dilles, J.H., 1984, Geologic map of the Yerington district, Nevada: Nevada Bureau of Mines and Geology Map 77, scale 1:24,000.

Proffett, J.M., Jr., and Proffett, B.H., 1976, Stratigraphy of the Tertiary ash-flow tuffs in the Yerington district, Nevada: Nevada Bureau of Mines and Geology Report 27, 28 p.

Rytuba, J.J., and McKee, E.H., 1984, Peralkaline ash flow tuffs and calderas of the McDermitt volcanic field, southeast Oregon and north central Nevada: Journal of Geophysical

Research, v. 89, p. B8616–8628.
Seedorff, C.E., 1981, Geology of the Royston porphyry copper prospect, Nye and Esmeralda Counties, Nevada: Stanford, California, Stanford University, M.S. thesis, 106 p.
———1991, Royston district, western Nevada: A Mesozoic porphyry copper system that was tilted and disrupted by Tertiary normal faults, *in* Geological Society of Nevada Symposium; The Geology and Ore Deposits of the Great Basin (in press).
Shapiro, Leonard, 1975, Rapid analysis of silicate, carbonate, and phosphate rocks—Revised edition: U.S. Geological Survey Bulletin 1401, 76 p.
Silberling, N.J., and John, D.A., 1989, Geologic map of pre-Tertiary rocks of the Paradise Range and southern Lodi Hills, west-central Nevada: U.S. Geological Survey Miscellaneous Field Studies Map MF–2062, scale 1:24,000, 2 sheets.
Silberman, M.L., Stewart, J.H., and McKee, E.H., 1976, Igneous activity, tectonics, and hydrothermal precious-metal mineralization in the Great Basin during Cenozoic time: Society of Mining Engineers of the AIME Transactions, v. 260, p. 253–263.
Snyder, D.B., and Healey, D.L., 1984, Interpretation of the Bouguer gravity map of Nevada: Tonopah sheet: Nevada Bureau of Mines and Geology Report 38, 14 p.
Snyder, W.S., Dickinson, W.R., and Silberman, M.L., 1976, Tectonic implications of space-time patterns of Cenozoic magmatism in the Western United States: Earth and Planetary Science Letters, v. 32, p. 91–106.
Steiger, R.H., and Jager, E., 1977, Subcommission on geochronology: Convention on the use of decay constants in geo- and cosmochronology: Earth and Planetary Science Letters, v. 36, p. 359–362.
Stewart, J.H., 1978, Basin-range structure in western North America: A review: Geological Society of America Memoir 152, p. 1–31.
———1988, Tectonics of the Walker Lane Belt, western Great Basin—Mesozoic and Cenozoic deformation in a zone of shear, *in* Ernst, W.G., ed., Metamorphism and crustal evolution of the Western United States, Rubey Volume VII: Englewood Cliffs, New Jersey, Prentice-Hall, p. 683–713.
Stewart, J.H., Carlson, J.E., and Johannesen, D.C., 1982, Geologic map of the Walker Lake 1° by 2° quadrangle, California and Nevada: U.S. Geological Survey Miscellaneous Field Studies Map MF–1382–A, scale 1:250,000.
Taggert, J.E., Lindsay, J.R., Scott, B.A., Vivit, D.V., Bartel, A.J., and Stewart, K.C., 1987, Analysis of geological materials by wavelength-dispersive x-ray fluorescence spectrometry, *in* Baedecker, P.A., ed., Methods for geochemical analysis: U.S. Geological Survey Bulletin 1770, p. E1–E19.
Vitaliano, C.J., 1963, Cenozoic geology and sections of the Ione quadrangle, Nye County, Nevada: U.S. Geological Survey Mineral Investigations Field Studies Map MF–255, scale 1:62,500.
Vitaliano, C.J., and Callaghan, Eugene, 1963, Geology of the Paradise Peak quadrangle, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ–250, scale 1:62,500.
Vitaliano, C.J., and Vitaliano, D.B., 1972, Cenozoic volcanic rocks in the southern Shoshone Mountains and Paradise Range, Nevada: Geological Society of America Bulletin, v. 83, p. 3269–3280.
Vikre, P.G., McKee, E.H., and Silberman, M.L., 1988, Chronology of Miocene hydrothermal and igneous events in the western Virginia Range, Washoe, Storey, and Lyon Counties, Nevada: Economic Geology, v. 83, p. 864–874.
Whitebread, D.H., 1976, Alteration and geochemistry of Tertiary volcanic rocks in parts of the Virginia City quadrangle, Nevada: U.S. Geological Survey Professional Paper 936, 43 p.
———1986, Generalized geologic map of the Tonopah 1° by 2° quadrangle, Nevada: U.S. Geological Survey Open-File Report 86–462, scale 1:250,000.
Whitebread, D.H., Silberling, N.J., Brem, G.F., and Andrews, T.D., 1988, Preliminary geologic map of the eastern half of the Ione quadrangle, Nye County, Nevada: U.S. Geological Survey Open-File Report 88–48, scale 1:62,500.

TABLES 1–17

Table 1. Characteristics of major ash-flow tuff units in the Menter Canyon section

Unit	Tuff of Green Springs	Tuff of Menter Canyon	Tuff of Camel Spring	Tuff of Gabbs Valley	Tuff of Arc Dome	Tuff of Brunton Pass	Tuff of Toiyabe (main phase)
Composition[1]	High-silica rhyolite	Rhyolite	Rhyolite	Rhyolite	Rhyolite-high-silica rhyolite	High-silica rhyolite	Rhyolite
Percent phenocrysts	1–6	1	0–10	5–7	30–40	6–8	14–30
Major phenocrysts[2]	S	P	A, P, S	S, P, Q	S, Q, P, B	Q, P	P, Q, S, B, H
Flattened pumice clasts	Locally abundant	Locally abundant	Locally abundant	Abundant, to 15 cm	Abundant, crystal-rich; black glass at base	Locally abundant	Locally abundant, crystal rich
Welding	Dense	Poor to dense	Poor to dense	Dense	Dense	Poor to dense	Dense
Lithics	Locally abundant	Abundant	Abundant	Abundant	Sparse except at base	Sparse	Sparse except at base
Simple or compound cooling unit	Compound	Compound	Compound	Simple (in Paradise Range)	Simple	Simple	Simple
Notable characteristics	Local secondary flow structures	Abundant pink rhyolite lithic fragments	Anorthoclase phenocrysts	Extremely densely welded; abundant granitic clasts	Abundant smoky quartz phenocrysts	Smoky quartz phenocrysts	Abundant accessory sphene
Thickness[3] (m)	300(?)	200	250	350	400	90	400+
Age (Ma) (see table 3)	>26	>26	>26	26–25	25–24.5	<25 and >22	23–22
Areal distribution[4]	PR	PR, SM	PR, SM, GV(?)	PR, SM, GV, GR, SS, Y	PR, SM, T, TQ(?), SS	PR	PR, SM, T, RH, PH, CM, GV(?), BH(?)
Source	Unknown	Unknown	Unknown	Gabbs Valley	Southern Reese River Valley	Unknown	Southern Toiyabe Range
Comments	Upper cooling unit commonly contains fragments of lower cooling unit	Commonly vitrophyric	—	Only lower member present in Paradise Range; commonly vitrophyric	Smoky quartz member of Toiyabe Quartz Latite of former usage (see Kleinhampl and Ziony, 1985; Bonham, 1970)	—	Correlative with the tuff of Copper Mountain of Ekren and others (1980)

[1]Classification is IUGS chemical classification (Le Bas and others, 1986) based on total alkali and silica contents of whole-rock samples recalculated to 100 percent volatile-free.
[2]S, sanidine; P, plagioclase; A, anorthoclase; Q, quartz; B, biotite; H, hornblende.
[3]Maximum thickness in the Paradise Range.
[4]PR, Paradise Range; SM, Southern Shoshone Mountains; GV, Gabbs Valley Range; GR, Gillis Range; SS, Southern Sand Springs Range; Y, Yerington district; T, Toiyabe Range; TQ, Toquima Range; RH, Northern Royston Hills; PH, Pactolus Hills; CM, North Cedar Mountain; BH, Barnett Hills.

Table 2. Summary of modal data for ash-flow tuffs in the Paradise Range and northern Pactolus Hills

[Numbers give range and (mean) values for all samples. Accessory minerals typically present in trace (tr) amounts; all, allanite; ap, apatite; cpx, clinopyroxene; sph, sphene; z, zircon]

Unit	Number of samples	Quartz	Plagioclase	K-feldspar	Groundmass	Biotite	Hornblende	Opaque minerals	Accessory minerals
					Menter Canyon section				
Tuff of Toiyabe (main phase)	22	1.7–11.5 (6.3)	7.1–25.1 (10.9)	1.8–7.8 (5.2)	61.1–85.6 (73.8)	0.9–3.4 (2.1)	0.0–2.9 (1.1)	0.1–1.1 (0.6)	sph (cpx, z)
Tuff of Toiyabe (Cloverdale Ranch unit)	3	0.4–4.4 (2.2)	20.6–26.3 (23.8)	2.3–3.6 (3.1)	62.1–66.6 (64.9)	3.3–3.9 (3.5)	0.4–1.4 (0.9)	0.5–1.6 (0.9)	cpx=0.6, z, (sph)
Biotite tuff	2	0.2–0.4	22.6–24.3	0.3–0.8	68.0–71.3	4.1–5.2	0.0	1.3–1.5	ap, z
Tuff of Brunton Pass	6	2.7–4.3 (3.4)	0.0–0.9 (0.4)	2.2–3.1 (2.5)	92.7–94.1 (93.5)	0.0–0.1 (0.0)	0.0–0.1 (0.0)	0.1–0.3 (0.2)	—
Tuff of Arc Dome	21	4.2–15.3 (8.4)	2.8–16.0 (9.1)	11.2–15.4 (13.0)	61.6–72.0 (67.8)	0.1–1.7 (1.0)	0.0–1.0 (0.3)	0.1–0.9 (0.3)	all, z
Tuff of Gabbs Valley	3	0.5–1.0 (0.8)	1.4–2.4 (1.8)	2.4–3.7 (3.0)	93.5–95.3 (94.1)	tr–0.1 (0.1)	0.0–0.1 (0.0)	tr–0.1 (tr)	(cpx)
Tuff of Camel Spring	8	0.0–2.0 (0.5)	0.1–10.4 (5.6)*	*	89.2–99.7 (93.7)	0.0–0.2 (tr)	0.0–tr	tr–0.8 (0.3)	(z, cpx)
Tuff of Menter Canyon	2	0.2–0.3	0.6–0.8	0.2	98.8–98.9	0.0	0.0	tr	—
Tuff of Green Springs	5	tr –0.6 (0.2)	0.0–0.7 (0.4)	1.2–5.3 (2.5)	93.6–98.7 (96.8)	0.0–0.1 (0.0)	0.0	tr–0.4 (0.2)	(z)
					Ellsworth section				
Tuff of Big Spring	8	4.9–14.4 (8.7)	6.9–17.4 (12.6)	9.7–18.0 (13.7)	55.7–68.6 (63.0)	0.3–2.3 (1.4)	0.0–0.6 (0.2)	tr–0.6 (0.3)	z, (all)
Brown rhyolite tuff	3	1.0–3.3 (2.4)	0.8–1.8 (1.4)	0.6–2.9 (2.1)	92.9–96.5 (94.1)	0.0–0.1 (tr)	0.0–tr (0.0)	0.1–0.2 (0.1)	z, (all)
White tuff	3	7.8–10.3 (8.9)	1.2–4.0 (2.6)	7.5–10.4 (9.0)	77.1–80.2 (79.0)	0.1–0.7 (0.4)	0.0	tr–0.2 (0.1)	z
Tuff of Camel Spring		See above in Menter Canyon section							
Tuff of Return Mine	10	3.9–13.9 (6.4)	0.5–10.3 (4.1)	1.9–8.9 (6.2)	74.7–89.0 (83.5)	0.1–2.0 (0.5)	0.0	tr–0.3 (0.1)	(all, z)
Purple biotite tuff	1	1.9	1.3	1.8	92.7	2.2	0.0	0.1	—
Purple tuff	1	7.5	1.9	5.9	84.1	0.3	0.0	0.3	z
					Sheep Canyon section				
Tuff of Sheep Canyon	29	0.1–9.0 (3.1)	6.8–32.1 (18.3)	0.0–10.3 (4.0)	55.7–86.1 (70.9)	0.5–5.8 (2.6)	0.0–1.4 (0.3)	tr–1.3 (0.8)	z (all, ap, cpx, sph)
Red rhyolite tuff	4	9.3–14.4 (11.4)	0.0–2.3 (0.7)	10.8–13.9 (12.8)	71.3–79.5 (74.8)	tr–0.3 (0.1)	0.0	0.1–0.4 (0.2)	z (all)
Upper white tuff	6	0.0–0.5 (0.2)	tr–5.2 (3.6)	1.6–2.5 (2.0)	92.8–98.0 (94.1)	0.0–0.3 (0.1)	0.0	0.1–0.4 (0.2)	(z)
Gray-green tuff	1	0.0	0.8	3.3	95.9	0.0	0.0	tr	z
Red tuff	14	tr–3.0 (2.1)	0.1–1.6 (0.3)	0.2–4.9 (2.7)	92.8–99.2 (94.8)	tr–0.1 (tr)	0.0	tr–0.3 (0.1)	(z)
Lower white tuff	36	0.0–3.5 (2.1)	0.0–7.8 (2.3)	0.2–5.7 (3.3)	83.4–96.1 (92.0)	0.0–1.4 (0.3)	0.0–0.2 (0.0)	0.1–0.5 (0.2)	(all, sph, z)
Tuff of Goldyke	19	1.0–8.7 (5.1)	3.3–28.1 (11.6)	1.6–13.9 (9.7)	63.6–90.6 (72.0)	0.2–2.1 (1.1)	0.0–0.4 (0.1)	0.2–1.0 (0.4)	z, (all, ap, sph)
Tuff	6	tr–2.5 (1.1)	0.3–5.2 (2.1)	0.3–3.4 (1.7)	92.0–99.4 (94.7)	0.0–0.4 (0.2)	0.0–0.3 (tr)	tr–0.4 (0.2)	z
Biotite-lithic tuff	1	1.9	32.1	1.8	58.5	2.8	0.8	1.1	cpx=1.0, z
Tuff of Davis Mine	2	0.5–0.6	4.1–5.7	2.1–2.6	91.2–92.3	0.3	0.0	0.1–0.2	z
Tuff of Pactolus	3	2.5–7.9 (5.1)	2.5–10.2 (7.5)	3.0–7.4 (4.6)	73.4–92.0 (81.6)	tr–2.0 (1.0)	0.0	tr–0.1 (0.1)	z

*Most feldspar is anorthoclase.

Table 3. Summary of K-Ar ages of Tertiary volcanic rocks in the Paradise Range, Nevada

[Pre-1976 ages recalculated using new I.U.G.S. constants (Steiger and Jager, 1977)]

	Rock type or unit	Location	Material dated	Reported age (Ma)	Comments	References
			Andesite of Stewart Valley			
1	Hornblende andesite flow -----	North end of Stewart Valley	Whole rock	12.1±0.3	Caps sedimentary rocks of Stewart Valley.	John and others (1989b)
			Silicic intrusive rocks			
2	Rhyolite dike -------------------	1 km east of Sheep Canyon, Paradise Range.	Biotite	16.2±0.5	Cut by Sheep Canyon fault.	McKee and John (1987)
3	Rhyolite dike -------------------	Mouth of Sheep Canyon, Paradise Range.	Biotite	19.2±0.6	Cut by Sheep Canyon fault.	John and others (1989b)
4	Rhyolite dike -------------------	2 km west of Willow Spring, Paradise Range.	Biotite	16.3±0.5	——	McKee and John (1987)
			Porphyritic dacite, hornblende andesite, and andesite and basaltic andesite units			
5	Porphyritic dacite flow --------	1.5 km east of Paradise Peak Mine.	Biotite	18.7±0.6	——	McKee and John (1987)
6	Porphyritic dacite flow --------	1 km southeast of Paradise Peak Mine.	Biotite	17.1±0.5	——	McKee and John (1987)
7	Andesite flow -------------------	3 km southwest of Paradise Peak Mine.	Whole rock	15.6±0.8	Caps younger andesite sequence.	John and others (1989b)
8	Porphyritic dacite flow --------	1.5 km south of Paradise Peak Mine.	Whole rock	15.5±0.6; 17.3±0.9	Replicate analyses from different labs.	John and others (1989b)
9	Hornblende andesite flow -----	Paradise Peak Mine	Whole rock	17.6±0.9	——	John and others (1989b)
10	Porphyritic dacite flow --------	1 km east of Paradise Peak Mine.	Whole rock	17.9±0.9; 17.6±0.7	Replicate analyses from different labs.	John and others (1989b)
11	Andesite porphyry flow -------	1 km southeast of Paradise Peak Mine.	Whole rock	18.2±1.0	——	John and others (1989b)
12	Porphyritic hornblende andesite flow.	Northern Pactolus Hills	Hornblende	18.9±0.6	——	McKee and John (1987)
13	Andesite flow -------------------	2 km west of Paradise Peak Mine.	Whole rock	19.3±0.9	——	John and others (1989b)
14	Hornblende andesite -----------	Sheep Canyon, Paradise Peak Mine.	Whole rock	20.1±0.6	Base of hornblende andesite unit.	John and others (1989b)
15	Basaltic andesite flow ---------	3 km north of Brunton Pass, Paradise Range.	Whole rock	18.9±0.9	Base of andesite and basaltic andesite unit.	McKee and John (1987)

			Tuffs in Menter Canyon section			
16	Tuff of Toiyabe ----------------	Near Brunton Pass, Paradise Range.	Biotite	21.4±0.7	——	McKee and John (1987)
17	Tuff of Toiyabe (Cloverdale Ranch unit).	Northern Pactolus Hills	Biotite	22.9±0.7	——	McKee and John (1987)
18	Tuff of Toiyabe ----------------	Peavine Canyon, southern Toiyabe Range.	Biotite	22.0±0.4	Base of tuff of Toiyabe.	Silberman and McKee (1972)
19	Tuff of Toiyabe ----------------	Shoshone Mountains southwest of Black Mountain.	Biotite	22.5±0.7	Vent for tuff of Toiyabe.	McKee and John (1987)
20	Tuff of Arc Dome -------------	Green Springs Summit, Paradise Range.	Biotite	24.9±0.6	——	McKee and John (1987)
21	Tuff of Arc Dome -------------	Mouth of Ione Canyon, Shoshone Mountains.	Biotite	24.4±0.4	Previously assigned to Toiyabe Quartz Latite by Armstrong (1970).	Armstrong (1970)
22	Tuff of Gabbs Valley ---------	Gillis Range	Sanidine	25.0±1.0	——	Ekren and others (1980)
23	Tuff of Gabbs Valley ---------	Gillis Range	Sanidine	26.1±0.8	——	Ekren and others (1980)
			Tuffs in the Ellsworth section			
24	Brown rhyolite tuff ------------	North end of Paradise Range	Sanidine	23.7±0.7	Sample identification and location from F.J. Kleinhampl (oral commun., 1986).	McKee and others (1971)
			Tuffs in the Sheep Canyon section			
25	Tuff of Sheep Canyon --------	Sheep Canyon, Paradise Range	Biotite	24.1±0.7	——	McKee and John (1987)
26	Tuff of Sheep Canyon --------	Sheep Canyon, Paradise Range	Biotite	23.2±0.7	——	McKee and John (1987)
27	Red rhyolite tuff ---------------	Sheep Canyon, Paradise Range	Sanidine	23.2±0.7	——	McKee and John (1987)
28	Lower white tuff ---------------	Northern Pactolus Hills	Sanidine	22.3±0.7	Age considered 1 m.y. too young.	McKee and John (1987)
29	Lower white tuff ---------------	2 km northwest of Paradise Peak Mine.	Sanidine	21.8±0.7; 25.1±1.0	Replicate analyses from different labs.	McKee and John (1987); John and others (1989b)
30	Tuff of Goldyke ----------------	2 km southwest of Paradise Peak Mine.	Biotite	23.0±0.9	——	John and others (1989b)
31	Tuff of Goldyke ----------------	Northern Pactolus Hills	Biotite	23.6±0.7	——	McKee and John (1987)
			Older andesite sequence			
32	Porphyritic rhyolite flow ------	0.5 km east of Gold Ledge Mine, Paradise Range.	Biotite	24.4±0.7	——	McKee and John (1987)
33	Dacite tuff (biotite-lithic tuff)	Sheep Canyon, Paradise Range	Biotite	25.6±0.8	——	McKee and John (1987)

Table 4. Chemical analyses of the tuff of Arc Dome

[All analyses except sample 83–DJ–97 by X-ray fluorescence spectroscopy (analysts: A. Bartel, J. Evans, D. Siems, J. Taggart, and D. Vivit; chemical determination of FeO, H_2O^+, H_2O^-, and CO_2 by W. Crandell, L. Espos, and H. Smith). Sample 83–DJ–97 analyzed by rapid rock analysis (analyst: N Rait). FeO*, total Fe as FeO; LOI, loss on ignition at 900°C]

	1	2	3	4	5	6	7	8	9	10	11
Sample number	83–DJ–96	83–DJ–97	86–DJ–79A	86–DJ–79B	86–DJ–79C	86–DJ–79D	86–DJ–79E	86–DJ–79F	87–DJ–151	85–SH–4	85–SH–5
Major elements normalized to 100 percent volatile-free (weight percent)											
SiO_2	77.18	77.26	77.01	73.55	73.17	73.68	73.43	73.81	74.48	76.99	74.31
Al_2O_3	12.85	12.71	12.89	14.46	14.39	14.25	14.30	14.15	13.58	12.53	13.48
FeO	.10	.16	.20	.29	.28	.24	.37	.35	.36	.16	.52
Fe_2O_3	.95	.99	.83	1.37	1.69	1.51	1.48	1.21	1.21	.86	1.21
MgO	.21	.18	.20	.29	.32	.23	.26	.25	.25	.17	.25
CaO	.56	.71	.59	1.09	1.16	1.13	1.06	1.13	1.31	.58	.99
Na_2O	3.17	3.33	3.52	3.81	3.83	3.83	3.84	4.05	3.57	3.49	2.94
K_2O	4.78	4.44	4.59	4.81	4.76	4.79	4.86	4.70	4.99	5.08	5.99
TiO_2	.09	.12	.09	.21	.25	.22	.23	.18	.18	.12	.22
P_2O_5	.02	.06	.03	.06	.09	.06	.09	.06	<0.05	<0.05	<0.05
MnO	.07	.05	.03	.03	.03	.03	.03	.05	.04	<0.02	.03
LOI	1.25	—	.87	1.12	1.00	1.12	.62	1.13	.91	.54	2.16
Total (volatile-free before normalization)	98.08	99.15	99.34	98.17	98.68	98.26	98.60	99.22	98.69	98.97	97.16
H_2O^+	.58	.54	.47	.64	.46	.56	.37	.29	.50	.13	1.30
H_2O^-	.44	.58	.25	.37	.42	.33	.20	.37	.30	.32	.77
CO_2	.11	.03	.08	.09	.05	.38	.05	.07	.41	.01	<0.01
F	—	.042	—	—	—	—	—	—	—	—	—
Minor elements (parts per million)											
Nb	25	21	24	20	20	20	18	20	17	18	17
Rb	240	141	240	160	160	170	160	160	175	195	204
Sr	36	123	30	160	160	150	140	160	124	52	119
Zr	140	165	140	220	270	250	270	240	174	153	195
Y	30	26	28	25	25	20	28	32	21	25	24
Ba	260	—	200	1,000	970	900	900	890	707	310	650
Ce	65	—	75	80	90	65	80	95	87	87	98
La	30	—	<30	45	55	40	45	55	45	61	64
Cu	<20	—	<20	<20	<20	<20	<20	<20	12	8	<5
Ni	<20	—	<20	<20	<20	<20	<20	<20	<5	<5	<5
Zn	45	—	50	50	56	56	60	42	50	56	64
Cr	<20	—	<20	<20	<20	<20	<20	<20	<20	<20	<20
K/Rb	165	261	159	249	247	234	252	244	236	216	244
Sr/Rb	.15	.87	.13	1.00	1.00	.88	.88	1.00	.71	.27	.58
FeO*	.96	1.05	.95	1.52	1.80	1.60	1.70	1.44	1.45	.94	1.61

Table 4. Chemical analyses of the tuff of Arc Dome—Continued

Sample descriptions

1 (83–DJ–96) Partially devitrified, densely welded basal part of the tuff of Arc Dome collected about 300 m east of Green Spring Summit, east side of the Paradise Range at lat 38°53'50"N., long 117°46'56"W.

2 (83–DJ–97) Devitrified, densely welded tuff of Arc Dome about 50 m above exposed base collected about 300 m east of Green Spring Summit, east side of the Paradise Range at lat 38°53'50"N., long 117°46'57"W.

3 (86–DJ–79A) Partially devitrified, densely welded basal part of the tuff of Arc Dome about 35 m above base collected on the east side of the Paradise Range about 3 km south of Sherman Peak at lat 38°54'23"N., long 117°46'16"W.

4 (86–DJ–79B) Devitrified, densely welded tuff about 65 m above the base collected on the east side of the Paradise Range about 3 km south of Sherman Peak at lat 38°54'23"N., long 117°46'14"W.

5 (86–DJ–79C) Devitrified, densely welded tuff about 130 m above the base collected on the east side of the Paradise Range about 3 km south of Sherman Peak at lat 38°54'23"N., long 117°46'12"W.

6 (86–DJ–79D) Devitrified, densely welded tuff about 200 m above the base collected on the east side of the Paradise Range about 3 km south of Sherman Peak at lat 38°54'23"N., long 117°46'10"W.

7 (86–DJ–79E) Devitrified, densely welded tuff about 260 m above the base collected on the east side of the Paradise Range about 3 km south of Sherman Peak at lat 38°54'23"N., long 117°46'08"W.

8 (86–DJ–79F) Devitrified, densely welded tuff at top of section (approximately 350 m above the base) collected on the east side of the Paradise Range about 3 km south of Sherman Peak at lat 38°54'23"N., long 117°46'04"W.

9 (87–DJ–151) Devitrified, densely welded tuff collected at the south end of the Sand Springs Range approximately 1 km north of Scheelite at lat 39°01'20"N., long 118°18'45"W.

10 (85–SH–4) Partially devitrified, densely welded basal part of the tuff collected in Peterson Canyon in the Shoshone Mountains at lat 39°10'15"N., long 117°30'05"W.

11 (85–SH–5) Devitrified, densely welded upper part of the tuff collected in Peterson Canyon in the Shoshone Mountains at lat 39°10'15"N., long 117°30'00"W.

Table 5. Chemical analyses of the tuff of Toiyabe

[All analyses except sample 83–DJ–100 by X-ray fluorescence spectroscopy (analysts: A. Bartel, J. Kent, D. Siems, and J. Taggart; chemical determination of FeO, H_2O^+, H_2O^-, CO_2 and F by W. Crandell, C. Papp, and H. Smith.) Sample 83–DJ–100 analyzed by rapid rock analysis (analyst: N. Rait). FeO*, total Fe as FeO; LOI, loss on ignition at 900°C]

	1	2	3	4	5	6	7	8	9	10
Sample Number	83–DJ–45	83–DJ–99	86–DJ–80	83–DJ–32	83–DJ–42	83–DJ–100	85–DJ–125	85–DJ–196	85–DJ–204	85–DJ–153
Major elements normalized to 100 percent volatile-free (weight percent)										
SiO_2	74.40	74.61	73.72	74.73	74.32	74.71	69.93	72.37	73.77	69.93
Al_2O_3	13.20	13.09	13.59	13.42	13.33	13.55	15.51	14.43	13.63	16.20
FeO	.56	.40	.44	.32	.44	.28	.53	.36	.40	.23
Fe_2O_3	1.19	1.49	1.41	1.58	1.48	1.52	2.22	1.66	2.04	2.51
MgO	.64	.68	.66	.41	.44	.48	.84	.59	.75	.54
CaO	1.53	1.60	1.67	1.35	1.50	1.52	2.72	2.23	1.56	2.29
Na_2O	3.18	3.10	2.99	3.23	3.41	3.03	3.43	3.48	2.84	3.60
K_2O	4.87	4.64	5.12	4.49	4.66	4.45	4.31	4.36	4.59	4.52
TiO_2	.25	.25	.26	.25	.26	.28	.36	.34	.29	.37
P_2O_5	.07	.07	.07	.16	.08	.13	.12	.10	.08	.12
MnO	.04	.04	.03	.02	.03	.05	.02	.05	.02	<0.02
Total (volatile-free before normalization)	97.72	97.04	97.13	98.36	99.03	98.91	97.38	98.39	97.60	96.94
LOI	1.81	2.20	2.51	.98	.42	—	1.50	.96	1.62	2.20
H_2O^+	1.30	1.70	2.10	.37	.16	.46	.57	.26	.80	.86
H_2O^-	.35	.29	.46	.55	.30	.44	.71	.70	1.50	.93
CO_2	.01	.03	.01	.01	.01	.08	.09	.16	.01	<0.01
F	—	—	—	—	—	.022	.020	—	—	—
Minor elements (parts per million)										
Nb	12	11	14	13	13	11	—	11	11	10
Rb	148	156	157	145	145	108	137	129	136	116
Sr	226	258	269	245	241	378	408	396	284	465
Zr	123	122	136	125	134	163	—	154	131	188
Y	18	16	17	19	19	20	—	14	13	10
Ba	702	762	737	835	821	1,000	—	1,290	1,100	1,500
Ce	56	54	67	62	64	110	—	53	58	30
La	40	28	35	28	26	45	—	27	26	50
Cu	<5	7	7	10	16	9	—	<5	<5	<20
Ni	<5	<5	<5	<5	<5	5	—	<5	<5	<20
Zn	47	51	49	49	45	67	—	54	46	50
Cr	<20	<20	<20	<20	<20	<10	—	<20	<20	<20
K/Rb	273	247	271	257	266	342	261	281	280	323
Sr/Rb	1.53	1.65	1.71	1.69	1.66	3.50	2.98	3.07	2.09	4.01
FeO*	1.63	1.73	1.71	1.74	1.76	1.65	2.53	1.86	2.23	2.40

Sample descriptions

1 (83–DJ–45) Densely welded glaasy tuff from near base of tuff of Toiyabe on the east side of the Paradise Range about 3 km south of Sherman Peak at lat 38°55'00"N., long 117°46'10"W.

2 (83–DJ–99) Densely welded basal vitrophyre of tuff of Toiyabe collected about 1 km south of Brunton Pass at lat 38°53'30"N., long 117°46'10"W.

3 (86–DJ–80) Densely welded basal vitrophyre of tuff of Toiyabe collected about 3 km south of Sherman Peak at lat 38°55'10"N., long 117°46'00"W.

4 (83–DJ–32 Devitrified densely welded tuff from the middle part of the tuff of Toiyabe collected about 4 km south of Sherman Peak along the crest of the east side of the Paradise Range at lat 38°54'30"N., long 117°46'00"W.

5 (83–DJ–42) Devitrified densely welded tuff from the middle part of the tuff of Toiyabe collected about 4 km south of Sherman Peak along the crest of the east side of the Paradise Range at lat 38°54'15"N., long 117°45'40"W.

6 (83–DJ–100) Devitrified densely welded tuff about 15 m above base of tuff of Toiyabe collected about 1 km south of Brunton Pass at lat 38°53'30"N., long 117°44'09"W.

7 (85–DJ–125) Devitrified, densely welded Cloverdale Ranch unit of the tuff of Toiyabe collected in the northern Pactolus Hills at lat 38°45'05"N., long 117°47'50"W.

8 (85–DJ–196) Devitrified, densely welded upper part of the tuff of Toiyabe from north Cedar Mountain about 3.5 km northwest of Simon at lat 38°35'20"N., long 117°54'00"W.

9 (85–DJ–204) Devitrified, densely welded upper part of the tuff of Toiyabe from north Cedar Mountain about 5 km northwest of Simon at lat 38°35'40"N., long 117°53'00"W.

10 (85–DJ–153) Devitrified, densely welded Cloverdale Ranch unit of the tuff of Toiyabe collected in the northern Pactolus Hills at lat 38°38'20"N., long 117°47'45"W.

Table 6. Chemical analyses of the younger andesite sequence

[All analyses by X-ray fluorescence spectroscopy (analysts: A. Bartel, M. Dyslin, L. Espos, J. Kent, B. King, R. Mendes, S. Pribble, K. Stewart, J. Taggart, D. Vivit; chemical determinations for FeO, H_2O^+, H_2O^-, CO_2, and F by N. Elsheimer and S. Neil). FeO*, total Fe as FeO; LOI, loss on ignition at 900°C]

Sample number	1 84–DJ–232	2 84–DJ–150	3 84–DJ–127	4 86–DJ–122A	5 87–DJ–7	6 87–DJ–8	7 84–DJ–114	8 85–DJ–67	9 D6–J–119	10 86–DJ–120	11 86–DJ–121
Major elements normalized to 100 percent volatile-free (weight percent)											
SiO_2	55.18	54.46	61.65	58.72	59.17	58.59	62.33	62.24	61.49	62.24	61.17
Al_2O_3	19.07	18.97	18.11	18.19	17.71	18.69	17.11	17.30	17.48	17.38	16.65
FeO	3.59	4.70	.42	1.12	1.43	1.30	1.11	.41	.17	.22	.42
Fe_2O_3	4.11	3.12	5.23	5.67	5.34	4.96	4.44	4.58	5.32	5.79	5.64
MgO	3.35	4.07	2.44	2.67	3.17	3.03	2.77	1.86	2.80	1.79	3.46
CaO	7.89	7.98	4.91	4.99	4.85	6.04	5.47	5.85	5.76	5.40	5.54
Na_2O	3.51	3.49	3.94	4.29	4.50	4.28	3.48	4.04	4.01	3.49	3.25
K_2O	1.58	1.47	2.38	2.89	2.48	1.75	2.24	2.45	1.91	2.57	2.79
TiO_2	1.12	1.12	.60	.80	.76	.79	.72	.65	.64	.71	.74
P_2O_5	.50	.51	.27	.45	.33	.46	.28	.36	.32	.33	.29
MnO	.10	.11	.06	.09	.10	.10	.06	.08	.10	.08	.05
Total (volatile-free before normalization)	98.58	98.05	95.54	96.22	97.69	95.75	96.43	98.85	97.25	96.08	95.47
LOI	.72	1.50	4.04	3.13	2.63	2.96	3.26	.59	2.00	3.38	4.26
H_2O^+	.43	.71	1.37	2.14	1.52	.90	.94	.22	.71	1.24	1.14
H_2O^-	.39	1.08	2.07	1.18	.84	1.69	1.93	.14	1.25	1.40	2.58
CO_2	.06	<.05	.53	.49	.19	.16	.14	.15	.05	.15	.15
F	.020	—	.040	—	.030	—	.050	.030	—	—	—
Minor elements (parts per million)											
Nb	—	<10	5	11	10	10	9	—	<10	<10	<10
Rb	36	40	41	81	52	36	17	60	30	62	62
Sr	1,193	1,200	700	724	926	1,100	787	1,226	850	820	740
Zr	—	138	97	100	140	152	130	—	160	130	150
Y	—	10	15	11	14	18	19	—	20	24	14
Ba	—	1,000	—	900	1,150	850	—	—	1,150	1,100	990
Ce	—	46	—	28	56	42	—	—	45	55	45
La	—	30	—	11	42	32	—	—	<30	<30	<30
Cu	—	<20	—	10	<20	<20	—	—	<20	<20	26
Ni	—	<20	—	6	<20	<20	—	—	<20	<20	<20
Zn	—	82	—	67	72	80	—	—	82	85	83
Cr	—	22	—	<20	<20	<20	—	—	<20	<20	20
K/Rb	365	305	481	296	395	405	1,094	339	529	344	373
Sr/Rb	33.14	30.00	17.07	8.94	17.81	30.56	46.29	20.43	28.33	13.23	11.94
FeO*	7.29	7.21	5.13	6.22	6.24	5.76	5.10	4.54	4.96	5.43	5.49

Table 6. Chemical analyses of the younger andesite sequence—Continued

[All analyses by X-ray fluorescence spectroscopy (analysts: A. Bartel, M. Dyslin, L. Espos, J. Kent, B. King, R. Mendes, S. Pribble, K. Stewart, J. Taggart, D. Vivit; chemical determinations for FeO, H_2O^+, H_2O^-, CO_2, and F by N. Elsheimer and S. Neil). FeO*, total Fe as FeO; LOI, loss on ignition at 900°C]

	12	13	14	15	16	17	18	19	20	21	22
Sample number	86–DJ–122	86–DJ–123	86–DJ–124	86–DJ–125	86–DJ–126	86–DJ–127	86–DJ–128	86–DJ–129	86–DJ–131	86–DJ–132	86–DJ–133
Major elements normalized to 100 percent volatile-free (weight percent)											
SiO_2	60.44	55.46	60.71	61.31	61.42	62.33	62.99	60.75	70.22	64.77	65.43
Al_2O_3	17.79	18.00	17.42	16.61	16.89	16.82	16.61	16.99	14.52	17.37	16.99
FeO	1.53	1.43	1.26	1.50	1.40	.29	.00	1.00	0.22	1.80	.78
Fe_2O_3	4.39	6.34	4.22	4.15	3.87	6.38	5.53	4.87	3.74	2.06	3.35
MgO	2.48	4.14	2.88	3.07	2.82	1.32	1.12	3.19	.86	1.67	1.24
CaO	6.37	8.53	6.50	6.11	6.62	5.25	5.69	6.04	3.77	4.53	4.32
Na_2O	3.50	3.42	3.92	3.59	3.86	4.02	4.16	3.95	3.33	3.58	4.12
K_2O	2.33	1.29	1.99	2.57	2.09	2.40	2.80	2.11	2.55	3.39	2.91
TiO_2	.75	.97	.65	.66	.59	.76	.67	.68	.53	.54	.57
P_2O_5	.34	.31	.35	.33	.32	.37	.33	.32	.24	.22	.21
MnO	.08	.11	.10	.11	.13	.05	.09	.10	.03	.07	.06
Total (volatile-free before normalization)	97.79	96.11	98.17	97.54	99.50	96.91	98.11	98.27	97.12	97.88	98.27
LOI	1.87	3.75	1.25	1.75	2.75	2.88	1.38	.87	2.88	1.88	1.50
H_2O^+	.70	1.07	.42	1.05	.78	.29	27	.72	.94	1.48	.39
H_2O^-	1.23	1.91	.58	.32	1.46	1.77	51	.38	1.70	.52	1.13
CO_2	.09	.47	.25	.14	.27	.07	49	.06	.21	.02	.03
F	—	—	—	—	—	—	—	—	—	—	—
Minor elements (parts per million)											
Nb	<10	<10	<10	<10	<10	10	10	<10	<10	10	<10
Rb	60	22	40	52	40	52	52	43	58	62	60
Sr	880	860	890	770	830	810	810	930	660	790	730
Zr	130	120	150	160	160	160	160	160	130	180	180
Y	17	17	18	20	14	20	20	16	<10	16	20
Ba	890	800	980	980	970	1,100	1,100	1,050	970	1,250	1,300
Ce	45	40	50	55	45	40	40	30	35	<30	35
La	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
Cu	<20	40	<20	<20	<20	<20	<20	<20	<20	<20	<20
Ni	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Zn	80	90	70	70	63	86	78	70	68	66	72
Cr	28	40	<20	<20	<20	<20	<20	<20	<20	<20	<20
K/Rb	323	487	412	411	433	384	408	407	365	454	403
Sr/Rb	14.67	39.09	22.25	14.81	20.75	15.58	13.33	21.63	11.38	12.74	12.17
FeO*	5.48	7.13	5.06	5.23	4.88	6.03	4.98	5.38	3.58	3.66	3.80

Table 6. Chemical analyses of the younger andesite sequence—Continued

[All analyses by X-ray fluorescence spectroscopy (analysts: A. Bartel, M. Dyslin, L. Espos, J. Kent, B. King, R. Mendes, S. Pribble, K. Stewart, J. Taggart, D. Vivit; chemical determinations for FeO, H_2O^+, H_2O^-, CO_2, and F by N. Elsheimer and S. Neil). FeO*, total Fe as FeO; LOI, loss on ignition at 900°C]

Sample number	23 86–DJ–134	24 86–DJ–135	25 86–DJ–136	26 86–DJ–137	27 86–DJ–138	28 86–DJ–139	29 86–DJ–140	30 86–DJ–14	31 88–PP–157	32 88–PP–158	33 88–PP–159
Major elements normalized to 100 percent volatile-free (weight percent)											
SiO_2	64.18	65.04	63.96	63.57	61.70	60.45	62.47	61.57	57.65	57.86	57.67
Al_2O_3	17.39	17.36	17.36	16.28	17.86	17.20	17.31	18.18	17.74	17.70	17.72
FeO	.78	.14	1.74	.83	1.11	.72	2.14	.56	2.55	1.88	2.19
Fe_2O_3	4.03	4.46	2.79	5.09	4.39	6.29	2.97	5.44	4.46	5.17	4.83
MgO	1.13	.49	1.61	2.00	1.59	2.19	2.56	1.16	3.13	2.97	3.13
CaO	4.56	4.35	4.80	4.97	6.01	6.24	5.65	5.72	7.30	7.26	7.33
Na_2O	4.18	4.36	4.02	3.48	3.60	3.38	3.38	3.68	3.76	3.78	3.74
K_2O	2.80	2.84	2.77	2.60	2.52	2.32	2.45	2.43	1.91	1.95	1.93
TiO_2	.64	.62	.62	.79	.78	.82	.65	.83	.84	.83	.85
P_2O_5	.24	.26	.24	.36	.37	.32	.34	.36	.27	.27	.27
MnO	.07	.08	.08	.04	.06	.06	.08	.07	.11	.10	.10
Total (volatile-free before normalization)	98.32	97.94	98.50	97.68	97.40	95.95	97.64	96.80	99.22	98.86	99.35
LOI	1.50	1.75	1.37	2.25	2.38	3.75	2.12	3.13	.66	.90	.74
H_2O^+	.48	.35	.73	.39	.54	.87	1.17	.69	.81	.95	.90
H_2O^-	.98	1.31	.71	1.23	1.40	2.99	.93	2.11	.20	.22	.22
CO_2	.15	.11	.13	.04	.26	.04	.03	.07	<.01	<.01	<.01
F	—	—	—	—	—	—	—	—	—	—	—
Minor elements (parts per million)											
Nb	<10	10	<10	12	10	10	<10	11	<10	<10	<10
Rb	52	56	52	58	60	53	62	55	54	45	61
Sr	800	780	790	760	920	870	790	920	1,030	1,010	1,050
Zr	180	180	170	130	170	150	130	160	105	91	105
Y	14	17	16	22	15	14	13	16	12	9	15
Ba	1,350	2,250	1,350	1,200	1,200	930	1,000	1,150	855	862	880
Ce	40	<30	<30	45	40	45	50	<30	50	44	55
La	<30	<30	<30	<30	<30	<30	<30	40	25	20	20
Cu	<20	20	<20	<20	<20	<20	<20	<20	14	9	11
Ni	<20	<20	<20	<20	<20	<20	<20	<20	5	<5	<5
Zn	69	70	73	82	80	88	60	94	76	67	66
Cr	<20	<20	<20	24	32	52	30	36	<20	<20	<20
K/Rb	446	421	442	372	348	364	328	366	294	360	263
Sr/Rb	15.38	13.93	15.19	13.10	15.33	16.42	12.74	16.73	19.07	22.44	17.21
FeO*	4.41	4.16	4.25	5.41	5.06	6.38	4.81	5.46	6.56	6.54	6.53

Table 6. Chemical analyses of the younger andesite sequence—Continued

Sample descriptions

1 (84–DJ–232) Vesicular, fine-grained basaltic andesite lava containing plagioclase, clinopyroxene, and altered olivine phenocrysts in a microcrystalline groundmass collected near the base of the andesite and basaltic andesite unit on the east side of the Paradise Range at lat 38°54'15"N., long 117°49'48"W.

2. (84–DJ–150) Fine-grained basaltic andesite lava containing plagioclase, clinopyroxene, and altered olivine phenocrysts in a microcrystalline groundmass collected near the base of the andesite and basaltic andesite unit on the east side of the Paradise Range at lat 38°54'10"N., long 117°47"05"W.

3. (84–DJ–127) Fine- to medium-grained, devitrified hornblende andesite lava collected in Sheep Canyon at lat 38°47'12"N., long 117°49'48"W. (hornblende andesite unit)

4. (86–DJ–122A) Propylitized, fine- to medium-grained porphyritic hornblende andesite dike intruding older andesite lavas and tuffs in the Sheep Canyon section collected in the southwestern Paradise Range along the range front about 2 km south of Sheep Canyon at lat 38°48'06"N., long 117°56'24"W. (hornblende andesite unit)

5. (87–DJ–7) Weakly propylitized fine-grained hornblende andesite lava collected in Sheep Canyon at lat 38°48'08"N., long 117°55'10"W. (hornblende andesite unit)

6. (87–DJ–8) Devitrified, fine- to medium-grained hornblende-plagiolcase andesite lava from the base of the hornblende andesite unit collected in Sheep Canyon at lat 38°42'02"N., 117°54'47"W.

7. (84–DJ–114) Vitrophyric, coarse-grained porphyritic biotite hornblende plagioclase andesite lava collected along the old Poleline Road in the southwestern Paradise Range at lat 38°44'59"N., long 117°59'00"W. (porphyritic dacite unit)

8. (85–DJ–67) Devitrified, medium-grained hornblende plagioclase andesite flow breccia collected near the base of the porphyritic dacite unit in the northern Pactolus Hills at lat 38°44'48"N., long 117°47'02"W.

9. (86–DJ–119) Devitrified, medium-grained porphyritic biotite-hornblende-plagioclase andesite porphyry flow breccia from Finger Rock Wash collected at lat 38°42'14"N., long 118°01'42"W. (porphyritic dacite unit)

10. (86–DJ–120) Devitrified, coarse-grained porphyritic hornblende-plagioclase andesite lava from Finger Rock Wash collected at lat 38°42'14"N., long 118°01'40"W. (porphyritic dacite unit)

11. (86–DJ–121) Devitrified, medium-grained, sparsely porphyritic hornblende-plagioclase andesite lava from Finger Rock Wash collected at lat 38°42'19"N., long 118°01'35"W. (porphyritic dacite unit)

12. (86–DJ–122) Devitrified, medium-grained, sparsely porphyritic clinopyroxene-hornblende-plagioclase andesite lava from Finger Rock Wash collected at lat 38°42'20"N., long 118°01'28"W. (porphyritic dacite unit)

13. (86–DJ–123) Devitrified, medium-grained, sparsely porphyritic basaltic andesite lava from Finger Rock Wash collected at lat 38°42'22"N., long 118°01'25"W. (porphyritic dacite unit)

14. (86–DJ–124) Devitrified, medium-grained porphyritic hornblende andesite porphyry flow breccia from Finger Rock Wash collected at lat 38°42'21"N., long 118°01'17"W. (porphyritic dacite unit)

15. (86–DJ–125) Devitrified, medium-grained porphyritic hornblende-plagioclase andesite porphyry from Finger Rock Wash collected at lat 38°42'24"N., long 118°01'14"W. (porphyritic dacite unit)

16. (86–DJ–126) Devitrified, medium-grained hornblende andesite lava from Finger Rock Wash collected at lat 38°42'24"N., long 118°01'09"W. (porphyritic dacite unit)

17. (86–DJ–127) Devitrified, medium-grained hornblende andesite lava from Finger Rock Wash collected at lat 38°42'23"N., long 118°01'02"W. (porphyritic dacite unit)

18. (86–DJ–128) Devitrified, medium-grained hornblende-plagioclase andesite lava from Finger Rock Wash collected at lat 38°42'27"N., long 118°00'50"W. (porphyritic dacite unit)

19. (86–DJ–129) Devitrified, medium-grained hornblende-plagioclase andesite porphyry from Finger Rock Wash collected at lat 38°42'27"N., long 118°00'50"W. (porphyritic dacite unit)

20. (86–DJ–131) Devitrified, coarsely porphyritic plagioclase rhyolite flow breccia collected on the southwest side of Newman's Ridge at lat 38°43'17"N., long 117°59'18"W. (porphyritic dacite unit)

21. (86–DJ–132) Devitrified, fine-grained sparsely porphyritic hornblende dacite lava collected on the southwest side of Newman's Ridge at lat 38°43'16"N., long 117°59'10"W. (porphyritic dacite unit)

22. (86–DJ–133) Devitrified, fine-grained sparsely porphyritic hornblende dacite lava collected on the southwest side of Newman's Ridge at lat 38°43'20"N., long 117°59'10"W. (porphyritic dacite unit)

23. (86–DJ–134) Devitrified, fine-grained sparsely porphyritic hornblende dacite lava collected on the southwest side of Newman's Ridge at lat 38°43'25"N., long 117°58'59"W. (porphyritic dacite unit)

24. (86–DJ–135) Devitrified, fine-grained sparsely porphyritic hornblende dacite lava collected on the southwest side of Newman's Ridge at lat 38°43'33"N., long 117°58'57"W. (porphyritic dacite unit)

25. (86–DJ–136) Devitrified, fine-grained sparsely porphyritic hornblende dacite lava collected on the southwest side of Newman's Ridge at lat 38°43'48"N., long 117°58'53"W. (porphyritic dacite unit)

26. (86–DJ–137) Devitrified, coarse-grained biotite-hornblende-plagioclase dacite porphyry collected about 500 m east of the Paradise Peak Mine at lat 38°45'07"N., long 117°57'35"W. (porphyritic dacite unit)

27 (86–DJ–138) Devitrified, coarse-grained hornblende-plagioclase andesite lava collected about 500 m east of the Paradise Peak Mine at lat 38°45'07"N., long 117°57'39"W. (porphyritic dacite unit)

28. (86–DJ–139) Devitrified, sparsely porphyritic hornblende-plagioclase andesite flow breccia collected about 500 m east of the Paradise Peak Mine at lat 38°44'55"N., long 117°57'36"W. (porphyritic dacite unit)

29. (86–DJ–140) Vitric, flow banded, hornblende andesite lava collected about 500 m east of the Paradise Peak Mine at lat 38°44'55"N., long 117°57'36"W. (porphyritic dacite unit)

30. (86–DJ–141) Devitrified, sparsely porphyritic, hornblende-plagioclase andesite lava collected about 500 m east of the Paradise Peak Mine at lat 38°44'55"N., long 117°57'39"W. (porphyritic dacite unit)

31. (88–PP–157) Devitrified, fine-grained clinopyroxene-plagioclase andesite lava collected in the northern Pactolus Hills at lat 38°46'34"N., long 117°47'00"W. (porphyritic dacite unit)

32. (88–PP–158) Devitrified, fine-grained clinopyroxene-plagioclase andesite lava collected in the northern Pactolus Hills at lat 38°46'34"N., long 117°47'02"W. (porphyritic dacite unit)

33. (88–PP–159) Devitrified, fine-grained clinopyroxene-plagioclase andesite lava collected in the northern Pactolus Hills at lat 38°46'34"N., long 117°47'01"W. (porphyritic dacite unit)

Table 7. Characteristics of major ash-flow tuff units in the Ellsworth section

Unit	Tuff of Return Mine	Tuff of Camel Spring	White tuff	Brown rhyolite tuff	Tuff of Big Spring
Composition[1]	Rhyolite(?)	Rhyolite	Rhyolite(?)	Rhyolite	Rhyolite
Percent phenocrysts	11–25	1–11	20–23	4–7	31–44
Major phenocrysts[2]	Q, S, P, B	A, P, S	Q, S, P	Q, S, P	S, P, Q, B
Pumice clasts	Abundant	Locally abundant	Sparse	Sparse	Sparse
Welding	Poor to moderate	Poor to dense	Poor to moderate	Dense	Dense
Lithic fragments	Locally abundant	Locally abundant	Sparse	Sparse	Sparse
Simple or compound cooling unit	Compound	Compound	Simple	Simple	Simple
Notable characteristics	Smoky quartz phenocrysts, commonly strongly argillized	Anorthoclase phenocrysts	—	Commonly vitrophyric	Base commonly vitrophyric
Thickness[3] (m)	300	250	50	125	200
Age (Ma) (see table 3)	>26	>26	>23	23–24	≤23
Areal distribution[4]	PR, SM	PR, SM, GV(?)	PR	PR	PR, SM
Source	Unknown	Unknown	Unknown	Unknown	Unknown
Comments	—	Also present in Menter Canyon section	—	—	—

[1]Classification is IUGS chemical classification (Le Bas and others, 1986) based on total alkali and silica contents of whole-rock samples recalculated to 100 percent volatile-free.

[2]Q, quartz; S, sanidine; P, plagioclase; B, biotite; A, anorthoclase.

[3]Maximum thickness in Paradise Range.

[4]PR, Paradise Range; SM, Southern Shoshone Mountains; GV, Gabbs Valley Range.

Table 8. Characteristics of major ash-flow tuff units in the Sheep Canyon section

Unit	Tuff of Pactolus	Tuff of Davis Mine	Tuff	Biotite-lithic tuff	Tuff of Goldyke
Composition[1]	Rhyolite	Rhyolite	Rhyolite	Dacite(?)	Rhyolite
Percent phenocrysts	10–25	8–9	1–8	40	20–35
Major phenocrysts[2]	Q, P, S, B	P, S	P, S, Q	P, B, H, C	P, Q, S, B
Pumice clasts	Locally abundant, crystal-rich	Locally abundant	Abundant	Sparse	Locally abundant
Welding	Dense	Extremely dense	Dense	Dense	Dense
Lithic fragments	Sparse	Abundant	Locally abundant	Abundant	Sparse
Simple or compound cooling unit	Compound(?)	Simple(?)	Simple(?)	Simple	Compound
Notable characteristics	Strongly altered throughout (argillic or silicic).	Abundant pre-Tertiary lithic fragments; strongly altered (propylitic).	Commonly vesicular due to weathered-out pumice lapilli.	Very lithic-rich; more mafic than other tuffs with abundant hornblende and clinopyroxene.	Sieve-textured quartz
Thickness[3] (m)	500	600	500	60	450
Age (Ma) (see table 3)	≥34(?)	approx. 34 (?)	approx. 24(?)	25.6	23.5–23.0
Areal distribution[4]	PH, SM	PR, PH, SM	PR	PR	PR, PH
Source	Southern Shoshone Mountains(?)	Southern Shoshone Mountains (?)	Unknown	Unknown	Unknown
Comments	Correlative(?) with lower part of Mission Spring Formation of Vitaliano and Vitalino (1972).	Correlative(?) with upper part of Mission Spring Formation of Vitaliano and Vitaliano (1972).	—	—	—

Unit	Lower white tuff	Red tuff	Upper white tuff	Red rhyolite tuff	Tuff of Sheep Canyon
Composition[1]	Rhyolite	Rhyolite	Rhyolite(?)	Rhyolite	Dacite-rhyolite
Percent phenocrysts	4–15	1–7	2–7	20–30	15–45
Major phenocrysts[2]	Q, S, P, B	Q, P	P, S	S, Q	P, S, Q, B
Pumice clasts	Abundant	Generally abundant	Generally sparse	Sparse	Abundant, crystal-rich, as long as 25 cm.
Welding	Dense to poor	Dense	Poor to moderate	Dense	Moderate to dense
Lithic fragments	Sparse except at base	Sparse	Sparse except at base of lowest cooling unit.	Sparse	Generally sparse
Simple or compound cooling unit	Simple	Simple	Compound	Simple	Compound
Notable characteristics	Persistant basal vitrophyre; sanidine commonly iridescent.	Local secondary flow structures; commonly spherulitic.	Middle member spherulitic; basal vitrophyres in lower and upper members.	Virtually no plagioclase or biotite phenocrysts; local sandstone overlying tuff.	Four cooling units; pumice contains abundant biotite.
Thickness[3] (m)	250	150	150	90	600
Age (Ma) (see table 3)	approx. 23	approx. 23	approx. 23	23	appox. 23
Areal distribution[4]	PR, PH	PR, PH	PR, PH	PR, PH	PR
Source	Unknown	Unknown	Unknown	Unknown	Unknown
Comments	—	—	3 cooling units	—	—

[1]Classification is IUGS chemical classification (Le Bas and others, 1986) based on total alkali and silica contents of whole-rock samples recalculated to 100 percent volatile-free.
[2]Q, quartz; P, plagioclase; S, sanidine; B, biotite; H, hornblende; C, clinopyroxene.
[3]Maximum thickness in Paradise Range.
[4]PR, Paradise Range; PH, Pactolus Hills; SM, Southern Shoshone Mountains.

Table 9. Volume estimates of major ash-flow tuff sheets in the Paradise Range

Unit	Present area (km^2)	Restored area (km^2)	Restored volume (km^3)
Tuffs of Davis Mine and Pactolus and Mission Spring Formation	475	325	250
Tuff of Gabbs Valley	2,100	1,050	370
Tuff of Arc Dome	3,350	2,300	800
Tuff of Toiyabe	4,150	2,650	1,100

Table 10. Chemical analyses of the older andesite sequence

[All analyses by X-ray fluorescence spectroscopy (analysts: A. Bartel, M. Dyslin, R. Mendes, K. Stewart, J. Taggart; chemical determinations for FeO, H_2O^+, H_2O^-, and CO_2 by N. Elsheimer and S. Neil). FeO*, total Fe as FeO; LOI, loss on ignition at 900°C]

Sample Number	1 84–DJ–38	2 84–DJ–41	3 84–DJ–49	4 84–DJ–58	5 87–DJ–10	6 87–DJ–11	7 87–DJ–12	8 87–DJ–2
Major elements normalized to 100 percent volatile-free (weight percent)								
SiO_2	66.08	62.68	61.39	70.60	62.76	60.17	61.57	63.34
Al_2O_3	16.01	17.61	17.81	15.07	17.24	17.63	17.65	16.76
FeO	.20	.46	1.36	.18	1.64	2.54	2.12	.26
Fe_2O_3	4.77	5.25	4.23	3.00	3.57	3.36	2.96	5.37
MgO	1.12	1.86	2.69	.79	2.35	3.28	2.67	1.85
CaO	3.73	3.81	4.66	2.90	4.98	5.72	4.54	4.30
Na_2O	3.67	3.63	3.93	2.97	4.39	3.49	4.21	3.60
K_2O	3.59	3.61	2.59	3.93	1.96	2.54	3.12	3.56
TiO_2	.53	.73	.79	.38	.63	.66	.64	.64
P_2O_5	.22	.27	.35	.14	.22	.25	.23	.25
MnO	.05	.04	.06	.02	.08	.09	.08	.07
Total (volatile-free before normalization)	98.06	96.52	96.60	96.88	98.00	97.56	97.45	97.25
LOI	1.38	3.50	3.62	2.68	1.88	2.00	2.25	2.37
H_2O^+	.63	1.58	1.73	.68	1.30	1.71	1.73	.88
H_2O^-	.37	1.30	.63	1.30	.50	.33	.41	1.08
CO_2	.38	.38	.48	.31	<0.05	<0.05	.23	.53
Minor elements (parts per million)								
Nb	12	12	12	<10	10	10	10	12
Rb	104	116	70	83	68	70	104	100
Sr	520	560	720	539	840	720	800	560
Zr	126	215	176	121	215	188	210	192
Y	14	18	16	15	16	18	20	20
Ba	1,000	1,450	1,200	—	1,050	1,150	1,250	1,250
Ce	60	68	72	—	48	48	42	54
La	48	54	52	—	36	38	30	40
Cu	24	24	<20	—	22	28	26	22
Ni	<20	<20	<20	—	<20	<20	<20	<20
Zn	62	74	78	—	72	78	74	78
Cr	92	34	42	—	<20	<20	<20	<20
K/Rb	286	258	307	393	239	301	249	295
Sr/Rb	5.00	4.83	10.29	6.49	12.35	10.29	7.69	5.60
FeO*	4.49	5.18	5.16	2.88	4.85	5.56	4.77	5.07

Sample descriptions

1 (84–DJ–38) Devitrified, flow-banded, medium-grained biotite-hornblende-plagioclase dacite lava collected along the range front in the southwestern Paradise Range at lat 38°48'00"N., long 117°56'21"W.

2 (84–DJ–41) Devitrified, medium-grained (biotite)-hornblende-plagioclase andesite lava collected along the range front in the southwestern Paradise Range at lat 38°47'35"N., long 117°56'09"W.

3 (84–DJ–49) Propylitized, medium-grained (biotite)-hornblende-plagioclase andesite lava collected near the Poleline Road in southwestern Paradise Range at lat 38°46'45"N., long 117°57'45"W.

4 (84–DJ–58) Weakly propylitized, flow-banded, medium-grained biotite-hornblende-plagioclase rhyolite lava collected about 300 m east of the Gold Ledge Mine, southwestern Paradise Range at lat 38°47'12"N., long 38°47'12"W.

5 (87–DJ–10) Propylitized, medium-grained clinopyroxene-hornblende-plagioclase andesite lava collected near the Davis Mine in the southwestern Paradise Range at lat 38°45'13"N., long 117°53'15"W.

6 (87–DJ–11) Propylitized, medium-grained hornblende-plagioclase andesite lava collected near the Davis Mine in the southwestern Paradise Range at lat 38°45'16"N., long 117°53'04"W.

7 (87–DJ–12) Propylitized, medium-grained, flow foliated clinopyroxene-hornblende-plagioclase andesite lava collected near the Davis Mine in the southwestern Paradise Range at lat 38°45'17"N., long 117°52'58"W.

8 (87–DJ–2) Propylitized, fine-grained clinopyroxene-hornblende-plagioclase dacite lava collected near the mouth of Sheep Canyon at lat 38°49'17"N., long 117°55'36"W.

Table 10. Chemical analyses of the older andesite sequence—Continued

[All analyses by X-ray fluorescence spectroscopy (analysts: A. Bartel, M. Dyslin, R. Mendes, K. Stewart, J. Taggart; chemical determinations for FeO, H_2O^+, H_2O^-, and CO_2 by N. Elsheimer and S. Neil). FeO*, total Fe as FeO; LOI, loss on ignition at 900°C]

Sample Number	9 87–DJ–3	10 87–DJ–4	11 87–DJ–5	12 87–DJ–6	13 87–DJ–9	14 88–DJ–66	15 84–DJ–132
Major elements normalized to 100 percent volatile-free (weight percent)							
SiO_2	61.57	68.34	63.35	66.43	59.22	60.76	65.06
Al_2O_3	16.61	15.87	17.04	15.31	17.98	16.59	16.70
FeO	.29	.30	.42	.10	2.10	3.10	1.20
Fe_2O_3	5.52	2.92	4.53	5.29	3.74	2.28	3.28
MgO	3.70	.93	2.26	1.35	3.72	2.91	1.81
CaO	4.80	3.86	4.13	3.95	4.71	6.14	4.19
Na_2O	3.60	3.81	4.00	3.41	3.62	3.56	3.68
K_2O	3.05	3.30	3.29	3.27	3.66	3.49	3.18
TiO_2	.59	.39	.62	.58	.66	.78	.57
P_2O_5	.19	.19	.25	.23	.27	.30	.23
MnO	.06	.06	.08	.07	.09	.09	.10
Total (volatile-free before normalization)	94.52	97.01	97.40	96.65	96.76	92.82	97.60
LOI	4.88	2.62	2.25	3.12	2.62	6.24	1.93
H_2O^+	2.08	.82	.92	1.09	1.68	2.09	1.11
H_2O^-	2.19	1.08	1.01	.74	.31	.17	.61
CO_2	.30	.51	<0.05	.92	.46	3.42	.29
Minor elements (parts per million)							
Nb	12	12	12	<10	10	12	<10
Rb	102	90	106	94	96	94	104
Sr	1,650	500	610	600	1,150	580	690
Zr	150	118	205	134	270	114	172
Y	18	12	20	12	20	14	14
Ba	1,450	1,000	1,200	1,000	2,150	1,000	1,200
Ce	40	46	48	44	50	34	34
La	34	36	30	36	38	<30	48
Cu	30	<20	22	<20	22	<20	<20
Ni	<20	<20	<20	<20	<20	<20	<20
Zn	78	54	82	60	78	68	68
Cr	32	<20	<20	<20	88	<20	44
K/Rb	248	304	257	289	316	308	253
Sr/Rb	16.18	5.56	5.75	6.38	11.98	6.17	6.63
FeO*	5.24	2.92	4.49	4.86	5.46	5.16	4.15

9 (87–DJ–3) Weakly propylitized, coarsely porphyritic hornblende-clinopyroxene-plagioclase andesite flow breccia containing clots of medium- to coarse-grained plagoclase crystals collected near the mouth of Sheep Canyon at lat 38°49'18"N., long 117°56'01"W.

10 (87–DJ–4) Devitrified, flow banded, fine- to medium-grained (quartz)-biotite-hornblende-plagioclase dacite lava collected near the mouth of Sheep Canyon at lat 38°49'18"N., long 117°56'06"W.

11 (87–DJ–5) Devitrified, sparsely porphyritic hornblende-plagioclase dacite lava collected near the mouth of Sheep Canyon at lat 38°49'10"N., long 117°56'00"W.

12 (87–DJ–6) Propylitized, medium-grained (quartz)-biotite-hornblende-plagioclase dacite lava collected near the mouth of Sheep Canyon at lat 38°48'47"N., long 117°55'38"W.

13 (87–DJ–9) Propylitized, medium-grained clinopyroxene-hornblende-plagioclase andesite lava collected near the Davis Mine in the southwestern Paradise Range at lat 38°45'19"N., long 117°53'30"W.

14 (88–DJ–66) Propylitized, medium-grained biotite-hornblende-plagioclase andesite dike in the footwall of the Sheep Canyon fault, southwestern Paradise Range collected at lat 38°47'34"N., long 117°54'09"W.

15 (84–DJ–132) Devitrified, flow foliated, medium-grained hornblende-plagioclase dacite lava collected near the Poleline Road in the southwestern Paradise Range at lat 38°47'20"N., long 117°55'20"W.

Table 11. Chemical analyses of the andesite of Stewart Valley

[All analyses by X-ray fluorescence spectroscopy (analyst: M. Dyslin; chemical determinations of FeO, H_2O^+, H_2O^-, and CO_2 by S. Neil and S. Pribble). FeO*, total Fe as FeO; LOI, loss on ignition at 900°C]

Sample number	1 314-4K	2 346-12K	3 346-3K	4 87-DJ-146
Major elements normalized to 100 percent volatile-free (weight percent)				
SiO_2	57.45	59.74	56.68	57.85
Al_2O_3	18.61	17.81	18.89	17.60
FeO	3.13	3.02	1.26	3.89
Fe_2O_3	3.52	3.25	5.97	3.40
MgO	2.95	3.21	2.04	2.88
CaO	7.16	6.23	7.19	6.53
Na_2O	3.86	3.31	4.19	3.81
K_2O	1.83	2.24	2.10	2.10
TiO_2	.94	.81	1.08	1.01
P_2O_5	.43	.29	.49	.78
MnO	.12	.09	.10	.15
Total (volatile-free before normalization)	98.34	96.59	97.92	97.15
LOI	.88	3.25	2.00	1.55
H_2O^+	.73	1.75	.83	.96
H_2O^-	.31	.39	.98	.70
CO_2	<0.05	.96	<0.05	.09
Minor elements (parts per million)				
Nb	<10	<10	12	18
Rb	38	50	44	50
Sr	1,300	760	1,250	920
Zr	166	134	174	260
Y	16	14	18	26
Ba	1,150	1,050	1,150	1,300
Ce	72	54	64	90
La	62	46	42	78
Cu	<20	<20	<20	<20
Ni	<20	<20	<20	<20
Zn	86	82	80	92
Cr	<20	42	<20	<20
K/Rb	400	372	396	349
Sr/Rb	34.2	15.2	28.4	18.4
FeO*	6.27	5.95	6.63	6.75

Sample descriptions

1 (314-4K) Fine-grained, porphyritic clinopyroxene-plagioclase andesite lava flow with a microcrystalline groundmass collected in the southern Pactolus Hills at lat 38°36'54"N., 117°47'13"W.

2 (346-12K) Devitrified, coarsely porphyritic biotite-clinopyroxene-hornblende-plagioclase andesite lava flow. Mafic minerals partially chloritized and plagioclase partially sericitized. Collected in the southern Pactolus Hills at lat 38°36'54"N., long 117°49'35"W.

3 (346-3K) Fine-grained, porphyritic olivine-clinopyroxene-plagioclase andesite lava flow with a microcrystalline groundmass. Olivine altered to bowlingite. Collected in the southern Pactolus Hills at lat 38°38'20"N., long 117°49'33"W.

4 (87-DJ-146) Devitrified, sparsely porphyritic fine-grained hornblende andesite lava collected in Finger Rock Wash at lat 38°44'05"N., long 117°59'25"W.

Table 12. Chemical analyses of silicic intrusive rocks in the Paradise Range

[All analyses by X-ray fluorescence spectroscopy (analysts: A. Bartel, J. Kent, D. Siems, J. Taggart; chemical determinations of FeO, H_2O^+, H_2O^-, and CO_2 by C. Papp). FeO*, total Fe as FeO; LOI, loss on ignition at 900°C]

Sample number	1 84–DJ–11	2 84–DJ–40	3 84–DJ–113	4 84–DJ–115	5 87–DJ–1	6 85–DJ–126	7 89–DJ–38
Major elements normalized to 100 percent volatile-free (weight percent)							
SiO_2	71.42	75.66	73.78	75.86	71.58	72.61	76.28
Al_2O_3	14.94	13.97	14.34	13.77	15.58	14.69	13.37
FeO	.36	.28	.48	.23	.14	0.26	—
Fe_2O_3	1.57	1.06	1.40	1.15	1.56	1.45	.97
MgO	.72	.42	.72	.51	.43	.32	.24
CaO	3.03	1.14	1.57	1.46	3.59	1.20	.31
Na_2O	4.36	3.34	2.76	2.96	3.33	4.10	3.74
K_2O	3.21	3.85	4.57	3.79	3.29	4.99	4.92
TiO_2	.25	.18	.26	.17	.24	.31	.12
P_2O_5	.11	.06	.11	.08	.13	.06	<0.05
MnO	.03	.03	<0.02	<0.02	.03	<0.02	.04
Total (volatile-free before normalization)	97.03	98.07	96.91	97.28	93.04	98.74	98.72
LOI	2.04	1.38	2.40	2.68	5.85	.56	.71
H_2O^+	.56	1.08	1.01	1.09	1.41	.28	.47
H_2O^-	.59	.60	1.08	.81	2.35	.34	.18
CO_2	.87	.01	.20	.64	1.80	<0.01	.13
Minor elements (parts per million)							
Nb	<10	<10	10	11	<10	12	14
Rb	70	102	140	95	68	166	180
Sr	460	250	230	249	310	240	52
Zr	144	124	126	136	136	260	160
Y	10	12	10	14	<10	18	20
Ba	1,300	1,200	1,100	—	1,100	1,500	480
Ce	66	32	46	—	56	72	70
La	34	36	52	—	66	52	48
Cu	<20	<20	<20	—	<20	<20	<10
Ni	<20	<20	<20	—	<20	<20	<10
Zn	62	40	46	—	48	58	68
Cr	<20	<20	<20	—	<20	<20	<20
K/Rb	380	314	271	331	401	250	227
Sr/Rb	1.54	2.45	1.64	2.62	4.56	1.45	.29
FeO*	1.77	1.23	1.74	1.26	1.54	1.57	.87

Sample descriptions

1 (84–DJ–11) Devitrified, sparsely porphyritic fine-grained biotite rhyolite dike collected in Sheep Canyon at lat 38°48'21"N., long 117°56'15"W.

2 (84–DJ–40) Devitrified, sparsely porphyritic fine-grained biotite rhyolite dike collected in Sheep Canyon at lat 38°47'20"N., long 117°56'10"W.

3 (84–DJ–113) Devitrified, medium-grained quartz-biotite-K-feldspar-plagioclase rhyolite dike collected in Sheep Canyon at lat 38°46'50"N., long 117°54'25"W.

4 (84–DJ–115) Devitrified, sparsely porphyritic fine-grained biotite rhyolite dike collected near Sheep Canyon at lat 38°47'29"N., long 117°55'33"W.

5 (87–DJ–1) Devitrified, sparsely porphyritic fine-grained biotite rhyolite dike collected in Sheep Canyon at lat 38°49'20"N., long 117°55'10"W.

6 (85–DJ–126) Glassy, medium-grained biotite rhyolite dike collected in the northern Pactolus Hills at lat 38°45'05"N., long 117°47'50"W.

7 (89–DJ–38) Devitrified, flow-banded, sparsely porphyritic rhyolite dome collected about 1 km southwest of Goldyke at lat 38°43'50"N., long 117°52'42"W.

Table 13. Sr isotope data for Tertiary volcanic rocks in the Paradise Range

[Rb and Sr analyses by X-ray fluorescence spectroscopy and Rb and Sr isotopic ratios by mass spectrometry (analyst: A. C. Robinson). ~, approximately]

Sample number	Unit[1]	Rb(ppm)	Sr(ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Age(Ma)	$(^{87}Sr/^{86}Sr)_I$
87–DJ–146-------	Tsv	50.7	951	.154	.704753	12	.70473
314–4K -----------	Tsv	36.8	1,278	.0833	.70475	12?	.704735
87–DJ–1 ----------	Tri	75.9	314	.699	.705206	19	.705017
84–DJ–127-------	Tha	48.0	696	.199	.704715	~18	.704664
86–DJ–129-------	Tpd	49.4	920	.155	.704859	~18	.70482
84–DJ–114-------	Tpd	31.7	849	.108	.704969	19	.70494
86–DJ–119-------	Tpd	23.9	897	.077	.704845	~19	.70482
85–DJ–67 --------	Tpd	59.5	1,226	.14	.704223	~19	.704185
86–DJ–131 -------	Tpd	70.2	641	.317	.704978	~19	.704895
86–DJ–123-------	Tpd	14.6	934	.0452	.704575	~19	.704563
87–DJ–7 ----------	Tha	50.4	926	.157	.704435	~19	.70438
84–DJ–232-------	Tba	36.0	1,193	.0873	.705112	19	.705088
83–DJ–100-------	Tt	163	217	2.17	.705851	22	.70517
84–DJ–119-------	Tsc	137	167	2.37	.706257	23	.70548
84–DJ–121 -------	Tsc	178	317	1.62	.705536	23	.70507
85–DJ–125-------	Tt	137	408	.971	.705348	23	.705031
85–DJ–151 -------	Tg	164	138	3.44	.706292	23.5	.70516
84–DJ–58 --------	Toa	92.3	480	.556	.705544	24.5	.70535
87–DJ–10 --------	Toa	67.4	820	.238	.705156	~25	.70507
87–DJ–11 --------	Toa	70.6	727	.281	.704985	~25	.704885
87–DJ–12 --------	Toa	101	759	.385	.705178	~25	.705041
87–DJ–5 ----------	Toa	96.6	594	.47	.705258	25–26	.705088
87–DJ–3 ----------	Toa	81.6	1,874	.126	.705354	~26	.705307
84–DJ–137-------	Tdm	156	133	3.39	.706698	—	—
84–DJ–174-------	Tdm	160	227	2.04	.706199	—	—
84–DJ–175-------	Tdm	149	403	1.07	.705561	33.8[2]	.70512[2]
85–DJ–170-------	Tdm	147	293	1.45	.705823	—	—

[1]Tsv=Andesite of Stewart Valley; Tri=Rhyolite intrusion; Tha=Hornblende andesite; Tpd=Porphyritic dacite; Tba=Andesite and basaltic andesite; Tt=Tuff of Toiyabe; Tsc=Tuff of Sheep Canyon; Tg=Tuff of Goldyke; Toa=Older andesite sequence; Tdm=Tuff of Davis Mine.

[2]Weighted linear regression using equations of Ludwig (1987) and four samples of the tuff of Davis Mine.

Table 14. Chemical analyses of units in the Menter Canyon and Ellsworth sections

[All analyses except samples 83–DJ–94, 83–DJ–95, and 83–DJ–98 by X-ray fluorescence spectroscopy (analysts: A Bartel, J. Kent, R. Mendes, K. Stewart, D. Siems, and J. Taggart; chemical determination of FeO, H_2O^+, H_2O^-, CO_2 by C. Papp and S. Neil); samples 83–DJ–94, 83–DJ–95, and 83–DJ–98 analysed by rapid rock analysis (analyst: N. Rait). FeO*, total Fe as FeO; LOI, loss on ignition at 900°C]

	1	2	3	4	5	6	7
Sample number	83–DJ–26	83–DJ–27	85–DJ–1	85–DJ–2	83–DJ–94	83–DJ–50A	89–DJ–40
Major elements normalized to 100 percent volatile-free (weight percent)							
SiO_2	75.39	75.79	77.57	77.85	76.51	75.15	74.10
Al_2O_3	13.13	12.75	11.71	11.53	12.96	13.55	13.90
FeO	.13	.05	.07	.13	.25	.18	—
Fe_2O_3	2.10	2.07	1.91	1.82	1.24	1.39	1.99
MgO	.23	.14	.11	.25	.10	.39	.44
CaO	.51	.30	.31	.71	.53	1.14	1.42
Na_2O	3.42	3.66	3.52	2.96	3.11	3.65	3.65
K_2O	4.85	5.07	4.61	4.52	5.08	4.37	4.21
TiO_2	.22	.17	.16	.21	.09	.13	.18
P_2O_5	<0.05	<0.05	<0.05	<0.05	.06	<0.05	.06
MnO	.02	<0.02	.03	.02	.06	.04	.04
Total (volatile-free before normalization)	97.49	98.04	98.24	97.11	96.46	98.87	97.84
LOI	1.94	1.13	1.15	2.30	—	.75	1.18
H_2O^+	.77	.40	.22	.74	2.90	.05	.35
H_2O^-	.88	.71	.83	1.07	.43	.40	.57
CO_2	<0.01	<0.01	<0.01	<0.01	.03	<0.01	.04
F	—	—	—	—	.025	—	—
Cl	—	—	—	—	—	—	—
Minor elements (parts per million)							
Nb	28	30	26	18	23	18	14
Rb	174	190	168	146	197	188	170
Sr	60	28	28	90	31	118	180
Zr	355	435	390	300	203	92	108
Y	34	46	38	28	31	22	24
Ba	540	182	168	680	200	220	340
Ce	64	116	92	110	160	42	30
La	82	74	58	78	68	<30	<30
Cu	<20	<20	<20	<20	<20	<20	10
Ni	<20	<20	<20	<20	<20	<20	<10
Zn	48	98	82	82	73	46	64
Cr	<20	<20	<20	<20	<10	<20	<20
K/Rb	231	221	228	257	214	193	206
Sr/Rb	.34	.15	.17	.62	6.35	.63	1.06
FeO*	2.02	1.91	1.79	1.77	1.37	1.43	1.79

Sample descriptions

1 (83–DJ–26) Devitrified, densely welded upper cooling unit of the tuff of Green Springs from Green Springs collected at lat 38°53'30"N., long 117°46'56"W.

2 (83–DJ–27) Devitrified, densely welded lower cooling unit of the tuff of Green Springs from Green Springs collected at lat 38°53'28"N., long 117°46'45"W.

3 (85–DJ–1) Devitrified, densely welded lower cooling unit of the tuff of Green Springs from Menter Canyon collected at lat 38°52'48"N., long 117°47'30"W.

4 (85–DJ–2) Devitrified, densely welded upper cooling unit of the tuff of Green Springs from Menter Canyon collected at lat 38°52'47"N., long 117°47'35"W.

5 (83–DJ–94) Vitrophyric, densely welded tuff of Menter Canyon from lower cooling unit in Menter Canyon collected at lat 38°54'23"N., long 117°47'45"W.

6 (83–DJ–50A) Devitrified, densely welded upper part of the lower cooling unit of the tuff of Camel Spring collected about 1 km west of Fifteenmile Spring on the east side of the Paradise Range at lat 38°53'07"N., long 117°46'30"W.

7 (89–DJ–40) Devitrified, densely welded upper part of the lower cooling unit of the tuff of Camel Spring collected near Fifteenmile Spring on the east side of the Paradise Range at lat 38°51'53"N., long 117°48'07"W.

Table 14. Chemical analyses of units in the Menter Canyon and Ellsworth sections—Continued

[All analyses except samples 83–DJ–94, 83–DJ–95, and 83–DJ–98 by X-ray fluorescence spectroscopy (analysts: A Bartel, J. Kent, R. Mendes, K. Stewart, D. Siems, and J. Taggart; chemical determination of FeO, H_2O^+, H_2O^-, CO_2 by C. Papp and S. Neil); samples 83–DJ–94, 83–DJ–95, and 83–DJ–98 analysed by rapid rock analysis (analyst: N. Rait). FeO*, total Fe as FeO; LOI, loss on ignition at 900°C]

Sample number	8 89–DJ–41	9 83–DJ–95	10 83–DJ–98	11 83–DJ–35	12 83–DJ–47	13 85–DJ–119A	14 85–DJ–117
Major elements normalized to 100 percent volatile-free (weight percent)							
SiO_2	74.82	73.72	76.92	77.05	65.07	77.24	76.00
Al_2O_3	13.71	14.06	12.67	12.44	18.39	12.89	13.38
FeO	—	.62	.16	.05	.87	.38	.28
Fe_2O_3	1.29	1.24	1.21	1.44	2.60	.70	.83
MgO	.40	.41	.18	.13	.70	.12	.17
CaO	1.32	1.24	.50	.30	4.33	.73	.87
Na_2O	3.53	3.10	3.52	3.67	4.09	3.56	3.48
K_2O	4.69	5.27	4.62	4.82	3.10	4.27	4.80
TiO_2	.14	.18	.11	.08	.54	.07	.19
P_2O_5	.05	.08	.06	<0.05	.25	<0.05	<0.05
MnO	.04	.07	.05	.02	.04	.04	<0.02
Total (volatile-free before normalization)	97.03	96.72	99.46	98.90	96.79	94.64	97.90
LOI	2.54	—	—	.68	2.81	4.82	1.18
H_2O^+	2.14	2.30	.55	.31	1.48	3.79	.37
H_2O^-	.22	.44	.60	.42	1.18	.74	.54
CO_2	.02	.02	.06	<0.01	<0.01	.08	<0.05
F	—	.026	.027	—	—	.020	.020
Cl	—	—	—	—	—	.072	.022
Minor elements (parts per million)							
Nb	12	12	35	34	10	—	14
Rb	176	130	202	245	92	—	148
Sr	156	182	42	24	690	—	112
Zr	92	216	221	205	220	—	168
Y	22	21	63	42	24	—	24
Ba	235	540	150	110	1,500	—	870
Ce	50	160	140	78	94	—	105
La	38	58	50	74	30	—	54
Cu	<10	<20	<10	<20	<20	—	<10
Ni	<10	<20	<10	<20	<20	—	<10
Zn	56	68	100	94	90	—	43
Cr	<20	13	<10	<20	<20	—	<10
K/Rb	221	337	190	163	280	—	269
Sr/Rb	.90	.71	4.81	.10	7.50	—	1.32
FeO*	1.16	1.74	1.25	1.32	3.10	1.01	1.02

Sample descriptions

8 (89–DJ–41) Vitrophyric, densely welded basal vitrophyre of the upper cooling unit of the tuff of Camel Spring collected near Fifteenmile Spring on the east side of the Paradise Range at lat 38°51'53"N., long 117°48'07"W.

9 (83–DJ–95) Vitrophyric, densely welded pumice-rich tuff. Lower cooling unit of the tuff of Gabb Valley collected in Menter Canyon at lat 38°54'07"N., long 117°47'23"W.

10 (83–DJ–98) Devitrified, densely welded part of the tuff of Brunton Pass from Brunton Pass collected at lat 38°52'18"N., long 117°44'13"W.

11 (83–DJ–35) Devitrified, densely welded part of the tuff of Brunton Pass from Green Spring Summit collected at lat 38°53'20"N., long 117°47'00"W.

12 (83–DJ–47) Devitrified, fine-grained porphyritic lava containing about 15 percent plagioclase, 2 percent clinopyroxene and 1 percent hornblende phenocrysts. From andesite unit that is between the tuff of Return Mine and the tuff of Camel Spring collected about 1 km south of Sherman Peak at lat 38°54'05"N., long 117°46'20"W.

13 (85–DJ–119A) Vitrophyric, densely welded brown rhyolite tuff collected about 1 km north of Fairview Peak in the northern Paradise Range at lat 38°59'56"N., long 117°46'09"W.

14 (85–DJ–117) Partially devitrified, densely welded basal part of the tuff of Big Spring collected about 1 km northeast of Big Spring at lat 38°59'40"N., long 117°45'09"W.

Table 15. Chemical analyses of units in the Sheep Canyon section

[All analyses by X-ray fluorescence spectroscopy (analysts: A. Bartel, M. Dyslin, J. Kent, R. Mendes, K. Stewart, J. Taggart, and T. Vercoutre; chemical determination of FeO, H_2O^+, H_2O^-, CO_2, F, and Cl by N. Elsheimer, S. Neil, C. Papp, and S. Pribble.) FeO*, total Fe as FeO; LOI, loss on ignition at 900°C]

	1	2	3	4	5	6	7	8	9	10	11
Sample number	85–DJ–54	85–DJ–151	88–PP–53	84–DJ–33	85–DJ–14	84–DJ–118	84–DJ–117	88–PP–52	88–PP–54	88–PP–55	88–PP–56
Major elements normalized to 100 percent volatile-free (weight percent)											
SiO_2	75.50	75.07	74.61	80.93	79.39	78.92	69.59	66.86	67.14	62.48	63.64
Al_2O_3	13.47	13.92	14.65	9.98	11.24	10.72	14.73	16.06	17.60	16.21	18.20
FeO	.36	.15	.24	.12	.99	.16	.19	1.61	.25	.31	4.46
Fe_2O_3	1.09	1.26	1.62	.79	.35	.60	3.77	3.04	3.22	5.02	.99
MgO	.30	.32	.36	.41	.17	.25	.70	.42	<0.20	.54	.72
CaO	1.29	.99	.60	1.33	.33	.95	3.41	3.67	3.81	7.82	3.45
Na_2O	3.66	3.13	1.56	2.58	1.37	1.17	3.00	3.55	3.58	3.44	3.91
K_2O	4.15	4.93	5.99	3.73	6.10	7.18	3.68	3.55	3.50	3.11	3.78
TiO_2	.13	.22	.29	.08	.06	.05	.61	.71	.63	.64	.53
P_2O_5	<0.05	<0.05	.08	.05	<0.05	<0.05	.25	.29	.25	.24	.25
MnO	.04	<0.02	<0.02	<0.02	<0.02	<0.02	.08	.25	.02	.19	.06
Total (volatile-free before normalization)	93.51	96.97	96.24	97.98	97.87	97.95	95.71	95.87	97.71	93.15	97.26
LOI	5.61	2.14	3.49	1.61	1.53	1.89	4.43	3.28	1.39	6.36	3.01
H_2O^+	3.56	.79	1.61	.41	.79	.62	1.11	1.43	.63	.93	.96
H_2O^-	1.64	.96	1.41	.40	.29	.34	1.72	.48	.45	1.33	1.15
CO_2	.21	.13	<0.01	.94	.25	.94	1.24	1.43	.16	3.5	.26
F	.01	.02	—	.01	<0.01	.02	.03	—	—	—	—
Cl	.038	<0.005	—	.008	.008	.012	.004	—	—	—	—
Minor elements (parts per million)											
Nb	14	17	14	35	—	19	8	16	12	10	14
Rb	345	154	150	238	—	189	96	84	92	72	102
Sr	287	139	80	66	—	45	453	385	620	485	550
Zr	153	163	170	224	—	132	128	148	136	126	156
Y	30	25	22	37	—	40	22	20	16	16	18
Ba	400	950	1,000	—	—	—	—	1,200	990	870	920
Ce	75	85	50	—	—	—	—	58	<30	58	<30
La	28	40	<30	—	—	—	—	<30	<30	30	<30
Cu	<10	<10	<20	—	—	—	—	<20	20	<20	<20
Ni	<10	<10	<20	—	—	—	—	<20	<20	<20	<20
Zn	56	52	96	—	—	—	—	58	42	52	50
Cr	<10	11	<20	—	—	—	—	<20	54	24	<20
K/Rb	100	266	331	130	—	315	318	350	316	359	308
Sr/Rb	.83	.90	.53	.28	—	.24	4.72	4.58	6.74	6.74	5.39
FeO*	1.35	1.29	1.70	.83	1.30	.71	3.58	4.34	3.15	4.83	5.35

Table 15. Chemical analyses of units in the Sheep Canyon section—Continued

Sample descriptions

1 (85–DJ–54) Densely welded, vitrophyric lapilli tuff. Part of the Tuff unit of John (1988) collected about 2 km north of the Paradise Peak mine at lat 38°45'57"N., long 117°59'20"W.

2 (85–DJ–151) Densely welded devitrified part of the tuff of Goldyke collected in the northern Pactolus Hills at lat 117°59'20"N., long 117°48'36"W.

3 (88–PP–53) Densely welded devitrified part of the tuff of Goldyke collected on the east side of Newmans Ridge at lat 38°45'16"N., long 117°59'18"W.

4 (84–DJ–33) Devitrified, weakly brecciated densely welded ash-flow tuff. Part of the red tuff unit of John (1988) collected in Sheep Canyon at lat 38°48'21"N., long 117°56'12"W.

5 (85–DJ–14) Devitrified, densely welded ash-flow tuff. Part of the red rhyolite tuff unit of John (1988) collected in Sheep Canyon at lat 38°46'44"N., long 117°54'33"W.

6 (84–DJ–118) Devitrified, densely welded ash-flow tuff. Part of the red rhyolite tuff unit of John (1988) collected in Sheep Canyon at lat 38°46'22"N., long 117°54'40"W.

7 (84–DJ–117) Devitrified, sparsely porphyritic dacite flow breccia. Part of the blue-gray dacite breccia unit of John (1988) collected in Sheep Canyon at lat 38°46'22"N., long 117°54'57"W.

8 (88–PP–52) Devitrified, sparsely porphyritic dacite flow breccia. Part of the blue-gray dacite breccia unit of John (1988) collected on the east side of Newmans Ridge at lat 38°45'20"N., long 117°59'16"W.

9 (88–PP–54) Weakly propylitized, moderately porphyritic hornblende-biotite-plagioclase dacite lava flow. Part of the rhyodacite to andesite unit of John (1988) collected on the north side of Newmans Ridge at lat 38°45'26"N., long 117°59'40"W.

10 (88–PP–55) Weakly propylitized, moderately porphyritic hornblende-biotite-plagioclase dacite lava flow. Part of the rhyodacite to andesite unit of John (1988) collected on the north side of Newmans Ridge at lat 38°45'26"N., long 117°59'41"W.

11 (88–PP–56) Weakly propylitized, moderately porphyritic hornblende-biotite-plagioclase dacite lava flow. Part of the rhyodacite to andesite unit of John (1988) collected on the north side of Newmans Ridge at lat 38°45'26"N., long 117°59'42"W.

Table 16. Chemical analyses of the lower white tuff

[All analyses by X-ray fluorescence spectroscopy (analysts: A. Bartel, M. Dyslin, J. Kent, R. Mendes, K. Stewart, J. Taggart, and T. Vercoutre; chemical determination of FeO, H_2O^+, H_2O^-, CO_2, and F by N. Elsheimer, S. Neil, C. Papp, and S. Pribble). FeO*, total Fe as FeO; LOI, loss on ignition at 900°C]

Sample number	1 84–DJ–200	2 84–DJ–204	3 85–DJ–133	4 85–DJ–58	5 88–DJ–69	6 88–DJ–70	7 88–PP–57	8 88–PP–58	9 88–PP–59	10 88–PP–60	11 88–PP–61
Major elements normalized to 100 percent volatile-free (weight percent)											
SiO_2	76.71	79.76	76.32	77.84	76.87	76.83	77.91	77.86	78.64	75.05	76.39
Al_2O_3	13.05	13.09	13.19	12.80	13.24	13.07	14.02	14.20	13.91	14.25	15.28
FeO	.31	.16	.28	.33	.22	.18	.06	.07	.09	.33	.10
Fe_2O_3	.89	.26	.77	.62	.97	1.13	.65	.82	.41	1.43	.52
MgO	.28	.18	.17	.16	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
CaO	1.11	.13	.75	.54	1.22	1.26	.44	.25	.25	1.49	.35
Na_2O	2.92	.89	3.32	3.96	3.31	2.95	1.04	.89	.95	1.40	1.14
K_2O	4.57	5.44	5.03	3.63	3.91	4.26	5.73	5.78	5.59	5.79	5.99
TiO_2	.11	.09	.12	.07	.13	.13	.10	.10	.12	.17	.19
P_2O_5	<0.05	<0.05	<0.05	<0.05	.02	.04	.04	.02	.04	.04	.04
MnO	.05	<0.02	.05	.05	.12	.15	<0.02	<0.02	<0.02	.04	<0.02
Total (volatile-free before normalization)	94.25	97.04	95.52	93.78	93.67	94.88	96.27	96.46	97.03	92.61	96.22
LOI	5.74	2.81	3.95	5.44	6.24	4.49	3.10	3.05	2.85	6.73	3.35
H_2O^+	2.68	2.00	2.82	4.34	3.17	1.73	1.55	1.69	1.81	3.30	1.94
H_2O^-	2.59	.66	.79	.80	2.47	2.11	.72	.62	.41	2.68	.52
CO_2	.21	.07	.13	.07	.04	<0.01	.08	<0.01	.21	.06	.13
F	.030	.030	.020	.010	—	—	—	—	—	—	—
Trace elements (parts per million)											
Nb	14	17	16	15	22	18	18	20	20	20	20
Rb	255	181	224	262	295	154	174	178	166	186	168
Sr	175	26	57	51	94	118	10	16	20	305	24
Zr	139	180	140	117	138	138	128	136	144	200	172
Y	26	21	26	27	30	22	18	22	20	26	22
Ba	—	—	235	76	164	245	106	120	220	1,300	360
Ce	—	—	88	75	<30	80	46	68	58	64	110
La	—	—	37	36	<30	44	<30	<30	<30	36	44
Cu	—	—	<1	<1	<20	<20	<20	<20	<20	<20	<20
Ni	—	—	<1	0	<20	<20	<20	<20	<20	<20	<20
Zn	—	—	75	57	56	56	30	30	<20	118	<20
Cr	—	—	6	0	<20	<20	<20	<20	<20	<20	<20
K/Rb	149	250	186	115	110	229	274	270	279	258	296
Sr/Rb	.69	.14	.25	.19	.32	.77	.06	.09	.12	1.64	.14
FeO*	1.11	.40	.98	.89	1.10	1.19	.65	.81	.46	1.62	.57

Table 16. Chemical analyses of the lower white tuff—Continued

Sample descriptions

1 (84–DJ–200) Densely welded, basal vitrophyre from Newman's Ridge collected at lat 38°45'16"N., long 117°59'20"W.
2 (84–DJ–204) Devitrified, moderately welded tuff from Newman's Ridge collected at lat 38°45'28"N., long 117°59'29"W.
3 (85–DJ–133) Densely welded, basal vitrophyre from northern Pactolus Hills collected at lat 38°45'15"N., long 117°48'13"W.
4 (85–DJ–58) Densely welded basal vitrophyre from the northern end of Newman's Ridge collected at lat 38°45'23"N., long 117°59'30"W.
5 (88–DJ–69) Densely welded basal vitrophyre from the Poleline Road collected at lat 38°47'12"N., long 117°57'33"W.
6 (88–DJ–70) Densely welded basal vitrophyre from the Poleline Road collected at lat 38°47'12"N., long 117°57'32"W.
7 (88–PP–57) Devitrified, moderately welded tuff from east side of Newman's Ridge collected at lat 38°45'24"N., long 117°59'30"W.
8 (88–PP–58) Devitrified, moderately welded tuff from east side of Newman's Ridge collected at lat 38°45'24"N., long 117°59'30"W.
9 (88–PP–59) Devitrified, moderately welded tuff from east side of Newman's Ridge collected at lat 38°45'20"N., long 117°59'29"W.
10 (88–PP–60) Densely welded, basal vitrophyre from the east side of Newman's Ridge collected at lat 38°45'18"N., long 117°59'22"W.
11 (88–PP–61) Devitrified, moderately welded tuff from east side of Newman's Ridge collected at lat 38°45'19"N., long 117°59'32"W.

Table 17. Chemical analyses of the tuff of Sheep Canyon

[All analyses by X-ray fluorescence spectroscopy (analysts: A. Bartel, J. Kent, R. Mendes, D. Siems, K. Stewart, and J. Taggart; chemical determination of FeO, H_2O^+, H_2O^-, CO_2, F, and Cl by N. Elsheimer and S. Neil.) FeO*, total Fe as FeO; LOI, loss on ignition at 900°C]

Sample number	1 84–DJ–119	2 84–DJ–120	3 84–DJ–121	4 84–DJ–126	5 85–DJ–13	6 85–DJ–167G	7 85–DJ–167J
Major elements normalized to 100 percent volatile-free (weight percent)							
SiO_2	72.54	68.05	69.48	69.12	70.09	69.88	67.93
Al_2O_3	14.47	16.09	15.74	15.99	15.60	15.59	16.17
FeO	.30	.60	.26	.34	.35	.45	.51
Fe_2O_3	1.91	2.56	2.75	2.52	2.44	2.71	2.82
MgO	.46	.76	.46	1.01	.50	.91	.98
CaO	1.50	3.17	2.89	3.32	2.63	2.57	3.02
Na_2O	3.41	3.41	3.09	2.84	3.48	3.17	3.80
K_2O	5.11	4.82	4.75	4.05	4.43	4.14	4.02
TiO_2	.23	.40	.40	.54	.36	.39	.42
P_2O_5	.07	.14	.16	.13	.12	.14	.26
MnO	<0.02	<0.02	.03	.14	<0.02	.04	.08
Total (volatile-free before normalization)	96.78	98.17	97.87	93.17	97.45	96.88	98.34
LOI	2.63	1.71	1.94	5.46	1.34	2.58	.92
H_2O^+	.81	.54	.73	1.40	.55	.93	.45
H_2O^-	1.01	.52	.50	2.84	.42	1.34	.31
CO_2	.75	.58	.55	.99	.28	.05	.05
F	.05	.04	.04	.03	.01	—	—
Cl	.009	.021	.007	.007	.010	—	—
Minor elements (parts per million)							
Nb	18	12	<10	12	14	10	<10
Rb	160	148	177	116	131	130	116
Sr	164	450	328	274	412	405	520
Zr	236	146	130	250	155	140	166
Y	29	21	18	22	20	16	12
Ba	—	—	—	1,900	1,275	1,100	1,400
Ce	—	—	—	76	95	54	36
La	—	—	—	56	55	50	<30
Cu	—	—	—	<20	<20	<20	<20
Ni	—	—	—	<20	<20	<20	<20
Zn	—	—	—	65	43	40	44
Cr	—	—	—	<20	<20	<20	<20
K/Rb	265	270	223	290	281	264	287
Sr/Rb	1.03	3.04	1.85	2.36	3.15	3.12	4.48
FeO*	2.02	2.90	2.73	2.61	2.55	2.89	3.05

Sample descriptions

1 (84–DJ–119) Devitrified, densely welded tuff from the lower part of the second cooling unit collected in Sheep Canyon at lat 38°46'24"N., long 117°54'37"W.

2 (84–DJ–120) Devitrified, densely welded tuff from the lower part of the third cooling unit collected in Sheep Canyon at lat 38°46'28"N., long 117°54'34"W.

3 (84–DJ–121) Devitrified, densely welded tuff from the lower part of the fourth cooling unit collected in Sheep Canyon at lat 38°47'53"N., long 117°54'32"W.

4 (84–DJ–126) Devitrified, densely welded tuff from the second cooling unit collected in Sheep Canyon at lat 38°48'34"N., long 117°55'32"W.

5 (85–DJ–13) Devitrified, densely welded tuff from the second cooling unit collected in Sheep Canyon at lat 38°46'48"N., long 117°54'33"W.

6 (85–DJ–167G) Devitrified, densely welded tuff from the middle part of the third cooling unit collected in Sheep Canyon at lat 38°46'28"N., long 117°54'32"W.

7 (85–DJ–167J) Devitrified, densely welded tuff from the upper part of the third cooling unit collected in Sheep Canyon at lat 38°46'28"N., long 117°54'30"W.

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