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MESOZOIC METAVOLCANIC AND METASEDIMENTARY ROCKS OF THE RENO-CARSON CITY AREA, NEVADA AND ADJACENT CALIFORNIA

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A detailed description of the Mesozoic metavolcanic and metasedimentary rocks of the Reno-Carson City area, including the Peavine sequence. Includes stratigraphic columns and a discussion of lithofacies and petrochemistry.

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ABSTRACT

Mesozoic metavolcanic and metasedimentary rocks in the Reno-Carson City area are a part of either a Middle Jurassic(?) predominantly metavolcanic unit (Peavine sequence and related rocks) or a marine clastic and carbonate unit (the Gardnerville Formation of latest Triassic and Early Jurassic age). In the Peavine Peak area, the Peavine sequence is considered to be nonmarine, and is characterized by lava flows, lahars, flow domes, ignimbrites, hypabyssal intrusives, and minor volcaniclastic rocks. Except near younger plutons, these rocks are metamorphosed to greenschist grade, but commonly not foliated. Elsewhere in the Virginia and Carson Ranges to the south and southeast, similar, possibly related metavolcanic rocks are found as pendants in Cretaceous granitic rocks. In these rocks, foliation is locally more strongly developed.

Peavine sequence and related rocks are apparently characterized by rapid lateral and vertical changes in lithofacies, and are only preserved as pendants in extensive Cretaceous plutons. Their age is poorly constrained, thus allowing only speculative correlations with similar, better-dated units exposed in the surrounding region.

INTRODUCTION

The research described in this report was done as part of a larger study, begun in 1989, of the geology and mineral deposits of the Triassic and Jurassic magmatic arc of western Nevada and eastern California. The fieldwork and most report writing were complete by the end of 1992. Work on the Peavine sequence petrochemistry was completed in 1993 (Garside, 1993a). The report has been updated by the addition of more recent references and the changes in the text that these new data required. Much of the other data produced by the larger study has been released in open file (e.g., John and others, 1994; Doebrich and others, 1996; Stewart, 1997).

ACKNOWLEDGMENTS

I benefitted greatly from discussions with H.F. Bonham, Jr., J.H. Stewart, D.A. Davis, and D.M. Hudson on the Mesozoic volcanic rocks of the Reno-Carson City area. J.R. Lecompte made many constructive review comments on an earlier version of the text. Reviews by J.H. Stewart, C.D. Henry, and D.A. Davis materially improved the manuscript.

PEAVINE SEQUENCE AND RELATED ROCKS OF WESTERN NEVADA AND EASTERN CALIFORNIA

Introduction

Bonham (1969) first applied the informal name "Peavine sequence" to "siliceous to intermediate volcanic flows, tuffs, and breccias ... interbedded with clastic sedimentary rocks ranging from slates to graywackes and volcanic conglomerates." He reported that the most extensive and best exposures of the sequence crop out on Peavine Peak and adjacent Petersen Mountain (figs. 1, 2). As originally defined, the sequence included volcaniclastic rocks, schist, and limestone exposed in the Virginia Range, Carson Range, and Steamboat Hills. These rocks have been mapped separately from the predominantly volcanic assemblage by several workers (e.g., Thompson, 1956), and are now believed to represent the Gardnerville Formation of latest Triassic and Early Jurassic age or related rocks (see section on the Steamboat Hills-Virginia Range). The Gardnerville is believed to be entirely marine. Thus, the Peavine sequence as discussed herein is restricted to the predominantly volcanic rocks exposed mainly in roof pendants enclosed within Cretaceous granitic rocks north of the Truckee River in Nevada and adjacent California (fig. 2). The Peavine sequence is part of the extensive Middle Jurassic volcanic and volcaniclastic succession in western Nevada (Stewart, 1997). No rocks older than the Peavine sequence have been identified in this area. All the Mesozoic rocks were deeply eroded during the latest Cretaceous and early Tertiary. A sequence of Oligocene and lower Miocene silicic ignimbrites unconformably overlies the Mesozoic rocks. These were themselves deeply eroded in the Reno area before Miocene andesitic volcanic rocks, younger basalts, and Quaternary surficial deposits were laid down. All of the units have been cut by late Cenozoic basin-and-range normal faults, further complicating stratigraphic correlations.

In many areas, rocks of the Peavine sequence contain well-preserved original sedimentary and volcanic textures and structures, and the relatively weak deformation and metamorphism have not obliterated stratigraphic relationships. Where appropriate, in the following lithofacies and area descriptions, the protolith terms are used interchangeably with metamorphic lithology terms.

Methods of Study

In addition to the regional studies of Bonham (1969), several areas underlain by the Peavine sequence have been mapped at 1:24,000 scale (Bell and Bonham, 1987; Bell and Garside, 1987; Garside, 1993b). During the 1989 and 1990 field seasons, traverses were made across nearly all roof pendants and inliers of the Peavine sequence and related nearby rocks for the purpose of compiling stratigraphic sections and interpreting depositional environments. Additionally, samples of the various rock types were collected for petrographic study and chemical and isotopic analysis. Approximately 35 thin sections were examined during the study, and an approximately equal number had been studied previously. Twenty-four samples were collected for chemical analysis for major and nine immobile trace elements (see the following section on petrochemistry). These samples were also used for Rb/Sr isotopic study by R.W. Kistler (see the discussion of age in the following Peavine Peak area description).

Lithofacies of the Peavine Sequence

The principal protoliths of the Peavine sequence consist of lava flows, lahars, flow domes, ignimbrites, hypabyssal intrusive

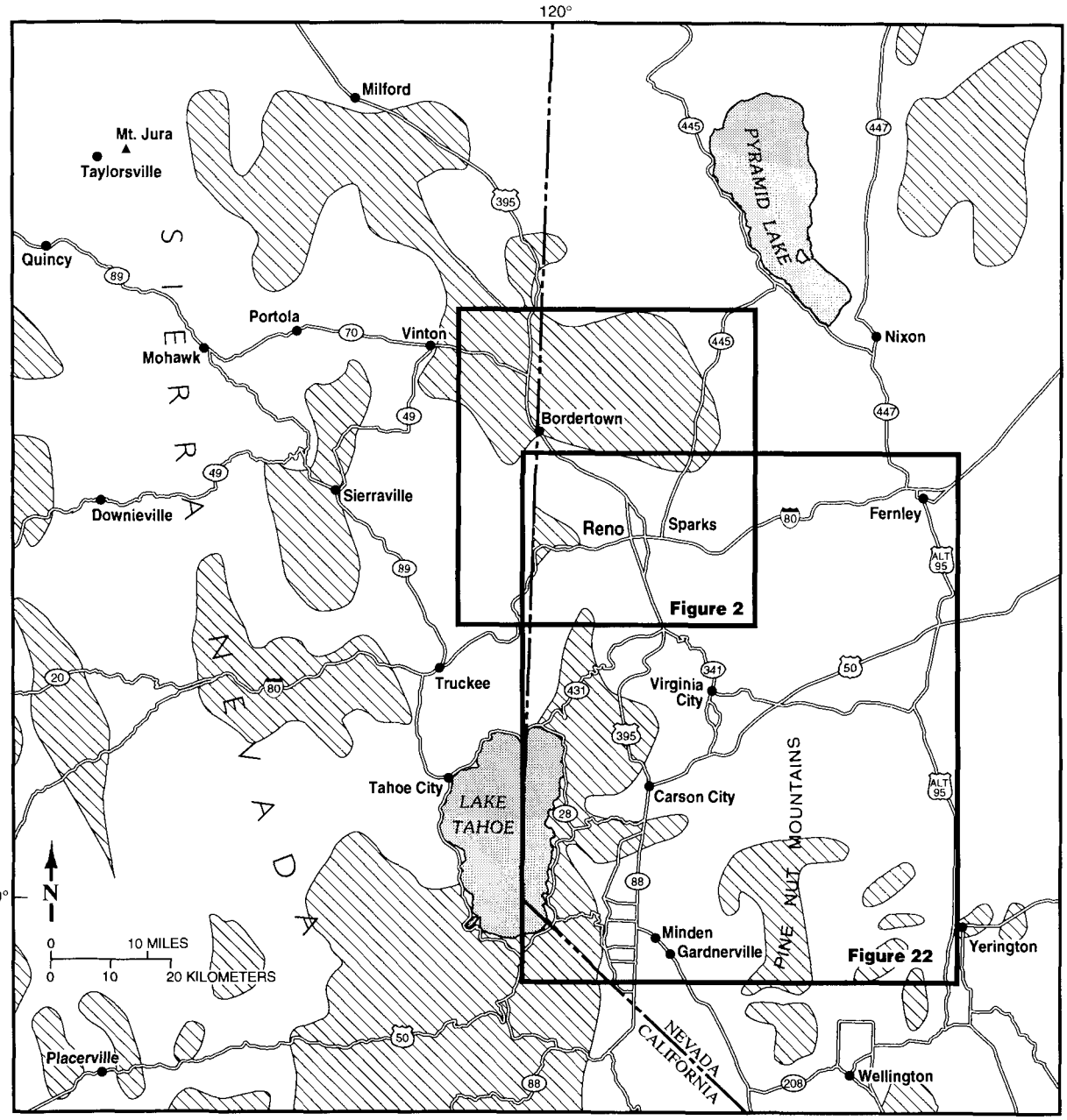


Figure 1. Location map showing areas described in text and outcrops of granitic rocks of the Sierra Nevada batholith (hachured).

rocks, and minor, but ubiquitous, volcaniclastic sedimentary rocks. The Peavine sequence is apparently characterized by rapid lateral and vertical changes in lithofacies; the interpretation and correlation of these lithofacies are complicated by discontinuous outcrops, locally poor exposures, destruction of primary textures by Mesozoic regional greenschist metamorphism and Tertiary hydrothermal alteration, high-angle faulting of Mesozoic(?) and Tertiary age, and intrusion by (mostly) Late Cretaceous plutons of the Sierra Nevada batholith. Based on the predominance in areal exposure of plutons over Peavine sequence pendants in areas of exposed Mesozoic rocks, a similar predominance is expected in areas covered by Cenozoic rocks. Plutonic rocks dominate over the Peavine sequence rocks in areas of exposure, and presumably in areas covered by Cenozoic rocks.

Diverse lithofacies of the Peavine sequence are exposed in pendants in Late Cretaceous plutons and in windows in Tertiary and Quaternary cover units in mountain areas and Basin and Range valleys. Some speculations concerning the lithofacies relationships of the Peavine sequence can be made, based on the rock units exposed in roof pendants of the Sierra Nevada batholith. However, correlations between the various pendants are usually not possible, because distinctive, widely distributed units (such as ignimbrites) could not usually be recognized with certainty in more than one pendant or area of exposure. This is probably not surprising, as the age range of the Peavine sequence is poorly constrained, and a complete section is never seen in the pendants examined. Based on comparisons with complex volcanic arc stratigraphy noted in Tertiary to Holocene arcs, the remnants of Peavine sequence

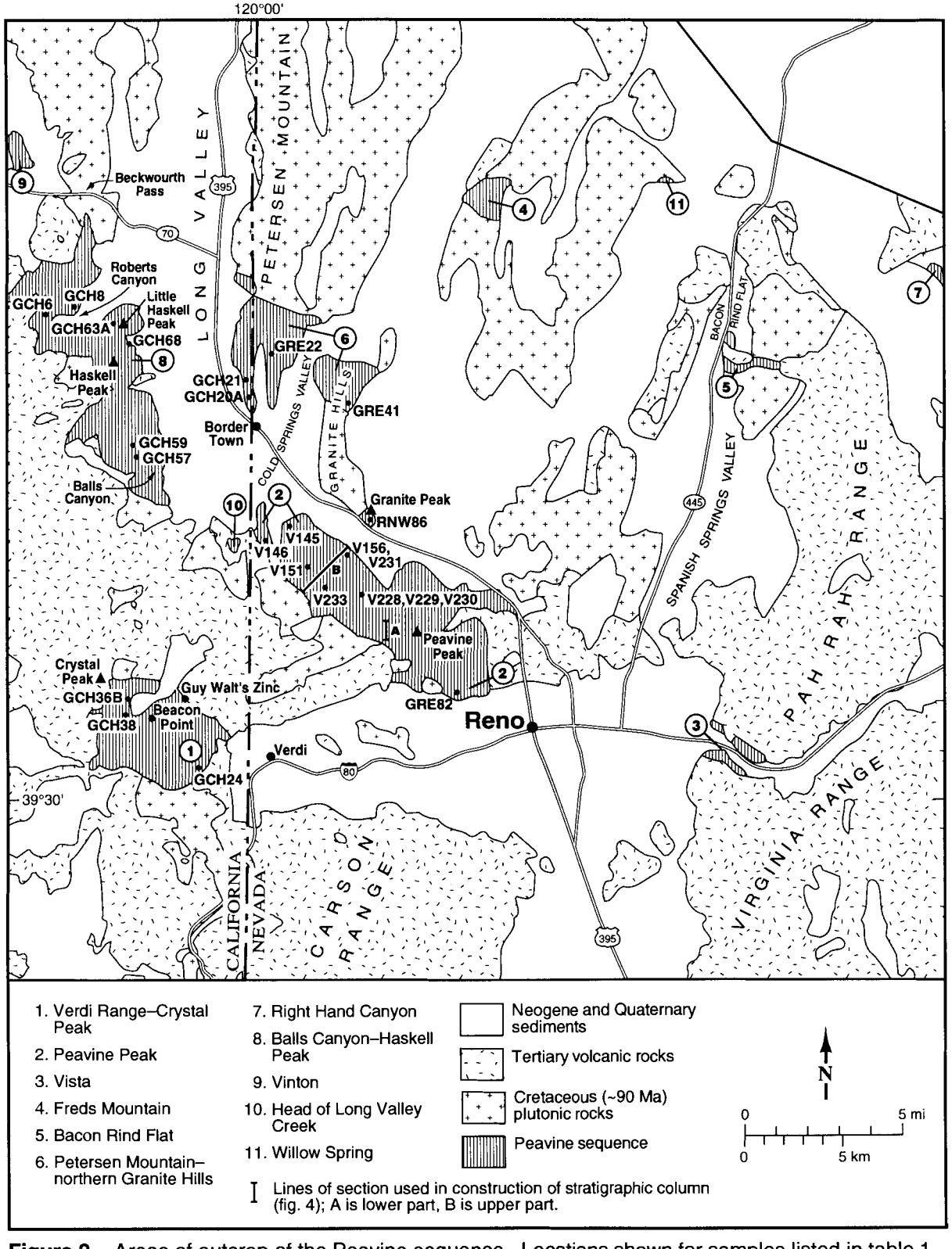


Figure 2. Areas of outcrop of the Peavine sequence. Locations shown for samples listed in table 1.

rocks may well represent parts of volcanic edifices of approximately the same age. Alternatively, because of poor age constraints on the sequence, the variation in lithology between pendants may be a reflection of unidentified age differences of tens of millions of years.

The Peavine sequence is a predominantly volcanic, apparently entirely a nonmarine part of a continental volcanic arc, most likely related to a single, east-dipping subduction zone along the western edge of North America. Although such volcanic-plutonic arcs have been referred to as "Andean-type" arcs, they are not necessarily areas of high relief. The Peavine sequence and other similar units in western Nevada may record rapid deposition of effusive volcanic rocks in an arc-graben depression (e.g., Busby-Spera, 1988). No features were noted in Peavine sequence rocks which are clearly indicative of marine deposition, and the welded ignimbrites in the unit are interpreted as indicative of subaerial deposition. No carbonate rocks are recognized in the sequence, and although quartz-bearing sandstone, grit, and wacke do occur, true quartzite is very rare or absent. The subaerial environments of deposition interpreted from scattered areas of exposure include proximal stratovolcano and caldera settings (including intracaldera, caldera rim flow-dome complex, ignimbrite outflow, and subvolcanic intrusive environments).

The Double Spring Formation (Noble, 1962; Wyld and Wright, 1993; Stewart, 1997) of the Pine Nut Mountains is a thick, predominantly subaerial volcanic unit, and may be correlative with the Peavine sequence (fig. 3). Noble (1962) reported that it has been subjected to less deformation than the older Mesozoic units. The Double Spring Formation is considered to be Middle Jurassic (Stewart, 1997) and thus may be approximately the same age as the Peavine sequence. Stewart (1977) has correlated the Double Spring Formation with the Fulstone Spring Volcanics of the Buckskin Range northwest of Yerington. The Middle Jurassic Tuttle Lake Formation (Harwood, 1992; Stewart, 1997) of the northern Sierra Nevada is also a possible correlative of the Peavine sequence. It is a marine, predominantly andesitic volcanic and volcaniclastic unit; debris flows are reported to represent a near-vent setting, and syndepositional hypabyssal intrusions are present (Templeton and Hanson, 1991).

Rocks quite similar lithologically to the Peavine sequence are exposed about 65 km northwest of the Reno area, in the vicinity of Taylorsville, California. The Kettle Rock sequence (Christe and Hannah, 1990) consists of a thick sequence of Jurassic subaerial andesitic to dacitic volcanic rocks and associated fluvial volcaniclastic sedimentary rocks. A thin ammonite-bearing pelitic unit appears to be the only marine unit; carbonate rocks are not reported. The volcanic rocks have chemical characteristics similar to modern continental arc volcanic rocks (Christe and Hannah, 1990). The Kettle Rock sequence is only weakly deformed and metamorphosed (Christe and Hannah, 1987, 1990). The upper part of the Kettle Rock sequence is Callovian (latest Middle Jurassic) in age based on a single ammonite (McMath, 1958); the age of the lower part is poorly constrained to the post-Sonoman (Triassic) to pre-Callovian (Jurassic). According to D.I. Axelrod (in Godwin, 1958), the Trail Formation (McMath, 1958) in this area (whose rocks were included in a revised Foreman Formation of the Kettle Rock sequence by Christe, 1987) contains plant fossils similar to those reported from the Peavine sequence on Peavine Peak. Rocks compositionally similar to the Kettle Rock sequence continue to the south toward Quincy and Vinton, California, (Christe, 1987; D'Allura, 1977) and the Peavine Peak area. The Trail Formation is apparently a predominantly shallow marine deposit in the Quincy area and consists of 60 to 70% slate (D'Allura, 1977, p. 181). Shallow-marine rocks, of at least partly equivalent age but uncertain relation to the Kettle Rock sequence, also occur in the Taylorsville area. They have been referred to as the Mount Jura sequence by Christe and Hannah (1990). This sequence includes volcanic units, but is otherwise lithologically dissimilar to the Peavine sequence.

The rocks of the Peavine sequence are not strongly deformed. No penetrative cleavage or major or minor folds are noted, and closely spaced cleavage or jointing is quite rare. Metamorphic grade is commonly characterized by the lower greenschist facies, except for areas within a few tens to hundreds of meters of Cretaceous granitic plutons, where the grade increases to the hornblende-hornfels facies. Metamorphic foliation also is only well developed near plutons and commonly is subparallel to the contact of the intrusive rocks and the Peavine sequence.

The lack of deformational features that are not clearly related to plutons of the Sierra Nevada batholith suggests that the Peavine sequence may be younger than most of the early to middle Mesozoic deformational events that have affected Triassic and Jurassic units to the south and southwest (e.g., Stewart, 1997, p. 13).

This apparent absence of deformation within the Peavine sequence is in contrast to the folding, penetrative cleavage, and extensive development of metamorphic foliation in Triassic and Lower and Middle Jurassic volcanic, siliciclastic, and carbonate units in the Carson City area and Pine Nut Mountains (Bingler, 1977; R.A. Schweickert, unpub. data, 1991; L.J. Garside, unpub. data, 1997). Although those rocks, because of their lithology, may better exhibit deformational effects than the commonly massive volcanic units of the Peavine sequence, it seems likely that they are truly more deformed, and thus probably older.

Area Descriptions

Peavine Peak

The Peavine sequence was named for its exposures on Peavine Peak (Bonham, 1969). The sequence there consists of subaerial calcalkaline volcanic rocks and associated pyroclastic and epiclastic volcanic units (fig. 4). These rocks are uniformly thermally metamorphosed to the greenschist grade, except adjacent to an epizonal Cretaceous pluton, where the metamorphic grade reaches the hornblende-hornfels facies. With the exception of the contact areas of the pluton, where a northwest-trending schistosity is rarely developed parallel to the pluton margin, rocks of the Peavine sequence do not exhibit obvious penetrative cleavage, secondary foliation, or folds. Because of limited exposures of the Peavine sequence and

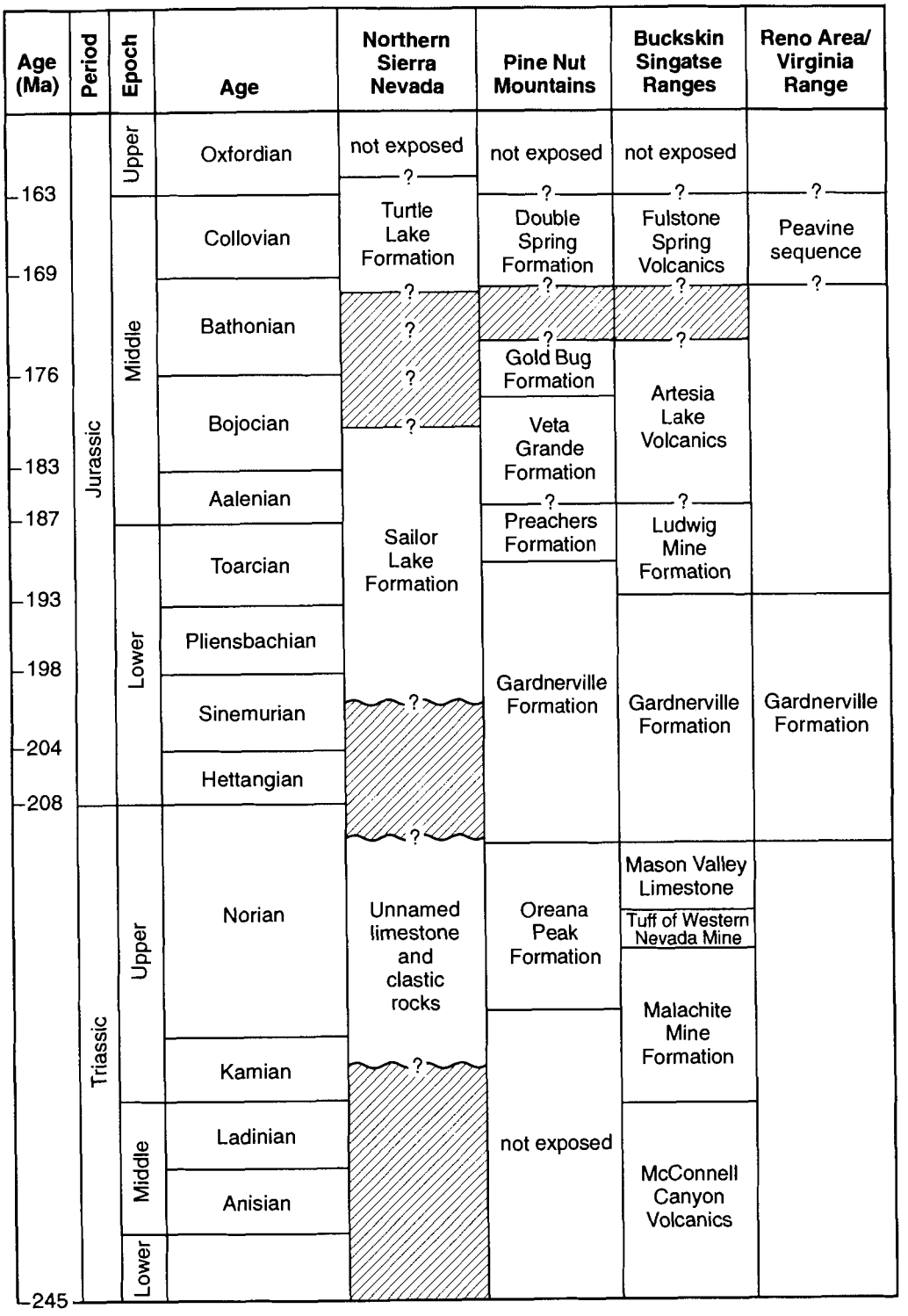


Figure 3. Nomenclature and ages of Triassic and Jurassic rocks in western Nevada and eastern California, modified from Stewart (1997, fig. 3). Queries indicate uncertain age boundaries. Wavy lines indicate unconformities. Diagonal lines indicate known or proposed absence of strata. Absolute time scale for base of the Triassic and for epochs and ages in the Jurassic is from Palmer (1983). Absolute time scale for epochs and ages within the Triassic are poorly known and ages are not shown.

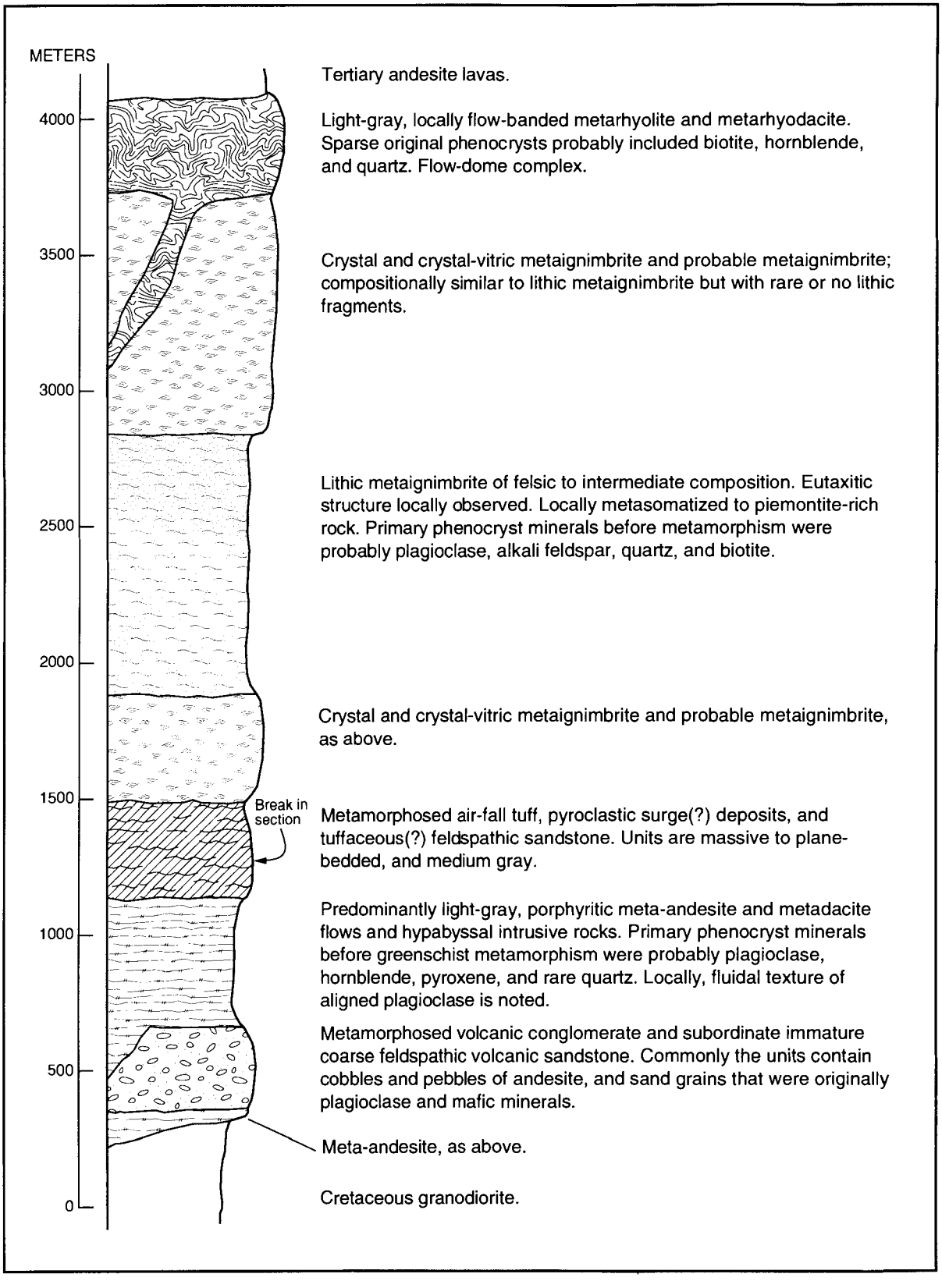


Figure 4. Speculative stratigraphic column of the Peavine sequence in the Peavine Peak area, Nevada. Column is based on the interpretation that thick ignimbrites are an intracaldera sequence on an andesitic composite volcanic edifice, and intruded by ring rhyolite domes. Other interpretive columns could be constructed. See figure 2 for locations of measured sections.

Mesozoic(?) and later faulting, continuous stratigraphic sections are not common. The interpretative stratigraphic column shown in figure 4 includes most of the rock types mapped on Peavine Peak, but was compiled from two partial sections which may not fit together in the manner shown.

The Peavine sequence on Peavine Peak, the largest and best known area of its exposure (over 15 km long and 4 to 5 km wide), consists of the metamorphosed equivalents of andesite and dacite flows and hypabyssal intrusive rocks, andesite cobble conglomerate, feldspathic sandstone, rhyolite to rhyodacite flows and domes, and crystal and lithic, silicic to intermediate ignimbrites and associated tuffaceous sedimentary rocks (photos 1–6) (Bell and Garside, 1987; Garside, 1989). Approximately 20% of the Peavine sequence outcrop area on Peavine Peak is ignimbrite, 10% volcaniclastic sedimentary rocks, and the remainder silicic and intermediate flows and hypabyssal intrusive rocks. A granodiorite porphyry of uncertain age (unit Mzgd of Bell and Garside, 1987) exposed on the east flank of Peavine Peak may be a part of a subvolcanic to epizonal pluton associated with Peavine sequence volcanism. It is lithologically similar to rocks in pendants nearby to the north and northeast at Granite Peak and the northern part of

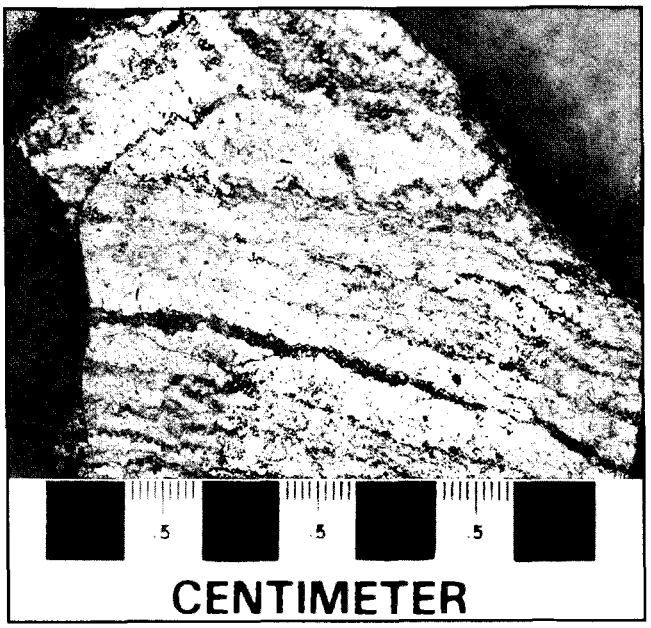


Photo 2. Fluidal flow banding in metarhyolite from Peavine sequence near top of Peavine Peak.

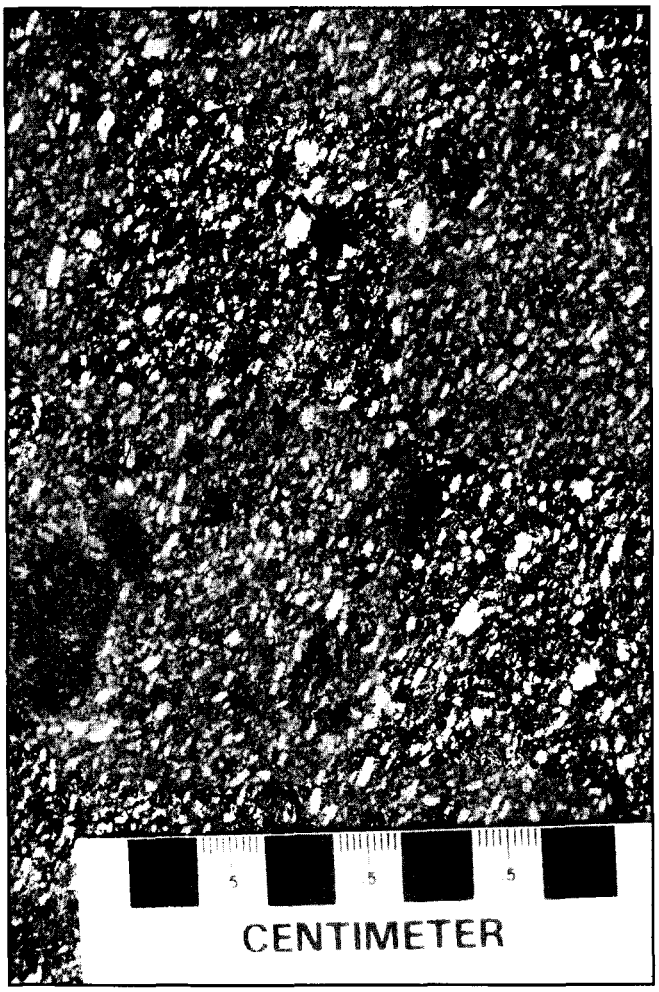


Photo 1. Cognate xenoliths and fluidal texture of aligned plagioclase in Peavine sequence meta-andesite from Peavine Peak.

Photo 3. Eutaxitic structure in silicic metaignimbrite of the Peavine sequence from Peavine Peak. Light fiamme in darker groundmass. Coin is approximately 2 cm.

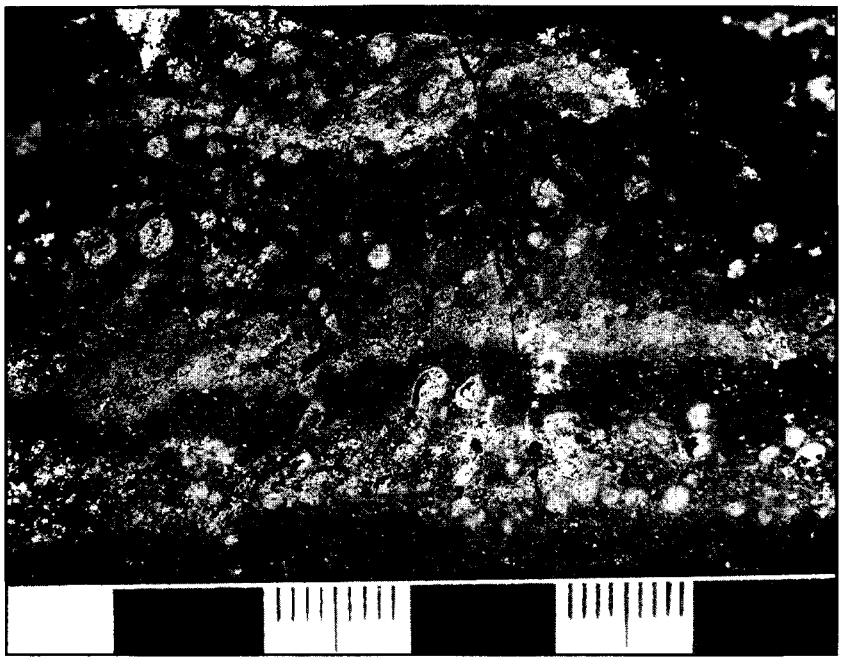


Photo 4. Accretionary lapilli in layered tephra deposit from the Peavine sequence of Peavine Peak. Centimeter scale.

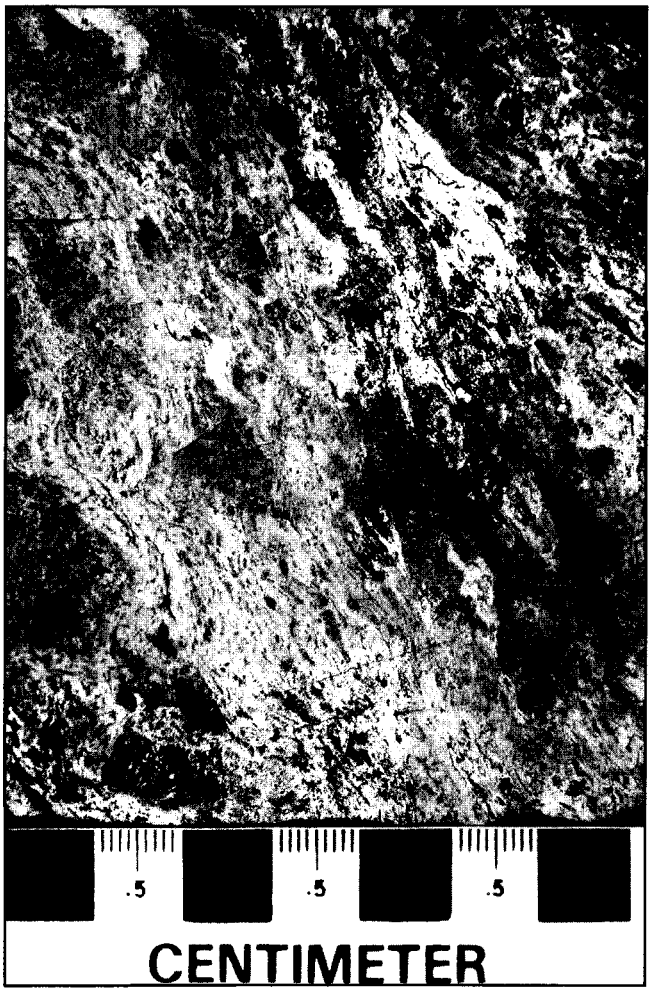


Photo 5. Light fiamme and dark lithic fragments in a metaignimbrite from the Peavine sequence of Peavine Peak.

Photo 6. Welded shards preserved in an ignimbrite lithic fragment in a metaignimbrite. Shards originally exhibited axiolitic structure. From the Peavine sequence on Peavine Peak. Lithic fragment is 3–4 mm in diameter.

the Granite Hills (fig. 2) that are also interpreted to be plutonic rocks related to the Peavine sequence. At the south end of Granite Peak (fig. 2), Soeller and Nielsen (1980) showed an area of less than 2 km^2 as Peavine sequence metavolcanic rocks; these rocks are also interpreted herein to be hornblende granodiorite porphyry. The mafic minerals of rocks at those outcrops are chloritized, epidote is present locally, and many samples of the rock contain an indistinct foliation that was probably developed during primary crystallization. The unit is intruded to the north by Cretaceous granodiorite.

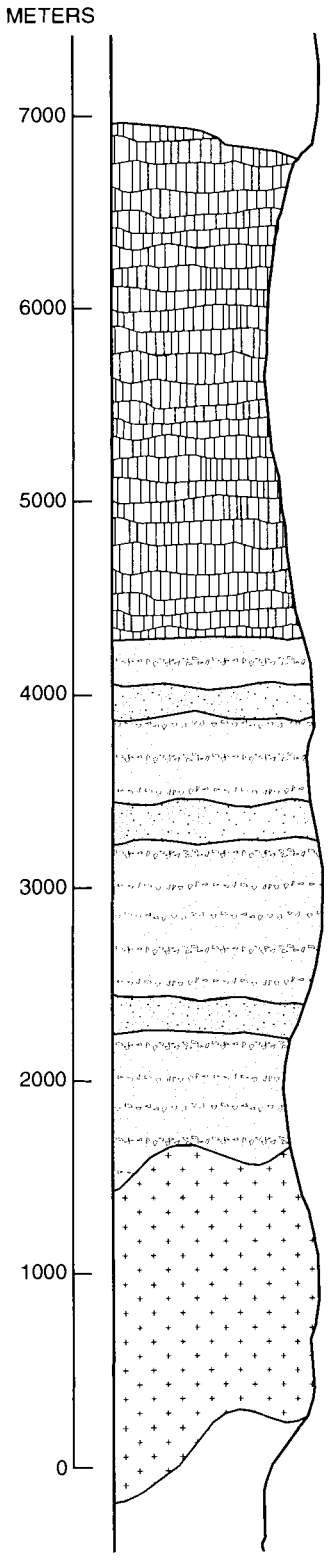
The interpretative stratigraphic column of the Peavine Peak area shown in figure 4 includes over 2,000 m of lithic and nonlithic silicic ignimbrite. Limited exposure, coupled with probable unrecognized high-angle faulting, severely restricts attempts at detailed correlation within the ignimbrite package. However, the absence of recognizable breaks in lithology over extensive areas, breaks that might be expected in a stack of outflow sheets, suggests that the northern part of Peavine Peak may consist mostly of intracaldera ignimbrites. Rocks interpreted to be stratigraphically below the ignimbrites include andesitic flows, lahars, and associated volcaniclastic sandstone which may represent the proximal part of a stratovolcano sequence. Thus, units within the Peavine sequence that are interpreted to be epizonal to hypabyssal intermediate-composition intrusive rocks (e.g. granodiorite porphyry and rhyodacite on the east flank of Peavine Peak, in the Granite Hills, and on Petersen Mountain) may represent the subvolcanic levels of a cauldron complex.

Metamorphic minerals developed in the rocks on Peavine Peak include actinolite, chlorite, epidote, calcite, and albite. Distinctive red to reddish-brown piemontite (Gianella, 1937) and pinkish Mn-bearing epidote (L.C. Hsu, oral commun., 1990) are locally common in metaignimbrites about 3 km northwest of Peavine Peak and on Petersen Mountain to the north. Piemontite occurs sporadically in greenschist-facies rocks (as well as in other metamorphic facies) in a variety of geologic environments; high oxygen fugacity is required for its formation (Keskinen and Liou, 1979). The only other known nearby occurrences of piemontite are in pyroclastic rocks in a sequence of upper Mesozoic arc rocks exposed in the Ritter and Goddard Peak roof pendants near Bishop, California (Keskinen, 1981) and in the Jurassic Fulstone and Artesia metavolcanic sequences of the Buckskin Range northwest of Yerington, Nevada (Geissman and Van der Voo, 1980). Possibly, the highly oxidized nature of subaerial ignimbrites (due to their method of emplacement, vapor-phase alteration, and devitrification) predisposed the ignimbrites to the development of piemontite during thermal metamorphism. Coarse hematite is noted locally as well in the ignimbrites on Peavine Peak, possibly also reflecting the oxidized character of the protolith.

Verdi Range-Crystal Peak

An irregular outcrop area of metavolcanic rocks about 7 by 7 km underlies the Verdi Range west of Verdi, Nevada. The rocks are intruded along their south, north, and probably east margins by Cretaceous quartz monzonite, and covered elsewhere by flows and lahars of Miocene andesite. The best exposures of layered rocks are along the crest and east flank of the Verdi Range south of Beacon Point (fig. 2). These rocks have a north to northwest strike that generally parallels the trend of the Verdi Range, and dip east at 55° to 65°. The stratigraphic section, as interpreted from traverses across the range and to the northwest (fig. 5), consists of two surficial units and a hypabyssal microdiorite. The lower surficial unit is predominantly andesitic lahars (photo 7) and subordinate feldspathic volcaniclastic sandstone, about 2,500 m thick; the upper surficial unit consists of dark metabasalt of approximately the same thickness (fig. 5). Local crossbedding features in the sandstones suggest that the rocks are upright, and placer-like concentrations of dark minerals are suggestive of fluvial deposition (oral commun., Jim Yount, 1990). Load cast-like features were noted in probable debris-flow units. Except near the margins of the Cretaceous granitic bodies, the meta-andesite and metabasalt units are not foliated. Rare closely spaced (about 2 cm), jointing was noted (attitudes include N20°W, 90°; N60°E, 90°; N50°E, 90°; and N40°E, 70°SE.

Photo 7. Outcrop of meta-andesite lahar from the Peavine sequence of the Verdi Range area. Pocket knife is 8.6 cm long.



Tertiary andesite lavas and lahars.

Metabasalt. Black, light- to dark-gray-weathering actinolitic hornfels with a protolith of finely crystalline basalt and basaltic andesite. At one locality in upper part of the unit a few, thin (1–2 m), light colored, finely laminated and slump(?)-folded calcsilicate bands occur along with tuffaceous metasiltstone in the metabasalt (biotite semischist). Local spaced cleavage of N40°E, 70° SE.

Meta-andesite laharic breccia with sparse interbeds of meta-volcaniclastic (feldspathic) sandstone of probable fluvial origin. Facing features in sandstone indicate beds are upright. The predominant lithology is heterolithologic andesite lahar consisting of rounded and subrounded cobbles, 2–10 cm in diameter (rarely 30–50 cm). Fragments are pyroxene and pyroxene-hornblende andesite flow rocks; phenocrysts in some fragments exhibit fluidal textures. Rare amygdaloidal basalt flow rocks and andesite flows(?) and dikes occur also. Rare vertical(?) spaced cleavages of N20°W and N50°–60°E were noted; nonfoliate.

Metamorphosed hornblende andesite and microdiorite. Dark-gray, aphanitic and microcrystalline phaneritic porphyritic, hypabyssal(?) mafic rocks having probable original phenocrysts of plagioclase and hornblende. Fine to medium grained. Locally contains inclusions, ranging in size from a few cm to 1 m in diameter, of bedded clastic sedimentary rock. May be separated from lahar unit by a fault rather than intrusive contact.

Cretaceous quartz monzonite.

Figure 5. Interpretive stratigraphic column on the Peavine sequence, northern Verdi Range-Crystal Peak

At the Guy Walt's Zinc property (fig. 2), located approximately 4 km northwest of Verdi, Nevada (see Doebrich and others, 1996, p. 21), an unusual group of very pale-orange-weathering, light-gray, siliceous calcsilicate bands crop out within what is interpreted to be the upper part of the metavolcanic unit. The 1- to 2-m-thick bands of light-colored, calcsilicate rocks preserve finely laminated(?), and slump(?)-folded textures. They are found with a few beds of darker, tuffaceous siltstone in a sequence of rocks that is predominantly metabasalt. At this locality, siltstone and basalt are metamorphosed to spotted biotite-sericite hornfels and biotite semischist (somewhat schistose rocks that are transitional between massive, slightly metamorphosed rocks and typical schists), apparently as a result of thermal metamorphism related to intrusion of the Cretaceous pluton exposed a few hundred meters to the east. The protolith of the calcsilicate bands is unknown, but may be a calcareous siliciclastic sediment. The zinc, in this interpretation, would be introduced in a skarn deposit. Fine slump(?) folding and sedimentary layering is preserved as alternating thin bands of fine-grained silica and epidote-group minerals; poikiloblastic scapolite also occurs.

A dark-greenish-gray hornblende microdiorite porphyry and associated hypabyssal(?) hornblende andesite is exposed in an area southeast of Crystal Peak. Inclusions of an unidentified laminated clastic sedimentary rock-type are present locally, but the unit is not observed directly to intrude the other nearby metavolcanic and metavolcaniclastic rocks as interpreted in figure 5. The hornblende microdiorite porphyry is cut by aplite-pegmatite dikes, and an indistinct foliation is developed by fine-grained biotite. Large (0.5 cm) phenocrysts of hornblende, however, are single continuous crystals, and appear unmetamorphosed. A K-Ar determination made on this hornblende yielded an age of 77.5 Ma (Garside and others, 1992). This age is younger that the nearby 91-Ma granitic intrusion, which is probably the source of the aplite-pegmatite dikes which cut the microdiorite porphyry. Thus, the 77.5-Ma age does not indicate the original age of the hornblende microdiorite porphyry. The K-Ar system has apparently been reset by later heating (later Cretaceous or Tertiary magmatism), with consequent partial to complete loss of radiogenic argon. Based on the geologic relations, the hornblende microdiorite porphyry and hornblende andesite are interpreted as hypabyssal or subvolcanic phases of the effusive volcanic sequence.

Except for the unusual siliceous calcsilicate bands of unknown protolith at the Guy Walt's Zinc property, no evidence has been found of marine deposition in the Mesozoic rocks of the Verdi Range-Crystal Peak pendant. The rocks of the Verdi Range-Crystal Peak pendant do not have any obvious correlations with rocks of the adjacent Peavine Peak and Balls Canyon areas (fig. 2), with the possible exception of some andesite lahars on Peavine Peak that resemble those in the Verdi Range-Crystal Peak area. Although basalt flows are present in the Balls Canyon area north of Peavine Peak, they are there interbedded with more felsic flows (unlike the basalts of the Verdi Range).

Head of Long Valley Creek

Saucedo and Wagner (1992) showed a very small outcrop (about 300 m by 600 m) of metavolcanic rocks in an area that is predominantly underlain by Cretaceous granitic rocks. Exposures are poor in this area, but it appears that the exposures heretofore interpreted as metavolcanic rocks are actually cataclastically deformed granodiorite (essentially foliated flaser gneiss). The gneiss is believed to be surrounded by undeformed Cretaceous granitic rocks having an aplitic phase at its contact with the gneiss. Based on numerous determinations, the best estimate of the foliation attitude is N45°W, 45°SW. A cleavage or closely spaced jointing is locally present; one measurement yields an attitude of N30°E, 90° and another N55°E, 50°NW. Highly deformed rocks like these are quite rare in the Mesozoic section of this area. A similar, very small outcrop of biotite schist, having a foliation attitude of N25°W, 30°SW, was noted about 1 km to the east at the extreme northwest corner of the Verdi Quadrangle (center SE ¼, NW ¼, SE ¼, sec. 6, T20N, R18E), and one sample from the pendant north of Border Town (fig. 2) 8 km to the north exhibited a similar cataclastic texture.

Petersen Mountain-Northern Granite Hills

Rocks of the Peavine sequence are found at the north end of Cold Spring Valley (Soeller and Nielsen, 1980) in a number of outcrop areas of varying size, totaling probably less than 20 km^2. They are intruded by Cretaceous quartz diorite and granodiorite (about 90 Ma; Garside and others, 1992; Garside, 1993a) to the north and south and are overlain elsewhere by Tertiary and Quaternary sedimentary rocks and surficial deposits. The majority of the rocks in this pendant consist of metarhyodacite and possibly associated hornblende granodiorite porphyry (equivalent to unit Mzgd of Bell and Garside, 1987). The massive, unfoliated, metarhyodacite appears to be a hypabyssal(?) unit that intrudes intermediate-composition effusive volcanic and volcaniclastic rocks, as observed near the southern end of Petersen Mountain (fig. 6). The hornblende granodiorite porphyry is locally somewhat foliated and rarely contains inclusions of porphyritic andesite; it is clearly a part of the pendant and is intruded by Cretaceous granitic rocks. Its relationship to the metarhyodacite and other metavolcanic rocks is less clear, but it is compositionally similar to granodiorite porphyry noted at Granite Peak and on the east flank of Peavine Peak. At one locality (center NW ¼ sec. 17, T21N, R18E) the hornblende granodiorite porphyry is strongly mylonitized. It is not certain whether this strong foliation or the weak schistosity noted elsewhere was developed during crystallization or later, but in thin section, some syncrystallization cataclastic deformation is evident. The volcanic and volcaniclastic rocks lithologically resemble certain units of the Peavine sequence on Peavine Peak and are probably subaerial in origin. Redbed units observed in this area (fig. 6) are somewhat similar lithologically to those noted near Vista (see above area description).

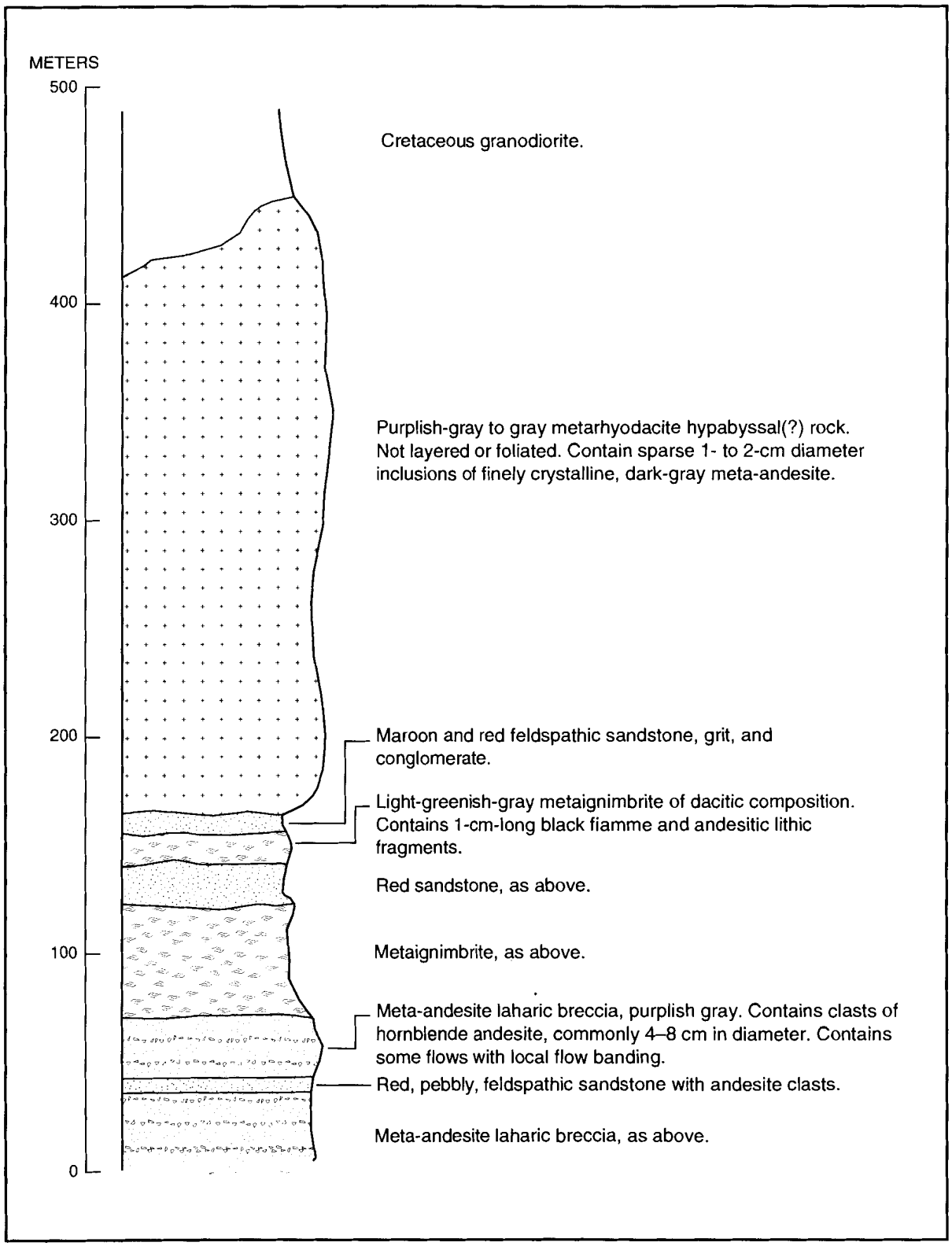


Figure 6. Stratigraphic column of a part of the Peavine sequence, southern Petersen Mountain, Nevada-California.

Balls Canyon-Haskell Peak

A large area of Mesozoic metavolcanic rocks is located just west of the California-Nevada boundary northwest of Border Town, Nevada. The inlier is approximately 14 km long and 4 km wide, extending from near Balls Canyon (photo 8) on the south to a few kilometers south of Beckwourth Pass. No base to the metavolcanic rocks is exposed; the western contact of the Mesozoic outcrop is with Miocene andesitic lahars and lavas. However, an intrusive contact between the metavolcanic rocks and Cretaceous (91 Ma; Bell and Garside, 1987) hornblende-biotite quartz monzonite or granodiorite locally forms the west margin of the metavolcanic rocks outcrop where it is not concealed by Miocene volcanic rocks. Probably, where not concealed, the pluton-metavolcanic rocks contact lies near, but just concealed by, the Miocene rocks, and only a small amount of the metavolcanic rocks is interpreted to extend westward beneath the younger rocks. The southern and northern ends of the exposure are intrusive contacts with the Cretaceous granitic rocks. The eastern limit of the exposure is defined by the alluvial fans formed in Long Valley. A concealed fault is probably present along the axis of Long Valley, separating rocks of the Balls Canyon-Haskell Peak area from Peavine sequence rocks of somewhat different lithologic character to the east of Long Valley.

North of Balls Canyon, at the south end of the exposure, the Peavine sequence consists of interbedded flows of meta-andesite(?), metabasalt, and metarhyolite-rhyodacite (photo 9). The rocks here appear to be a homoclinal sequence approximately 3,500 m thick (fig. 7), striking northerly and

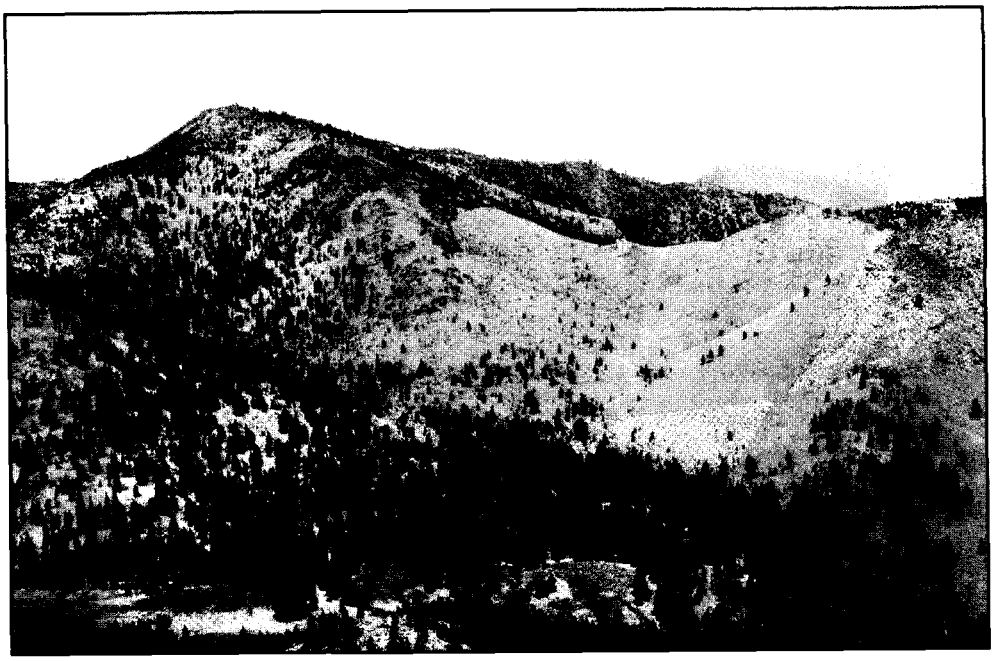


Photo 8. Peavine sequence rocks exposed north of Balls Canyon (looking north). Rocks strike northerly and dip steeply east (right). The ridge is the site for the stratigraphic section of figure 7.

Photo 9. Foliated meta-rhyolite exposed south of Balls Canyon. Field notebook is 18 cm long.

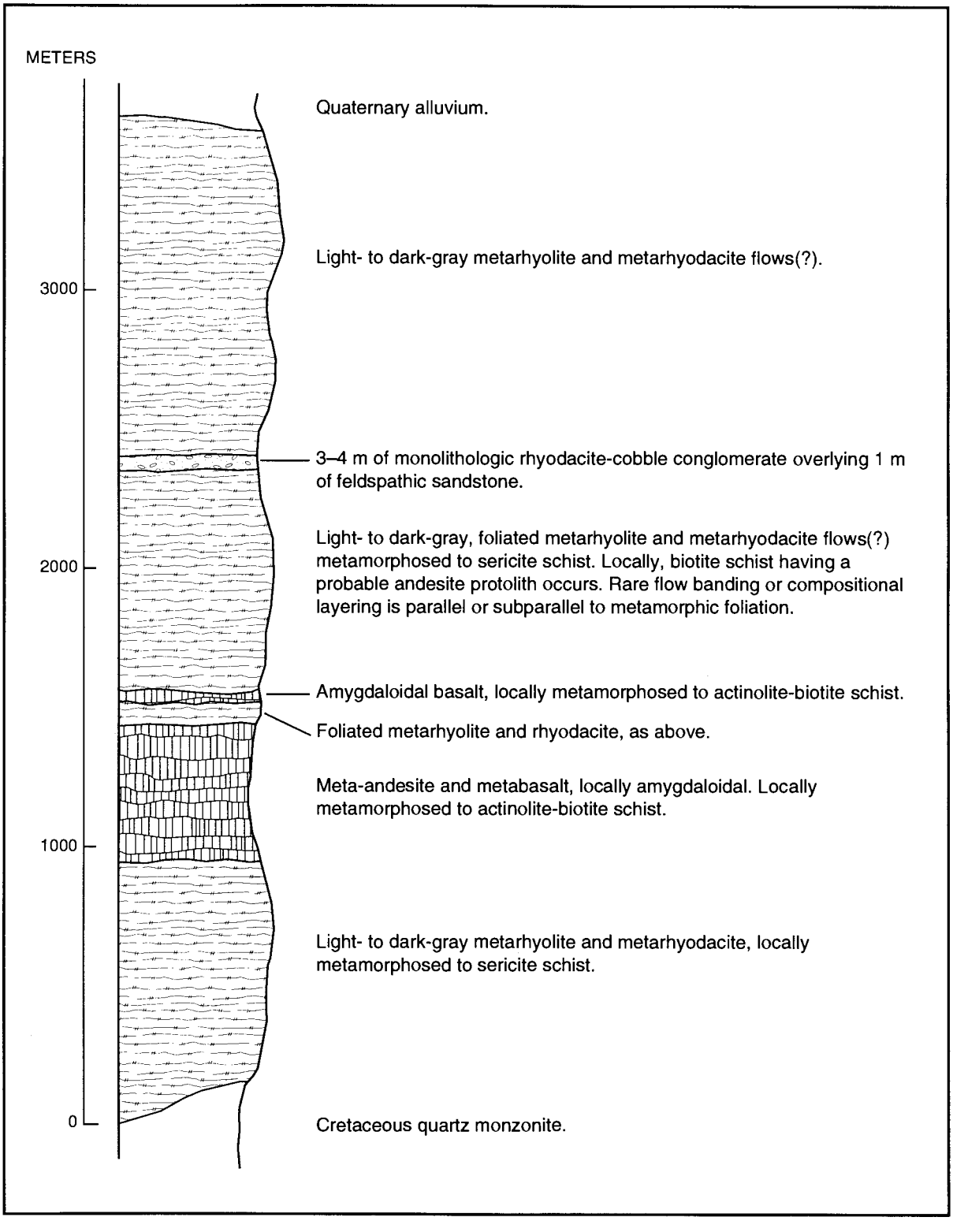


Figure 7. Interpretive stratigraphic column of the Peavine sequence rocks exposed north of Balls Canyon, Sierra County, California.

dipping to the east at 60° or more. The felsic volcanic rocks make up about 85% of the section exposed north of Balls Canyon. They are interpreted to have originally contained small, sparse plagioclase and potash-feldspar phenocrysts and rare mafic minerals (biotite?, now as ghosts) in a flow-banded, originally glassy matrix with quartz occurring as phenocrysts and microcrystalline aggregates. In hand specimen, quartz phenocrysts are not an obvious component of many of the felsic flow rocks.

Mafic rocks, comprising about 15% of the section north of Balls Canyon, are black to dark gray, and locally contain aligned, chalcedony-filled amygdules. The mafic rocks probably represent metamorphosed basalt and basaltic andesite. In thin section, one rock sample exhibited a fluidal texture of small plagioclase and sparse hornblende phenocrysts in a fine-grained matrix. Mafic minerals as phenocrysts and in the groundmass have been converted to ubiquitous, fine actinolite.

To the north of the Balls Canyon area, in the vicinity of Little Haskell Peak and Roberts Canyon, felsic volcanic flow(?) rocks lithologically similar to those of the Balls Canyon section occur with rocks of andesite and basaltic andesite compositions. The andesites are commonly light-gray to dark-greenish-gray porphyritic rocks with probable original phenocrysts of plagioclase (up to 1 cm long) and hornblende (up to 1 cm by 2 mm). The plagioclase has been albitized, and mafic minerals are commonly partly or entirely converted to actinolite, green biotite, chlorite, and epidote. The meta-andesite units that are more prevalent at the north end of the 14-km-long outcrop are probably hypabyssal intrusions in part, although flows are present as well. Basalts are rare in the area. The meta-andesites do not exhibit metamorphic foliation, and metarhyolites have locally obvious primary flow banding. In thin section, metarhyolite contains sparse recrystallized biotite; the groundmass was probably originally glassy.

Just north of Roberts Canyon, in the northern part of the area, the metavolcanic rocks are intruded by a chloritic, primarily(?) foliated granodiorite porphyry. Somewhat farther to the east, this granodiorite porphyry is in contact with, and probably intruded by, leucocratic quartz monzonite of probable Cretaceous age. A dike of microdiorite cuts the granodiorite porphyry. For this reason and others outlined below, both the dike and the granodiorite porphyry are believed to be a part of the Peavine sequence. Microgranodiorite (which originally contained feldspar, hornblende, pyroxene, and biotite) exposed on the west flank of Little Haskell Peak is interpreted in a similar manner.

Rhyolitic and rhyodacitic rocks and interlayered amygdaloidal basalts of the southern part of the area are interpreted to represent flows; felsic rocks probably are associated with flow-dome complexes like those described from Peavine Peak. The units lithologically resemble flow and hypabyssal intrusive(?) units in the Peavine sequence at Peavine Peak as well. A subaerial environment of deposition is postulated for the rocks, mainly based on the lack of subaqueous features such as pillows, hyalloclastites, marine fossils, or marine carbonate rocks. No silicic pyroclastic rocks were noted in the entire package, in contrast to the Peavine Peak section to the south. The granodiorite porphyry (described above) is similar to dacite and granodiorite porphyry that crop out in the northern Granite Hills and near Granite Peak 15 to20 km to the southeast (see Peavine Peak and Petersen Mountain-northern Granite Hills descriptions). There, the dacite and granodiorite porphyry are intruded by Cretaceous (about 90 Ma) granitic plutons. The most logical interpretation for all of these intrusive rocks is that they are supracrustal intrusions related to Peavine sequence volcanism; however, no age data are available to confirm this.

Vinton

A small (1–2 km^2) pendant of metavolcanic rocks is exposed on the east side of a hill just north of Vinton, California. The rocks are intruded by Cretaceous (90 Ma, Evernden and Kistler, 1966) granitic rocks. The rocks exposed in the pendant consist of a variety of meta-andesite units, possibly flows. Based on two flow-banding attitudes in the rocks, they are interpreted to strike northwest and dip 55°–70°NE; the maximum thickness that can be interpreted for the rocks in the pendant is thus about 800 m. The rocks are medium-gray to dark-greenish-gray meta-andesites that originally contained hornblende and plagioclase phenocrysts. They are rarely flow banded and locally contain 1- to 3-cm- (rarely 5 cm) diameter cognate inclusions of darker and finer grained andesite. Plagioclase phenocrysts, locally glomeroporphyritic, can comprise up to 25% of the rock. Several sets of jointing were noted, including N5°W, 80°E and N55°W, 65°SW; even this jointing is rare. Where observed, foliation defined by secondary biotite strikes northerly and dips steeply to the east; this strike parallels the elongate trend of the pendant and its well exposed western contact.

Freds Mountain

Rocks that underlie the north end of Freds Mountain, in an approximately 5-km^2 roof pendant enclosed within Cretaceous granitic rocks, consist of dark-gray hornfels, schist, and semischist which have intermediate volcanic flow rocks as a probable protolith (Garside, 1993a). Most of the protoliths are andesite or dacite flows or hypabyssal intrusions, and original porphyritic textures are locally preserved. Foliation, as defined by recrystallized biotite, is high angle, better developed near intrusive contacts, and where observed, northwest striking. The foliation is subparallel to an intrusive contact with primarily foliated Cretaceous(?) granodiorite at the south margin of its exposure. H.F. Bonham (unpub. data, ca. 1968) reported the presence of metaignimbrite and impure quartzite as well. The rocks on Freds Mountain compositionally resemble meta-andesite units in the Peavine sequence on Peavine Peak, although they are more metamorphosed. The increased grade and dynamic nature of the metamorphism is probably due to the smaller size of the roof pendant at Freds Mountain.

Vista

Metadacite and meta-andesite flows, flow breccia, and lahars are interbedded with lesser redbed siltstone, sandstone, and conglomerate (photo 10) in a 2-km^2 area east of Sparks, where the Truckee River and Interstate Highway 80 enter the Virginia-Pah Rah Ranges. A relatively thick section of Mesozoic

metadacite and/or meta-andesite crops out in the canyon and on lower canyon walls on the north side of the Truckee River immediately southeast of the gaging station in NE ¼ sec. 13, T19N, R20E (Bell and Bonham, 1987). The exposure just southeast of the gaging station is meta-andesite breccia. The meta-andesite breccia consists of hornblende and pyroxene(?) andesite fragments in a dark matrix. The meta-andesite breccia is entirely unsorted, and the rounded and subrounded fragments are 3–5 cm in diameter, but large ones can be over 15 cm. A number of the fragments exhibit relatively obvious flow lamination (flow banding). A single thin (1- to 3-cm-thick) discontinuous bed was seen within the unsorted and unbedded meta-andesite breccia. It appears to be crossbedded and probably represents a surge deposit. The dip appears to be approximately 40° northeast. The meta-andesite breccias could represent, in part, pyroclastic block flows; some could represent lahars. The metavolcanic and metavolcaniclastic rocks near Vista are interpreted to be subaerial. They do not contain pillows or recognizable marine sedimentary units, and the epiclastic rocks appear to be subaerial redbed alluvial-fan deposits. The rocks were almost certainly subaerially deposited. No foliation or folding was observed in the rocks. The best exposure of volcaniclastic sedimentary rocks is at the road cut for Interstate 80 northeast of the Vista exit adjacent to the westbound off-ramp. The exposure consists of reddish-brown laminated siltstone and fine-grained sandstone. The correlation of the metasedimentary and metavolcanic rocks near Vista is somewhat problematic; their composition and subaerial nature suggest that they may be part of the Peavine sequence, but they could also be related to Triassic rocks exposed southeast of Carson City.

Photo 10. Metaconglomerate red beds exposed in road cut at the Vista off ramp of Interstate 80 east of Sparks. Maroon, poorly sorted conglomerate with clasts and matrix derived mainly from andesitic volcanic rocks. Nearby this unit is interbedded with meta-andesite flows (Bell and Bonham, 1987).

Bacon Rind Flat

Two small (less than 1 km^2) outcrops of the Peavine(?) sequence are found east of Nevada Highway 445 east of the pass between Spanish Springs Valley and Bacon Rind Flat 22 km north of Sparks. The rocks are intruded by Cretaceous(?) granodiorite and overlain by Oligocene ignimbrites. A small area of greenschist facies metavolcanic rocks exposed near the highway is reported to consist of metarhyolite, metadacite, or metarhyodacite (H.F. Bonham, Jr. unpub. data, ca. 1968). To the east, a metadacite(?) porphyry (probably a hypabyssal rock) is intruded by the granodiorite; a schistose foliation is developed in the metavolcanic rocks near the granodiorite.

Willow Spring

A small outcrop of Peavine sequence is present near Willow Spring on the east flank of Warm Springs Mountain (fig. 2, locality 11). The Peavine sequence is intruded just to the north by Cretaceous(?) granitic rocks. Samples collected by D.A. Davis (unpub. data, 1994) are dark-gray biotite schists and hornfels which have probable protoliths of both andesite and fine-grained feldspathic sandstone. Shape-fabric foliation from one site is N32°W, 85°SW (D.A. Davis, unpub. data, 1994).

Right Hand Canyon

In Right Hand Canyon of the Pah Rah Range, a small area underlain by the Peavine sequence is intruded by granitic rocks on the east and overlain by Quaternary alluvium to the west. Bonham (1969, plate 1) showed this outcrop as metavolcanic rocks and an unpublished thin section description by him also reports the presence of volcaniclastic sandstone. Samples collected by D.A. Davis (unpub. data, 1994) are dark-gray and dark-greenish-gray biotite schists, which in thin section appear to have a protolith of medium- to coarse-grained feldspathic sandstone.

Peavine Sequence Petrochemistry

Twenty-four rock samples of representative lithologies of the Peavine sequence were collected during this study and analyzed for major elements and a select group of predominantly immobile trace elements (see table 1). Analyses were performed by the Nevada Bureau of Mines and Geology Analytical Laboratory using the methods described below (P. Lechler, written commun., 1998).

Table 1. Chemical analyses of rocks from the Peavine sequence. See figure 2 and notes below for locations.

Sample	SiO_2 %	TiO_2 %	Al_2O_3 %	Fe_2O_3 %	MnO %	MgO %	CaO %	Na_2O %	K_2O %	P_2O_5 %	LOI %	Total %	Zr ppm	Y ppm	Sr ppm	Rb ppm	Ga ppm	Ni ppm	Cr ppm	Ba ppm	DI	AI	IUGS NAME	FIELD NAME
GCH6	63.2	0.52	15.1	6.66	0.044	3.61	0.87	2.60	5.84	0.3	1.23	99.9	113	9	173	141	18	13	<5	2500	74.6	73.1	trachyte	hornblende(?) meta-andesite
GCH8	74.8	0.20	12.9	1.56	0.024	0.41	1.01	4.01	4.17	0.1	0.38	99.6	198	19	105	99	11	4	12	893	92.4	47.7	rhyolite	flow-banded metarhyolite
GCH20A	73.0	0.28	14.0	2.74	0.052	1.30	0.39	1.14	4.63	0.1	2.10	99.7	155	33	108	167	13	6	16	1130	85.3	79.5	rhyolite	lithic dacite metaignimbrite
GCH21	63.9	0.49	15.9	4.05	0.077	5.13	2.32	3.91	2.61	0.1	1.33	99.8	72	13	613	62	16	16	12	1090	68.0	55.4	andesite	metadacite hypabyssal intrusive (?)
GCH24	49.0	1.31	16.0	8.75	0.160	10.20	8.68	2.33	1.72	0.4	1.22	99.8	146	30	445	29	20	131	237	447	30.5	52.0	basalt	metabasalt
GCH36B	50.1	0.62	12.5	9.30	0.410	10.70	9.57	2.03	3.16	0.5	0.98	99.9	18	16	768	93	16	140	489	392	36.3	54.4	trachybasalt	meta-andesite intrusive
GCH38	50.5	0.82	16.9	9.63	0.200	7.11	9.04	1.82	2.77	0.3	0.44	99.5	5	22	987	56	17	11	<5	706	32.3	47.6	basalt	metamicrodiorite
GCH57	73.9	0.18	13.6	1.12	0.042	0.20	0.69	3.78	5.83	0.1	0.32	99.8	202	16	97	169	13	4	21	770	95.1	57.4	rhyolite	metarhyolite
GCH59	55.9	0.92	15.7	8.15	0.150	4.56	8.96	2.65	2.32	0.3	0.63	100.2	121	26	535	37	18	28	38	723	53.2	17.5	basaltic andesite	hornblende meta-andesite
GCH63A	63.7	0.53	15.4	4.96	0.095	3.95	0.68	4.58	4.85	0.2	0.91	99.9	128	17	176	124	15	12	<5	4240	79.1	62.6	trachyte	porphyritic meta-andesite
GCH68	64.4	0.63	15.0	5.57	0.100	0.33	1.26	1.89	9.78	0.2	0.55	99.7	128	9	85	227	14	8	19	1920	87.1	76.2	trachyte	porphyritic meta-andesite
GRE22	75.0	0.18	14.0	2.14	0.057	1.30	0.20	2.77	3.07	0.1	1.53	100.3	157	22	164	96	13	2	15	784	87.7	59.5	rhyolite	felsic metaignimbrite
GRE41	63.8	0.45	16.0	3.25	0.049	3.97	2.33	7.22	1.26	0.1	0.91	99.3	95	8	256	49	17	10	17	251	76.9	35.4	trachyte	subvolcanic(?) granodiorite porphyry
GRE82	61.7	0.65	17.3	5.42	0.190	1.48	4.70	4.04	2.97	0.2	0.61	99.3	147	24	588	64	16	5	16	1140	67.0	33.7	trachyandesite	porphyritic meta-andesite
RNW86	63.4	0.50	16.2	4.07	0.100	2.73	3.91	4.29	2.82	0.2	1.13	99.3	81	13	672	62	19	13	25	1210	69.9	40.4	andesite	subvolcanic(?) granodiorite porphyry
V145	72.3	0.36	13.4	3.39	0.012	0.13	0.10	0.15	9.71	0.2	0.55	100.3	233	12	33	227	11	6	8	1670	92.9	97.5	rhyolite	quartz latite metaignimbrite
V146	71.3	0.23	15.5	1.50	0.008	0.10	0.10	0.30	10.50	0.1	0.45	100.1	199	9	101	311	11	3	12	3090	94.2	96.4	rhyolite	quartz latite metaignimbrite
V151	69.8	0.31	15.2	2.41	0.097	0.60	0.51	2.51	7.03	0.1	0.83	99.4	192	17	653	184	14	4	24	1650	90.7	71.6	rhyolite	quartz latite metaignimbrite
V156	61.8	0.61	17.4	4.58	0.031	2.29	2.57	3.84	5.45	0.2	0.80	99.6	112	11	640	161	20	16	<5	873	75.4	54.7	trachyte	flow-banded(?) meta-andesite
V228	70.0	0.38	15.4	2.34	0.010	0.26	0.38	3.50	6.32	0.1	0.58	99.3	232	19	242	175	12	2	15	1770	92.8	62.9	rhyolite	flow-banded metarhyolite
V229	60.8	0.62	15.4	6.11	0.210	3.55	5.21	3.92	2.78	0.2	1.26	100.1	114	15	612	111	17	10	6	502	61.9	40.9	andesite	meta-andesite
V230	51.3	1.55	18.3	10.00	0.210	4.80	5.78	6.38	0.92	0.2	1.07	100.5	153	37	874	42	22	57	126	288	54.1	32.0	trachyandesite	amygdaloidal metabasalt
V231	66.7	0.59	16.7	3.76	0.110	1.01	2.38	1.84	5.35	0.2	0.91	99.6	237	30	276	158	16	3	10	922	77.7	60.1	dacite	hornblende meta-andesite
V233	68.2	0.52	15.7	3.10	0.078	1.23	1.44	4.25	4.01	0.2	0.72	99.4	218	25	420	99	13	5	20	1700	84.6	47.9	rhyolite	metarhyodacite

GCH-6; Loyalton 7.5'; NE ¼ sec. 25, T22N, R16E; north of Roberts Canyon.

GCH-8; Evans Canyon 7.5'; NW ¼ sec. 29, T22N, R17E; Roberts Canyon.

GCH-20A; Evans Canyon 7.5'; NE ¼ sec. 18, T21N, R18E; south end of Petersen Mountain.

GCH-21; Evans Canyon 7.5'; NE ¼ sec. 7, T21N, R18E; south end of Petersen Mountain.

GCH-24; Dog Valley 7.5'; center sec. 7, T19N, R18E; just west of Henness Pass Road.

GCH-36B; Dog Valley 7.5'; NE ¼ sec. 34, T20N, R17E; 3 km northwest of Beacon Point. Hornblende meta-andesite intrusive; related to GCH-38.

GCH-38; Dog Valley 7.5'; SW ¼ sec. 34, T20N, R17E; 2.5 km west-northwest of Beacon Point. Hornblende metamicrodiorite intrusive (dated at 78 Ma, probably reset); related to GCH -36B.

GCH-57; Evans Canyon 7.5'; SW ¼ sec. 16, T21N, R17E; north of Balls Canyon.

GCH-59; SE ¼ sec. 16, T21N, R17E; 1.5 km northeast of Balls Ranch. Porphyritic hornblende meta-andesite.

GCH-63; Evans Canyon 7.5'; SE ¼ sec. 29, T22N, R17E; between Haskell and Little Haskell Peaks.

GCH-68; Evans Canyon 7.5'; SE ¼ sec. 34, T22N, R17E; Cobble in Quaternary alluvium derived from Haskell Peak (approx. sec. 33).

GRE-22; Reno NW 7.5'; NW ¼ sec. 8, T21N, R18E; southeast flank of Petersen Mountain, 3 km north of Border Town, NV.

GRE-41; Reno NW 7.5'; SW ¼ sec. 14, T21N, R18E; northern Granite Hills, 5 km east of Border Town, NV.

GRE-82; Reno 7.5'; SW ¼ sec. 33. T20N, R19E; 1 km east of mouth of Peavine Creek, northwest of Reno.

RNW-86; Reno NW 7.5'; SE ¼ sec. 2, T20N, R18E; 1 km southeast of Granite Peak.

V-145; Verdi 7.5'; SE ¼ sec. 5, T20N, R18E; 6 km northwest of Peavine Peak.

V-146; Verdi 7.5'; NW ¼ sec. 8, T20N, R18E; 6 km northwest of Peavine Peak.

V-151; Verdi 7.5'; SW ¼ sec. 9, T20N, R18E; 3.5 km northwest of Peavine Peak.

V-156; Verdi 7.5'; SW ¼ sec. 11, T20N, R18E; 1 km east of Red Metal Mine, 3 km northwest of Peavine Peak.

V-228; Verdi 7.5'; NW ¼ sec. 23, T20N, R18E; Peavine Peak.

V-229; Verdi 7.5'; NW ¼ sec. 23, T20N, R18E; Peavine Peak.

V-230; Verdi 7.5'; NW ¼ sec. 23, T20N, R18E; Peavine Peak.

V-231; Verdi 7.5'; SE ¼ sec. 10, T20N, R18E; near Red Metal Mine 3 km northwest of Peavine Peak.

V-233; Verdi 7.5'; center S ½ sec. 15, T20N, R18E; 1.5 km northwest of Peavine Peak.

Major oxides were determined using 200 mg of sample pulp (nominally 98% minus 200 mesh). After dissolution with 6 mL of hydrofluoric acid and 1 mL of aqua regia in a sealed teflon reaction vessel (175°C for 1 hour) 100 mL of boric acid solution (44 g/L) were added and the mixture was diluted to 200 mL. The major oxides were determined by atomic absorption spectroscopy by comparison with U.S. Geological Survey standard reference materials BCR-1 (basalt), AGV-1 (andesite), and RGM-1 rhyolite (modified from Hutchison, 1974). Quantification of P_2O_5 was based on the colorimetric method of Shapiro (1975) and loss-on-ignition was measured gravimetrically as described by Lechler and Desilets (1987).

Trace elements were determined by x-ray fluorescence on pressed pellets (3 g sample and 1.125 g Chemplex binder; 30,000 psi for 2 minutes). A Philips PW1404 sequential, wavelength-dispersive x-ray fluorescence spectrometer was employed after calibration with 12 U.S. Geological Survey standard rocks. Mass absorption differences were corrected from peak height changes induced in the rhodium tube Compton peak.

Metamorphic grade of the rocks is characterized by the lower greenschist facies. An attempt was made to collect the least metamorphosed rocks for analysis; however, it is likely that some of the major elements, especially the alkalis, have been remobilized. It is possible that some rocks have also lost or gained silica, calcium, alumina, and magnesium.

In a particular volcanic rock association, the closely constrained, tight trends on variation diagrams generally suggest that the elements displayed have not been mobile. For example, the SiO_2–log Zr/TiO_2 plot (fig. 8) illustrates that SiO_2 apparently is relatively immobile. A number of other variation diagrams illustrate similar relationships, for example SiO_2–Fe_2O_3 (total iron) and SiO_2–CaO (figs. 9 and 10). Variation diagrams which display K_2O and Na_2O against an immobile factor (log Zr/TiO_2) have considerable scatter (figs. 11 and 12), as do plots of Na_2O+K_2O–SiO_2 (alkali-silica diagram, fig. 13). The scatter noted on many of the major-element variation diagrams may result from losses or gains in certain of these elements, although the lack of a positive linear trend (scatter) in K_2O–SiO_2 plots is reported to be common in continental magmatic arcs, and indicative of the effect of crustal contamination of magmas (Wilson, 1989, p. 210). Another indication of the possible mobilization of major elements is high values of the Alteration Index (Ishikawa and others, 1976). The Alteration Index is calculated as follows (values in weight percent): $MgO+K_2O/MgO+CaO+Na_2O+K_2O$ x 100. In felsic rocks, an Alteration Index of 50 is suggested as the upper threshold for unaltered rocks. More than half of the analyzed Peavine sequence rocks have values over 50 (column AI, table 1), but more severely altered (metamorphosed) rocks are limited to about one-fifth of the samples (Alteration Index > 65). The Alteration Index was designed to test for alteration associated with Koroko deposits, and may not be applicable to low-grade thermal metamorphism. In Peavine sequence rocks, the Alteration Index tends to vary directly with silica content, indicating a possible problem with its application to these rocks. An alternate explanation for the scatter of points on alkali-element variation diagrams is that it results from an original

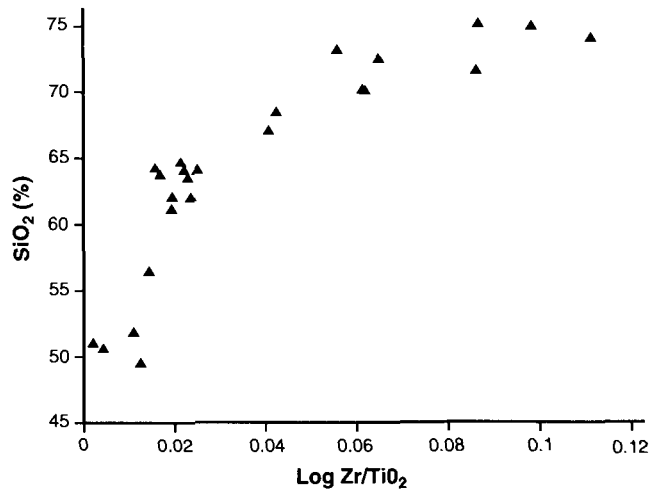


Figure 8. SiO_2 vs. log Zr/TiO_2 for Peavine sequence rocks.

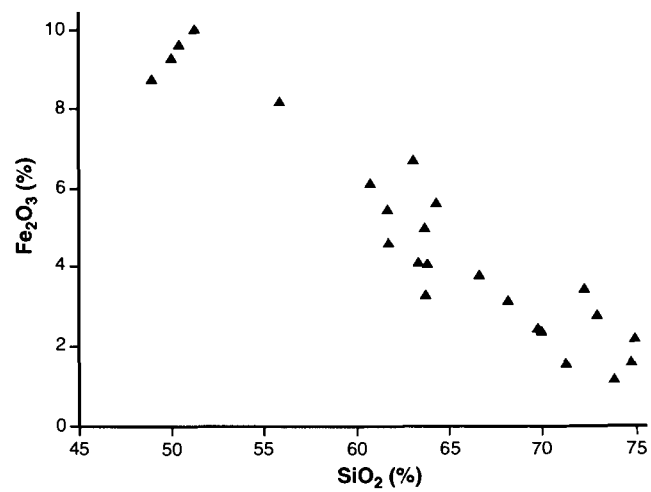


Figure 9. Fe_2O_3 vs. SiO_2 for Peavine sequence rocks.

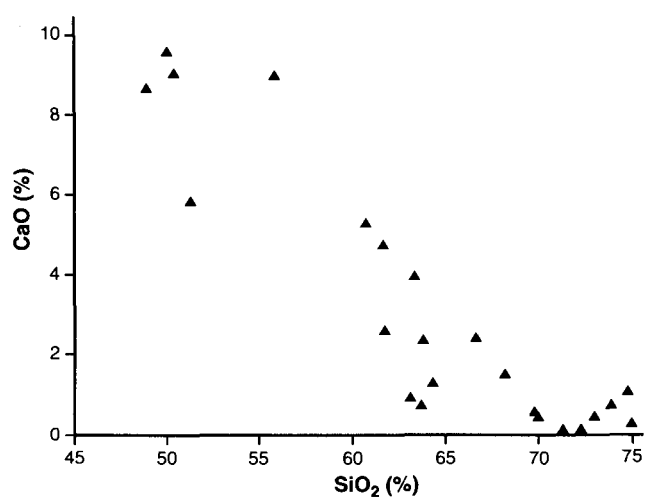


Figure 10. CaO vs. SiO_2 for Peavine sequence rocks.

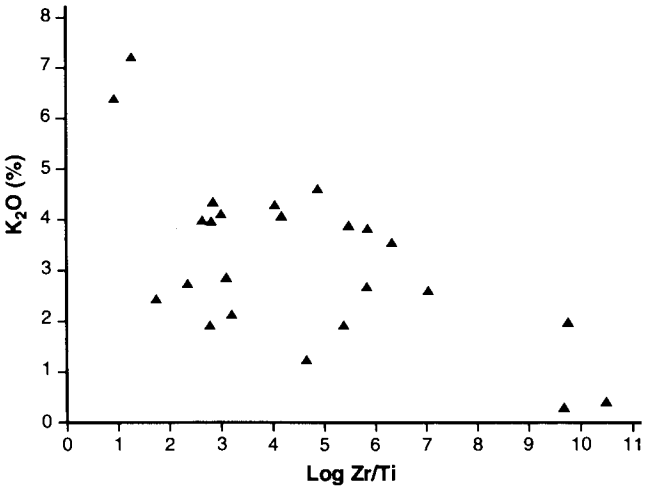


Figure 11. K_2O vs. log Zr/Ti for Peavine sequence rocks.

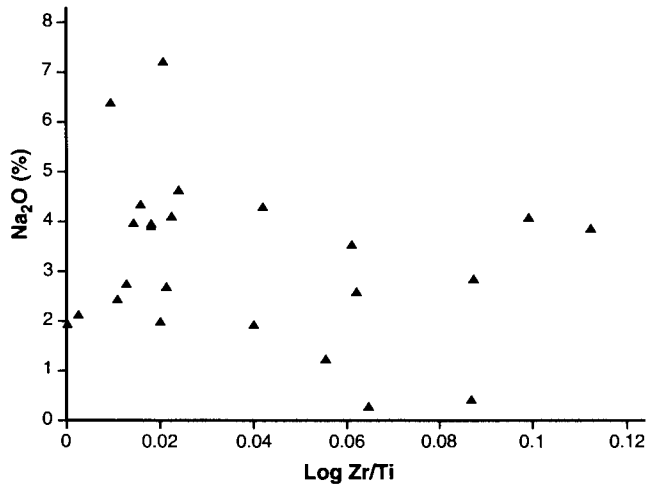


Figure 12. Na_2O vs. log Zr/Ti for Peavine sequence rocks.

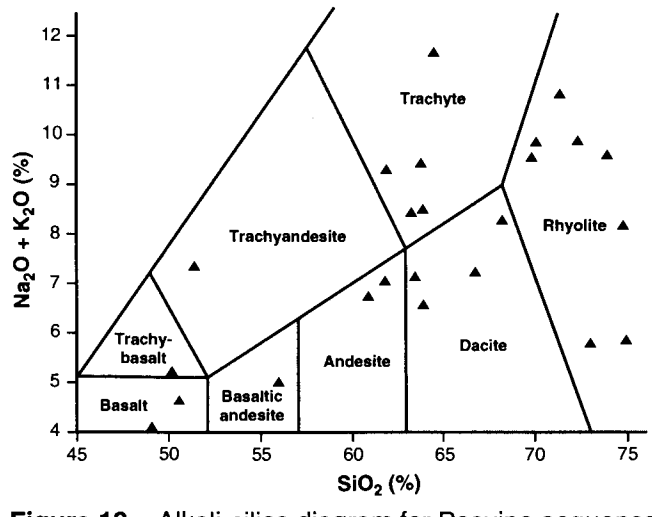


Figure 13. Alkali-silica diagram for Peavine sequence rocks. IUGS rock names from Zanettin (1984).

range of values commonly noted in high-K rocks (Hatherton and Dickinson, 1969; Christe and Hannah, 1990). At least for the intermediate-composition Peavine sequence rocks, if the analyzed potassium contents are original, the rocks would have to be considered high-K (for example, see MacKenzie and Chappel, 1972).

The high-K calc-alkaline suite of rocks is reported to be more common in active continental margin settings (continental magmatic arcs) than in island arcs, and these high-K characteristics may reflect an increased degree of crustal contamination in the active-margin magmas (Wilson, 1989, p. 208). Christe and Hannah (1990) reported high-K early Mesozoic magmatic arc volcanism from a number of sites in western Nevada and in the eastern Sierra Nevada of California; they proposed that this high-K magmatism may be associated with a phase of long-lived extensional tectonism following the Permian-Triassic Sonoma orogeny (Christe and Hannah, 1990).

Most of the Peavine sequence samples are calc-alkalic, utilizing classifications of either Miyashiro (1974) or Irvine and Baragar (1971). These magma series classifications utilize plots of elements that are likely to be somewhat mobile under greenschist metamorphic conditions. In general, those samples that show the highest alteration index tend to be classified as alkalic or tholeiitic rather than calc-alkalic. Also, a differentiation trend that shows a decline in total iron (Fe_2O_3) with increasing silica (e.g., fig. 9) is typical of calc-alkaline rocks (Wilson, 1989, p. 210). For the basic volcanic rocks, a Ti–Zr variation diagram (see Pearce and Cann, 1973) also suggests a calc-alkalic affinity (fig.14). The overall impression from the data is that the rocks are of the calc-alkalic magma series, and some would be considered high-K if the more mobile elements have not be redistributed.

The Peavine sequence rocks range from basalt to rhyolite, having normalized silica contents from 50% to nearly 76% (table 1); this range is well displayed on SiO_2–TiO_2 and SiO_2–Zr variation diagrams (figs. 15, 16) as well as the regular pattern on the SiO_2-Differentiation Index (Thornton and Tuttle, 1960) diagram (fig. 17). Rock names based on the total alkali-silica variation diagram (IUGS names; Zanettin, 1984) include quite a number of samples classified as trachytes (table 1, fig. 13). Utilizing other alkali-silica-based rock classifications, many of the rocks would be high-K andesites, high-K dacites, and toscanites (e.g., MacKenzie and Chappel, 1972). Intermediate-composition rock names derived from variation diagrams utilizing elements less likely to be mobile (see the SiO_2–Zr/Ti plot, fig.18; Floyd and Winchester, 1978) are usually dacite and rhyodacite.

Another indication that the alkali elements may have been mobilized during metamorphism, and thus not useful for determination of petrogenetic affinity, is the lack of correspondence between many of the samples on a Na_2O–K_2O diagram (fig. 19) and the area of the plot considered to have "normal" amounts of alkali for rocks having greater than 60% silica (see Smith and others, 1990).

Despite the greenschist-grade metamorphism of Peavine sequence rocks, and indications of mobilization of alkali elements, major element analyses indicate the rocks to be calc-alkalic. This is confirmed by plots of immobile elements (Ti,

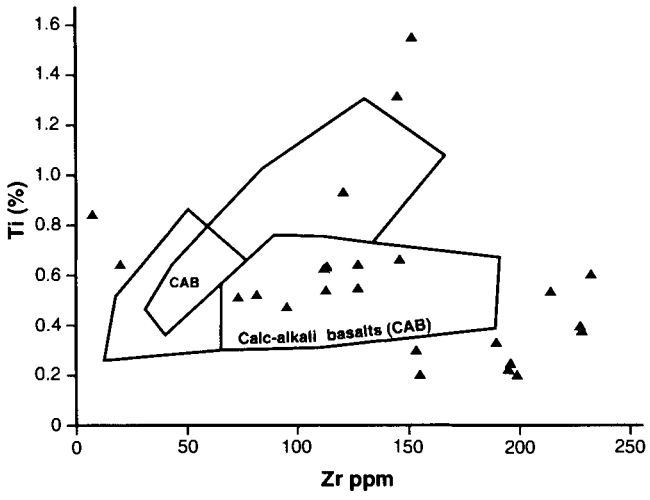


Figure 14. Ti – Zr discrimination diagram for Peavine sequence rocks. Fields for basic volcanic rocks from Pearce and Cann (1973). Ocean-floor basalts plot in fields D and B, low-K tholeiites in fields A and B, and calc-alkali basalts (CAB) in fields C and B.

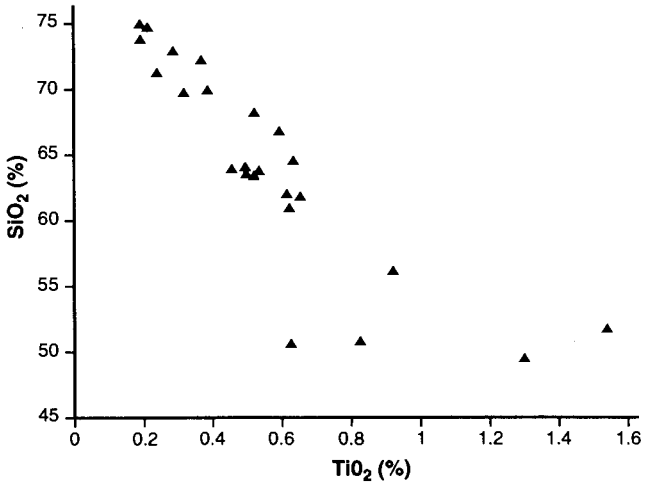


Figure 15. SiO_2 vs. TiO_2 for Peavine sequence rocks.

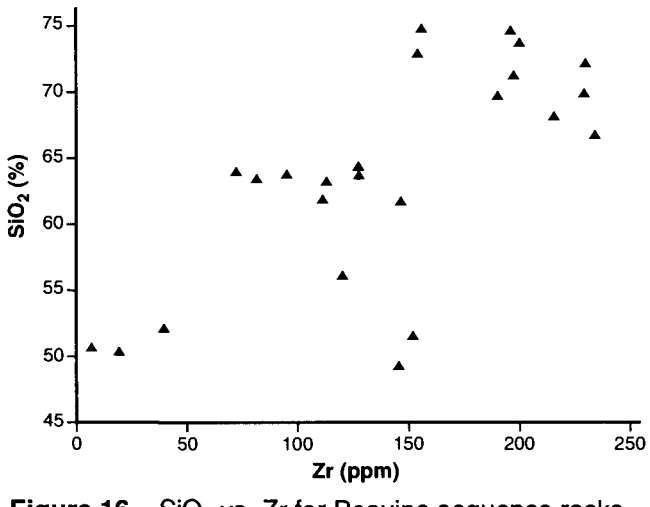


Figure 16. SiO_2 vs. Zr for Peavine sequence rocks.

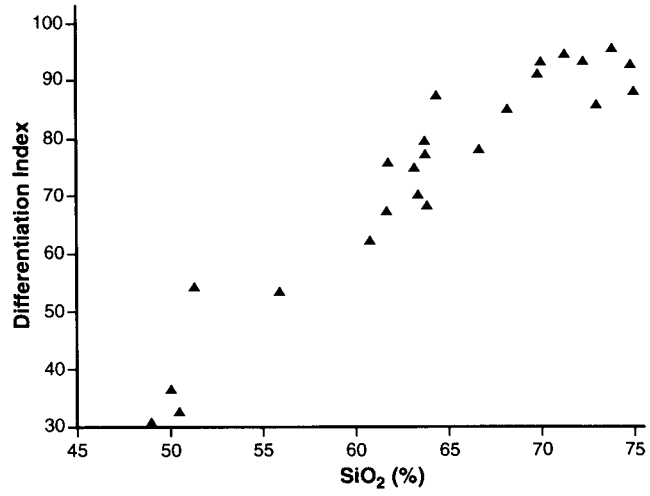


Figure 17. Differentiation index vs. SiO_2 for Peavine sequence rocks.

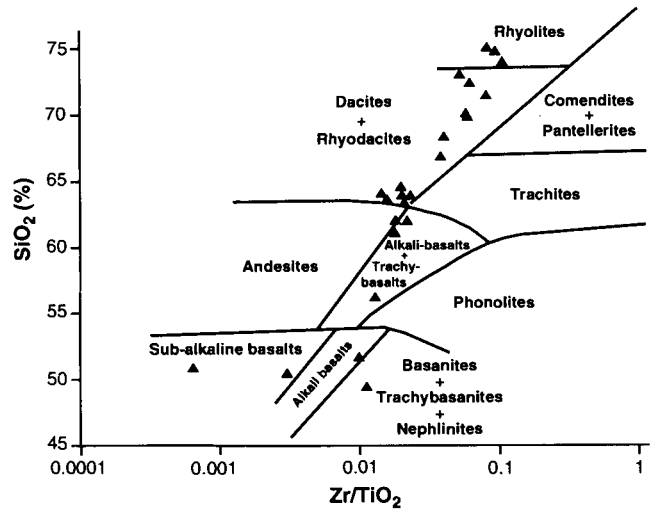


Figure 18. Zr/TiO_2 vs. SiO_2 for Peavine sequence rocks. Fields from Floyd and Winchester (1978).

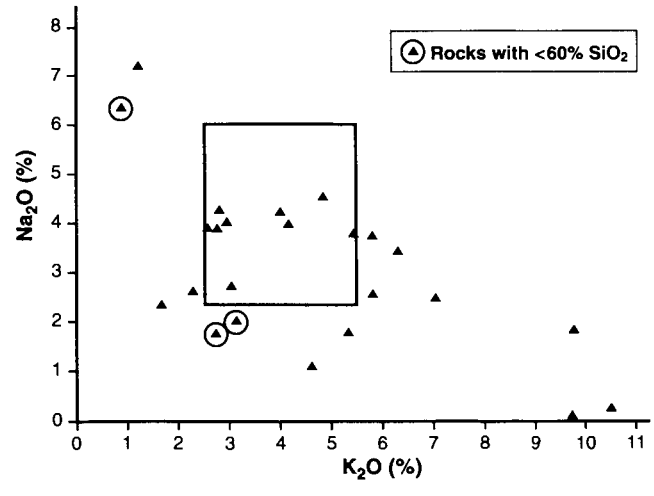


Figure 19. Na_2O–K_2O variation diagram for Peavine sequence rocks. Box indicates area of >60% silica rocks with "normal" alkali (from Smith and others, 1990).

Zr, Y). The calc-alkaline nature of the rocks is compatible with a subduction-related contintental arc; bimodal (basalt-rhyolite) magmatism in some areas suggests an extensional regime in the arc (Garside, 1993a). Regional greenschist metamorphism is most likely related, at least in part, to regional Cretaceous igneous-related hydrothermal activity (Barton and others, 1988). Known pre-Tertiary mineralization in Peavine sequence rocks is limited to small, high-temperature Cu-Au quartz-tourmaline veins and volcanic-hosted magnetite deposits (see Doebrich and others, 1996), both of probable Late Cretaceous age. Hydrothermal alteration envelopes around these deposits are commonly narrow; there is no obvious widespread alteration effect in the Peavine sequence wall rocks.

Age of the Peavine Sequence

The rocks of the Peavine sequence on Peavine Peak are older than the 91-Ma granodiorite (Garside and others, 1992) that intrudes them and contain a black shale with a poorly preserved Jurassic(?) flora (Godwin, 1958), identified by D.I. Axelrod as containing a fern, a cycadophyte, and a ginko(?). The fossils were of poor quality, and were not retained (D.I. Axelrod, oral commun., 1989). The fossil site could not be relocated during this study. An interpretation of Rb-Sr whole rock isotopic analysis of samples collected from the Peavine sequence in the Peavine Peak area, the Verdi Range/Crystal Peak area, Petersen Mountain and north Granite Hills, and Balls Canyon/ Haskell Peak areas suggests that the sequence may contain rocks of two different ages (figs. 20, 21), 167±20 Ma and 117±5 Ma (R.W. Kistler, written commun., 1991). The 167 Ma age is in agreement with the Jurassic(?) flora and regional correlations with other Middle Jurassic metavolcanic units of the region (see the section on Lithofacies above). The samples which fall into the younger (117 Ma) group (table 3, fig. 20) include all but one of the samples collected from the Peavine Peak area (fig. 2), and several of these are from the area of Godwin's (1958) Jurassic flora. No distinction between rocks of potentially different ages was observed in the field in any of the sampled areas. Possibly some samples are not entirely closed systems to Rb and Sr movement, which would make it impossible to determine a reasonable age using this method. Certainly, Cretaceous metavolcanic rocks are known from areas in west-central Nevada and the southern Sierra Nevada of adjacent California, and they must have been present at one time above the Cretaceous plutons of the Reno area; however, none have been identified for certain from the study area. The ~167-Ma age is certainly preferred, based on regional correlations; if that age is correct, Peavine sequence rocks are a temporal equivalent of the volcanic rocks of Fulstone Spring (Dilles and Wright, 1988; Proffett and Dilles, 1991) in the Buckskin Range and northern Pine Nut Mountains 75 km to the southeast, as well as the upper part of the Kettle Rock sequence in the Taylorsville area (see section on Lithofacies).

MESOZOIC METAVOLCANIC AND METASEDIMENTARY ROCKS OF THE VIRGINIA RANGE AND ADJACENT AREAS

Introduction

Metasedimentary rocks of Late Triassic(?) and Jurassic age and metavolcanic rocks of probable Jurassic age are exposed as inliers in a predominantly Tertiary volcanic terrane in the Virginia Range. Figure 22 shows the location of these rocks, and identifies the areas described in detail below. These descriptions summarize previous work and report on information collected during the present study. With the exception of the Mound House exposures of gypsum and marble, metasedimentary and metavolcanic rocks that crop out in the southern part of the Virginia Range (north of Carson City, around American Flat, and south of Jumbo) are not described herein. Further information on these areas is available

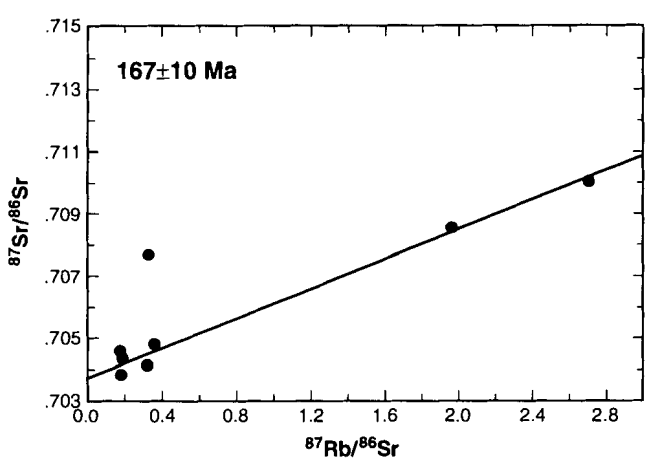


Figure 20. Whole-rock isochron of metavolcanic rocks from the "older" group of Peavine sequence samples (table 3). Provided by R.W. Kistler (written commun., 1991).

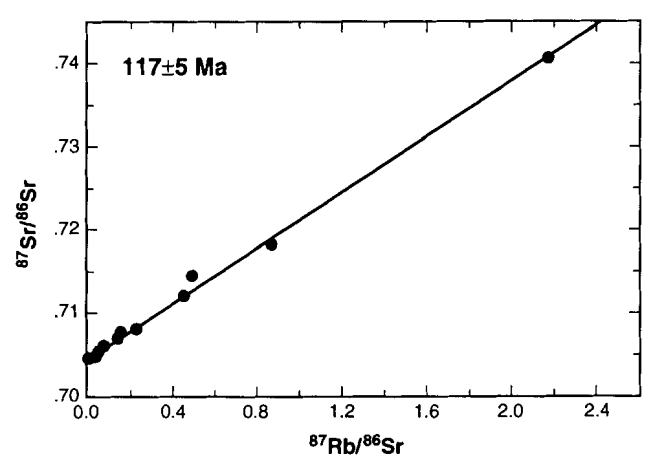


Figure 21. Whole-rock isochron of metavolcanic rocks from the younger group of Peavine sequence samples (table 3). Provided by R.W. Kistler (written commun., 1991).

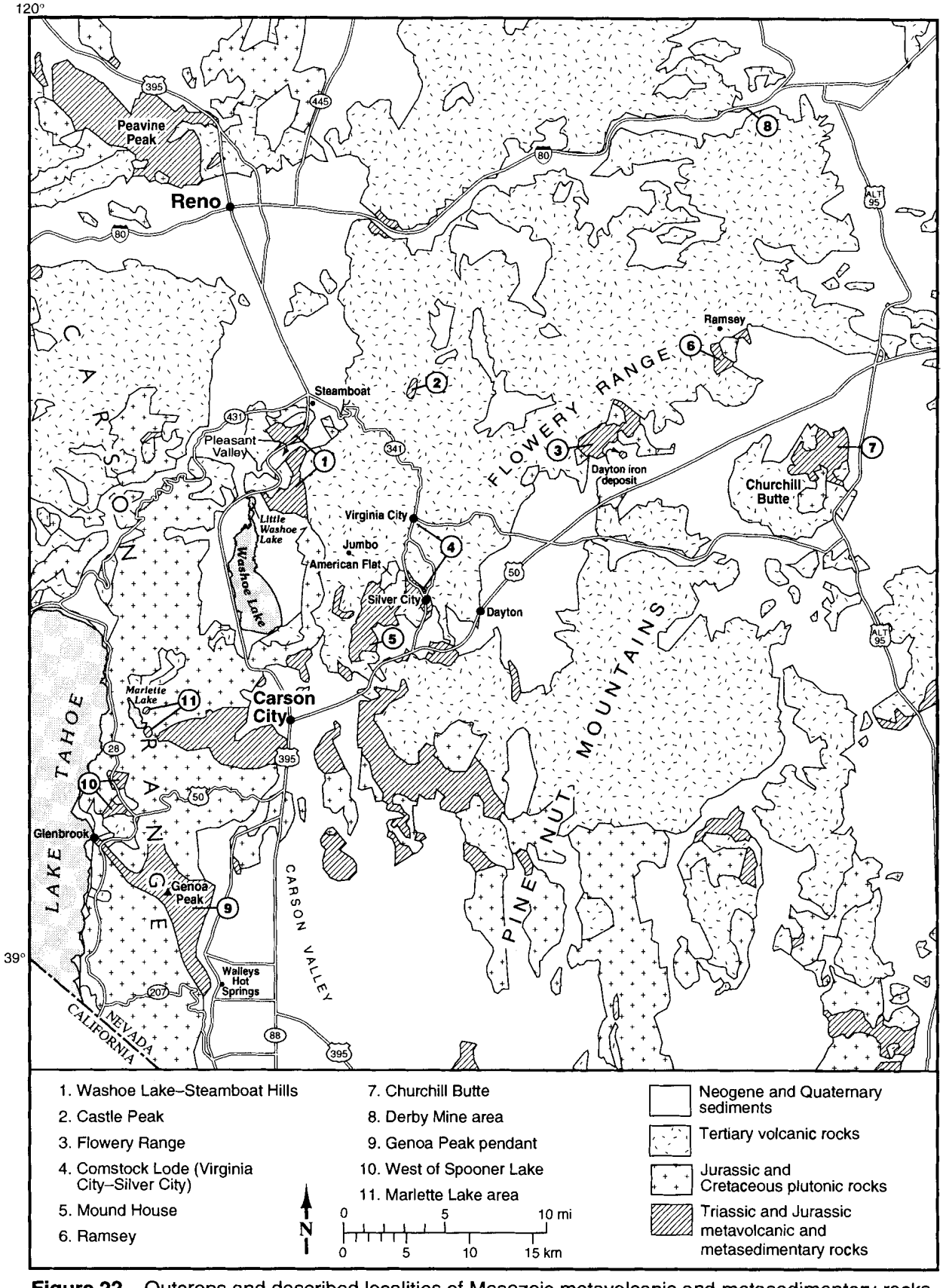


Figure 22. Outcrops and described localities of Mesozoic metavolcanic and metasedimentary rocks of the Virginia and Carson Ranges.

in Thompson (1956), and Bingler (1977), and some information is summarized in Stewart (1997). Locally, these rocks are pendants in Cretaceous granitic plutons. The predominantly metasedimentary layered rocks seem to be lithologically equivalent to the uppermost Triassic and Lower Jurassic Gardnerville Formation (locally to Upper Triassic Oreana Peak Formation and Middle Jurassic Preachers Formation?), whereas the metavolcanic rocks are most likely the age equivalents of the Peavine sequence and other Middle Jurassic volcanic units of western Nevada. One outcrop area of metavolcanic rocks in the northwestern Virginia Range at Vista is described with the Peavine sequence in the section above.

In the Silver City area, southeast of American Flat, the metavolcanic rocks are reported to unconformably overlie metasedimentary rocks interpreted herein as belonging to the Gardnerville(?) Formation (Gianella, 1936); they occupy a similar position at Churchill Butte as well (L.A. Fraticelli, written commun.,1991). D.M. Hudson (oral commun., 1991) believes this contact to be a low-angle thrust fault.

Area Descriptions

Washoe Lake-Steamboat Hills

Metasedimentary rocks crop out in an area between Washoe and Steamboat Valleys; a very small outcrop of dark, fine-grained sandstone and siltstone is present at the bottom of Geiger Grade about 2 km northeast of Steamboat. The rocks are intruded by 75-Ma granodiorite at the north and south margins and overlain by Tertiary and Quaternary units (Tabor and Ellen, 1975). The rocks consist of gray and gray-green metagraywacke, volcanic conglomerate, metatuff, volcanic breccia, dark slate and phyllite, and rare gray marble. The rocks are metamorphosed to hornfels within 60 m of the granodiorite contact, and are foliated parallel to the contact. Andalusite and sillimanite are present in the rocks near the intrusive contact. The rocks strike generally northeast, and dip both northwest and southeast; local overturned beds and variable facing directions (Tabor and Ellen, 1975) suggest complex folding. A particularly well-exposed partial section is present east of Little Washoe Lake. Thompson and White (1964) suggested that the rocks are mostly, if not entirely, water laid. A thickness of 1,000 m or more for the metasedimentary rocks is possible. They are most likely correlative with the Gardnerville Formation. The rocks examined east of Pleasant Valley, in the vicinity of the Rocky Hill Mine, consist of light-gray-weathering, dark-gray and greenish-gray hornfels and semischist from protoliths of tuffaceous(?) siltstone, volcaniclastic and feldspathic sandstone, pebbly mudstone, and coarse, andesitic pebble and cobble conglomerate. Pebbles in the conglomerate are mostly 1–4 cm, but range up to 20 cm. In this area, schistosity in the rocks has north to northwest strikes and easterly dips of 30°– 40°. Locally, there is evidence of stretching of pebbles in the finer grained conglomeratic units. Two directions of cleavage are locally observed: a well-developed, slaty cleavage has an attitude of N0°–10°W, 50°– 80°E, and another cleavage has an attitude of N65°–75°W, 70°– 85°NE. The rocks clearly are more deformed than the rocks of the Peavine sequence observed in the Reno area to the north.

Castle Peak

Thompson (1956) showed a small (0.5 km^2) outcrop of Mesozoic metasedimentary rocks in a canyon just southwest of Castle Peak. The outcrop is surrounded by Miocene andesite flows. Poorly exposed, dark-gray, thin-bedded recrystallized limestone (marble) is interbedded with dark argillaceous rocks. Foliation in the argillite and slate appears to be parallel to compositional banding and has an attitude of N20°–35°E, 45°–55°NW. Marble beds commonly are foliated. Shale and siltstone may have a fine foliation or prominent shaly parting, and are locally somewhat contorted. Cleavage is rare, but at one locality in marble it is N55°W, 75°SW. Black, cherty-looking silicified wood from the area has been identified as a conifer, possibly *Araucarioxylon* (Thompson, 1956, p. 47). Small unidentifiable pelecypods were also reported by Thompson. The units present lithologically resemble the Gardnerville Formation.

Comstock Lode (Virginia City-Silver City)

At the northern end of the Comstock Lode in Virginia City (fig. 22, locality 4, north area), Mesozoic(?) meta-andesite and flow-banded metarhyolite are reported to crop out in the footwall of the Comstock fault and below the Tertiary Alta Formation near Cedar Ravine immediately north of Virginia City (Vikre, 1989, p. 1583, and oral commun., 1989). The rocks are strongly hydrothermally altered, and it is possible that these outcrops are Tertiary in age instead, as shown on maps by Thompson (1956) and Hudson (1987). Microdiorite of probable Mesozoic age is observed on the dump of workings 200 m west-northwest of the Hebrew Cemetery. This rock-type is most likely a hypabyssal(?) unit of the Middle Jurassic volcanic succession and apparently represents the subsurface footwall rocks of the Comstock fault immediately to the west of the workings. About 400 m to the southeast, at the Sierra Nevada Mine, Gianella (1936, p. 35) and Becker (1882, Atlas sheet 5, 8) reported that limestone was encountered at the 1,450-foot level; 400 m further southwest, at the Union shaft, limestone was cut in a crosscut to the footwall of the lode from the 2,000-foot station, and Hudson (1984, p. FT 11-8) reported the presence of meta-andesite on the dump. According to D.M. Hudson (oral commun., 1990) core from a drill hole near the California shaft (east of the picnic area at the north end of Virginia City) showed a thick section of skarn developed in massive carbonate rocks (probably equivalent to the Oreana Peak Formation of Late Triassic age). Dikes of granitic rock were also penetrated, but little of the intrusive Tertiary Davidson Granodiorite was noted. ASARCO, Inc. drilled into the footwall(?) of the projected Comstock fault near the Utah shaft on the northeast flank of Cedar Hill and 1.5 km to the northeast in Long Valley, and encountered granodiorite in both areas below the Tertiary rocks. The granodiorite was also encountered in the Utah workings; a sample from the dump gave a hornblende K-Ar age of 84.9±4.0 Ma (Vikre and others, 1988). The presence of Cretaceous granodiorite and Jurassic(?) metavolcanic rocks in the subsurface on the north end of the Comstock Lode suggests that probable Oreana Peak subcrops below the Tertiary rocks may represent a small(?) pendant or

pendants, and that Cretaceous granitic rocks underlie a major part of the Virginia City area. Vikre (1989, p. 1578) suggested that similar granitic rocks, which crop out about 8 km to the south in the Silver City area extend several miles westward beneath the surface (suggesting that Mesozoic rock outcrops in the vicinity of McClelland Peak are pendants in an extensive pluton extending westward to exposures on the east side of Washoe Lake). Also, granitic rocks were penetrated in the Baltimore shaft, located on the north edge of American Flat (Becker, 1882, Atlas sheet 6).

Near the south end of Virginia City, a schist probably from a protolith of siltstone of the Gardnerville(?) Formation, was sampled by G.F. Becker (U.S. Geological Survey) in the early 1880s (and archived at the Smithsonian Museum) from the footwall of the lode in the Sutro tunnel (D.M. Hudson, oral commun., 1990). North of American Flat, in the mines of Gold Hill (especially the Belcher and Yellow Jacket), black shale or slate was encountered in the footwall of the Comstock lode (Gianella, 1936, p. 36; Becker, 1882, Atlas sheet 7), and samples of lithologically similar rock can be found on the dumps of the Belcher-Crown Point Mine and in a small outcrop of cordierite schist on the north edge of American Flat (D.M. Hudson, oral commun.,1990).

Thus, from numerous pieces of subsurface and surface information, several Mesozoic units are present below Tertiary volcanic rocks along the Comstock Lode, and crop out to the southwest in the American Flat area. Apparently, roof pendants in Cretaceous granodiorite consist of one or more of the following: meta-andesite and metarhyolite (Middle Jurassic volcanic rocks?), marble (Oreana Peak(?) Formation or Gardnerville(?) Formation), shale (Gardnerville(?) Formation), and Jurassic(?) microdiorite (possibly equivalent to similar intrusions found north of the Verdi Range, in the Flowery Range, northwest of Carson City, and in the Pine Nut Mountains (John and others, 1994).

Mound House

Bingler (1977) showed coarse-grained gypsum and overlying yellowish-tan, medium-grained marble apparently interbedded in meta-andesite at the Adams Mine, 2 km north of Mound House (locality 5, fig. 22). Grayish-green, massive meta-andesite, having phenocrysts of plagioclase and ghosts of hornblende and biotite(?), appears to underlie and overlie a thick, white gypsum (anhydrite at depth) unit and an overlying 10-m-thick yellowish-tan marble. Some poorly preserved, unidentifiable fossils(?) were noted at one locality. The marble and overlying(?) meta-andesite are somewhat broken (e.g., Papke, 1987, p. 19) possibly due to collapse associated with gypsum dissolution.

The gypsum unit is more that 40 m thick and crops out in an area that is surrounded by meta-andesite. The simplest stratigraphic explanation, that gypsum is interbedded with meta-andesite, poses a problem for the Triassic age proposed by Bingler (1977). All the known bedded gypsum occurrences in western Nevada may be the same age (Stewart, 1980, p. 66); those whose ages are known are latest Early Jurassic (Ludwig area; Dilles and Wright, 1988) or Early to Middle Jurassic (Lovelock Formation of Speed, 1974). Alternatively, part or all of the meta-andesite may be a Jurassic(?) hypabyssal intrusion, and the gypsum and subordinate marble maybe pendants (Stewart, 1997, p. 11). A third possibility is that the gypsum and marble may be in a fault block surrounded by meta-andesite (see Archbold, 1969).

Flowery Range

A 2- by 5-km band of Jurassic(?) metasedimentary rocks intruded by Jurassic(?) microdiorite and Cretaceous(?) granodiorite and quartz monzonite crops out beneath Alta Formation on the southeast flank of the Flowery Range about 18 km northeast of Dayton (Bonham, 1969; Moore, 1969). The metasedimentary rocks are lithologically similar to those at another outcrop area located approximately 8 km to the northeast near Ramsey but apparently are more thermally metamorphosed. The rocks of both areas consist of schist, hornfels, and limestone, probably belonging to the Gardnerville Formation. Reeves and others (1958) reported feldspathic sedimentary rocks, and an upper unit of relatively pure quartzite (possibly equivalent to the Preachers Formation) from the vicinity of the Dayton iron deposit. The Jurassic(?) microdiorite, which intrudes the metasedimentary rocks in the Flowery Range, consists of dark-gray to black rocks composed primarily of plagioclase and hornblende. Rose (1969, p. 18) reported that diorite and microdiorite are probably Late Jurassic, as they are cut by aplite and microgranite dikes of probable Cretaceous age and intrude Lower Jurassic sedimentary rocks.

At the Dayton iron deposit (Reeves and others, 1958; Roylance, 1966), the Gardnerville(?) Formation is reported to be folded into a northwest-trending asymmetrical anticline, overturned to the east, and having a core of Cretaceous(?) granodiorite. Folding is reported to postdate the Late Jurassic(?) microdiorite, but precede the Cretaceous(?) granodiorite intrusion, which is proposed to be responsible for the formation of iron skarn (Roylance, 1966). A Cretaceous(?) quartz monzonite intrusion is reported to postdate the skarn formation (Roylance, 1966). John and others (1994) suggested that the granodiorite at the Dayton iron deposit which is inferred to be the source of mineralizing fluids is probably Jurassic instead of Cretaceous. Massive carbonate rocks, the predominant host for skarn, could represent either the Upper Triassic Oreana Peak Formation or massive carbonate rocks in the Gardnerville Formation. The lower massive carbonate unit (Roylance, 1966, fig. 13A) is apparently only known from diamond drilling at the Dayton iron property.

The overturned anticline at the Dayton iron property has a similar trend and vergence to other folds in rocks laterally equivalent to the Gardnerville Formation about 28 km to the southwest (Bingler, 1977). Roylance (1966, p. 140) speculated that the fold at the Dayton iron property was displaced by a pre-granodiorite fault with right-lateral displacement of about 300 m. Another possible interpretation is that the northwest-trending overturned fold is refolded into open folds having a northeast trend. However, this relationship is not observed in the relatively straight fold axes of northwest-trending folds mapped by Bingler (1977) near Carson City to the southwest.

Churchill Butte

Mesozoic metasedimentary and metavolcanic rocks crop out on the northeastern and eastern side of Churchill Butte (about 45 km west of Carson City, locality 7 of fig. 22) (Moore, 1969; L.A. Fraticelli, unpub. mapping, 1986). The metasedimentary unit, which is the most widespread, consists of dark-gray to black carbonaceous shales, hornfels, calcareous siltstone, feldspathic sandstone, and minor limestone. This unit contains Early Jurassic ammonites (Moore, 1960; Stewart, 1997, p. 26), and one collection is suggestive of about middle Pliensbachian age. Lithologically and paleontologically this unit is correlative with the Gardnerville Formation. Overlying this metasedimentary unit is a metavolcanic unit composed of mafic lava flows and breccias and possibly a few tuffs (L.A. Fraticelli, written commun., 1991). This unit is considered to be younger than the metasedimentary unit, although no sedimentary facing directions are reported to confirm the relative positions of the two units. The metavolcanic unit is considered to be part of the widespread Middle Jurassic volcanic rocks in the project area.

Ramsey

Approximately 3 km northeast of Ramsey (locality 6, fig. 22), Jurassic metasedimentary rocks crop out around a small (2 km diameter) stock of Cretaceous (?) granodiorite. The area of outcrop of the metasedimentary rocks is approximately 1 km^2, and the rocks are overlain by Quaternary alluvium and Oligocene ignimbrites and overlain and intruded by Miocene andesitic rocks (Rose, 1969). Exposures present to the northeast and mapped as Jurassic metavolcanic rocks by Rose (1969) are now interpreted as part of the Miocene Alta Formation (L.J. Garside, H.F. Bonham, Jr., and L. McMaster, unpub. information, 1988). Thus, present interpretations indicate that only the metasedimentary rocks at Ramsey are of Jurassic age. These rocks consist mainly of slate with thin interbeds of metasandstone and dolomitic limestone (marble). Slate units are dark bluish gray with poor to moderately well-developed cleavage apparently parallel to original bedding (Rose, 1969, p. 10). Dips vary from steep to shallow, and strikes range from north-south to east-west. Limestone interbeds are dark gray, finely crystalline, and generally less than a few meters in thickness. Some beds show relict clastic textures and contain small pebbles of volcanic rock (Rose, 1969, p. 10). Slates are converted to dark hornfels and limestone units are converted to calc-silicate hornfels in a narrow thermally metamorphosed zone that reaches hornblende hornfels facies. Fossils, especially anarietitid-type ammonite from a locality in north-central sec. 23, T18N, R23E (Stockton Well 7.5' Quadrangle), indicate an Early Jurassic age (Moore, 1960, p. 288; Rose, 1969, p. 11; Stewart, 1997, p. 26); another nearby fossil locality in the Ramsey outcrop (probably NW ¼ sec 23) may contain a more diverse assemblage (D.M. Hudson, oral commun., 1989). Thus, these rocks are lithologically similar to, and almost certainly correlative with, the Gardnerville Formation.

Derby Mine Area

A small area (about 500 x 300 m) of dark hornfels and quartz-garnet skarn crops out at the Derby Mine about 1 km west of the Gilpin Rest Stop along Interstate 80, 40 km east of Reno (locality 8, fig. 22). Rose (1969) mapped the general geology of the area, and Stager and Tingley (1988) described the geology of the scheelite-bearing skarn mineralization at the Derby Mine.

At the locality, dark Mesozoic rocks are intruded by biotite-hornblende granodiorite to the east and overlain in other directions by Quaternary alluvium. Biotite granite dikes also cut the hornfels. Local, small patches of phyllite and tremolite marble are present, and probably are remnants of more extensive pelitic and carbonate rocks replaced by skarn. Medium-grained to pegmatitic diorite is also present in complex relation to the other Mesozoic rocks in this outcrop area. It may be older than the granodiorite, and thus be the protolith for much of the dark hornfels; alternatively, as suggested by Rose's mapping, the hornfels protolith may be Jurassic(?) volcaniclastic or mafic volcanic rocks. The pelitic and carbonate rocks are most likely Gardnerville Formation, although they are too altered and replaced to be certain.

Mesozoic Metavolcanic Rocks in the Genoa Peak Pendant and Vicinity, Carson Range

A large pendant (over 35 km^2) of metavolcanic and metavolcaniclastic rocks centered on Genoa Peak is exposed in the southern Carson Range between Walleys Hot Springs and Glenbrook (locality 9, fig. 22). The surrounding plutonic rocks are predominantly Cretaceous (John and others, 1994). The pendant is nearly continuous at its northern end with a 2.5 km^2 pendant of similar rocks west of Spooner Lake (locality 10, fig. 22), which are cut by a Tertiary latite plug at Captain Pomin Rock 1.5 km northwest of Glenbrook (Grose, 1985). Exposures of the pendant rocks are poor in much of this area, but a few good outcrops are present near a peak located in the NE ¼ sec. 35, T15N, R18E. In outcrop, light- to dark-gray quartzose sandstone, having alternating bands 3 to 4 cm wide, strikes northeast and dips southwest. Similar metasandstone crops out at the north edge of the Glenbrook 7.5-minute Quadrangle (Grose, 1985). There it is metamorphosed to hornblende hornfels and semischist.

Two small pendants 5–10 km to the northeast, near Marlette Lake (locality 11, fig. 22), are composed of silicic to intermediate-composition metavolcanic rocks (Grose, 1985), which are presumably equivalent to parts of the metavolcanic section of the Genoa Peak pendant described below.

Strongly foliated quartzofeldspathic schist is exposed in a long, narrow (400 m wide) pendant exposed 0.5 km southeast of Glenbrook along U.S. Highway 50. The north- to northwest-trending, high-angle foliation is parallel to the granitic bodies which enclose the pendant, suggesting an origin of schistosity

Photo 11. Mesozoic amygdaloidal metabasalt from the Genoa Peak area.

relating to Cretaceous intrusive events. To the south, in the vicinity of Genoa Peak, where the pendant is up to 4 km wide, original bedding and primary igneous foliation are preserved in the rocks, except near pluton margins or where the pendant thins at its south end.

Exposures in the vicinity of Genoa Peak allow the construction of a stratigraphic section, albeit a somewhat speculative one (fig. 23). The metavolcanic rocks (photo 11) in this area are interpreted to be entirely subaerial, and closely resemble the varied metavolcanic rocks exposed on Peavine Peak 60 km to the north; however, there are no units that have the potential to be widely distributed (such as distinctive ignimbrites) that are distinct enough to make a firm correlation. The ignimbrites that are intercalated with lavas have compacted pumice lapilli that are most likely formed during subaerial deposition. The chert pebble conglomerate and quartzose sandstone (photo 12) units in the Genoa Peak area are, however, an anomaly. This lithology is, except for a quartzite described by Bonham (1969, p. 7) from Freds Mountain (and not observed there during this study), completely absent from the Peavine sequence rocks as defined in this report. The quartzose units are more reminiscent of Preachers Formation in the Pine Nut Mountains to the east, but it lies on Gardnerville Formation there, and is older than the Double Spring Formation (see fig. 3), the most likely correlative of the Peavine sequence in the area south of Carson City. Sandstone bedding features (flaser bedding, cross bedding, etc.) are permissive of a fluvial and/or shallow marine depositional environment. An alternate correlation for the rocks of the Genoa Peak pendant is the Jurassic metavolcanic rocks of the Buckskin Range northwest of Yerington (see Proffett and Dilles, 1991).

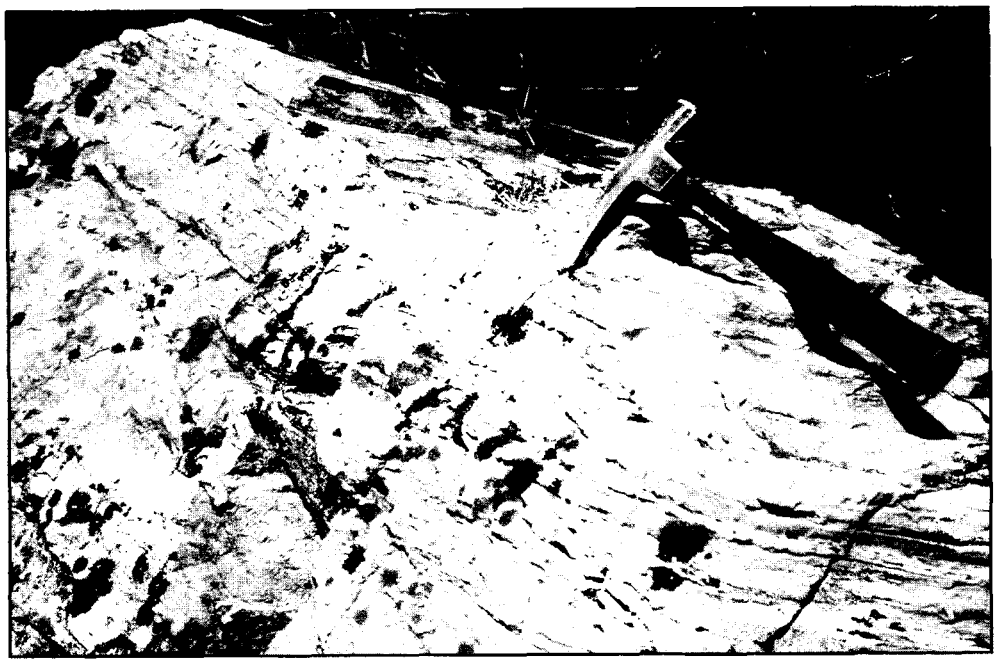


Photo 12. Outcrop of quartzose metasandstone in the vicinity of Spooner Summit.

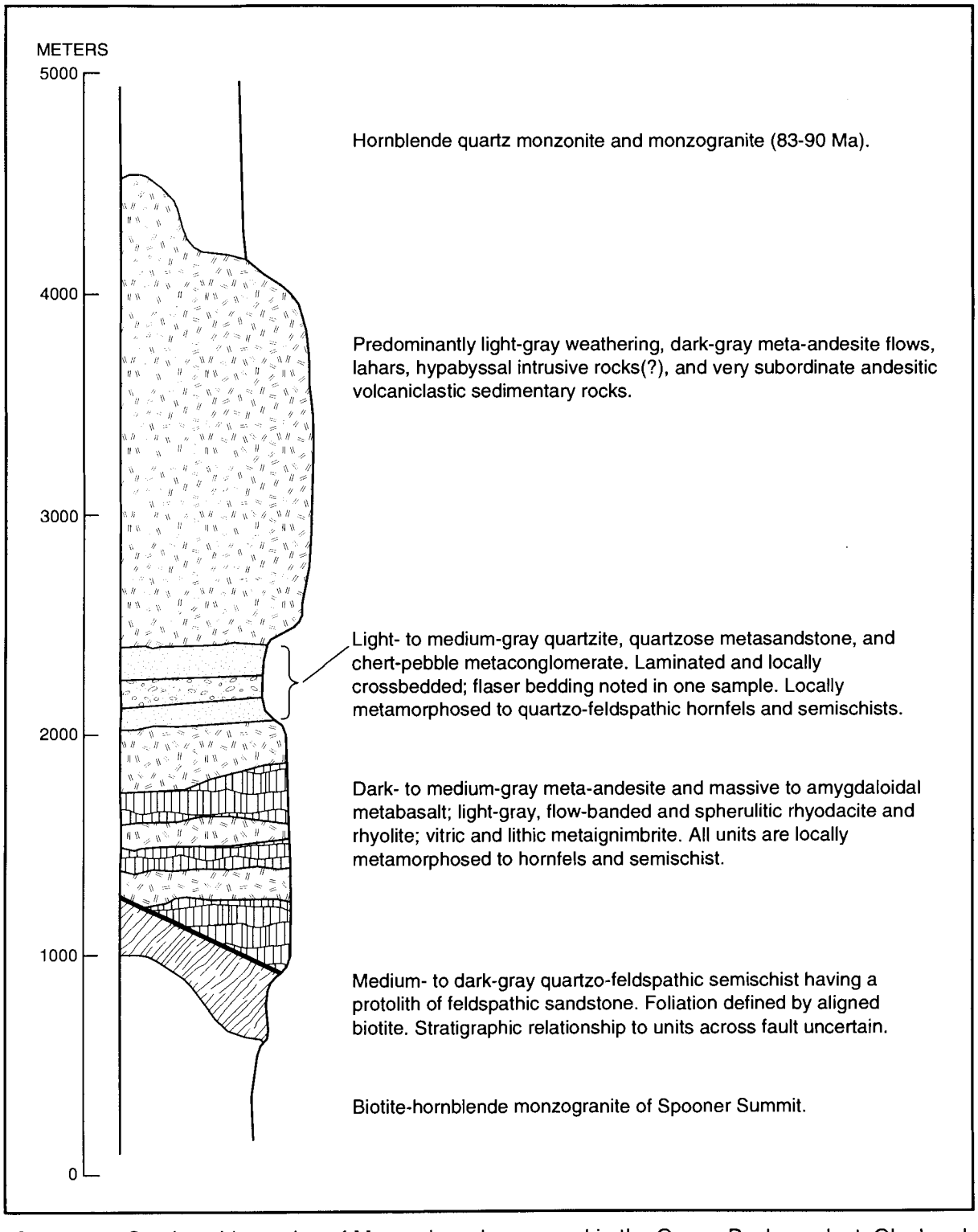


Figure 23. Stratigraphic section of Mesozoic rocks exposed in the Genoa Peak pendant, Glenbrook Quadrangle, Nevada. Unit thicknesses estimated from Grose (1985).

Southeast of Genoa Peak, the pendant consists predominantly of intermediate flows, lahars, pyroclastic(?) rocks, and minor volcanic sandstone and conglomerate (Pease, 1980; Armin and John, 1983). They are locally intruded by small masses of fine-grained diorite. Much of the rocks in this area are dynamothermally metamorphosed to schist and flaser gneiss. Armin and John (1983) reported that most of this unit in the outcrop area northwest of Walleys Hot Springs (fig. 22) is well foliated, although relict pyroclastic textures and bedding subparallel to the foliation are common. Most rocks throughout the pendant are metamorposed to the greenschist facies; amphibolite-facies assemblages are found near contacts with granodiorite. Foliation appears to be mainly subparallel to the northeast trend of the pendant margins, although east-west foliation is reported locally.

CONCLUSIONS

The following conclusions can be drawn from this study:

- The remnants of once more extensive Middle Jurassic (?) metavolcanic rocks and Triassic and Lower Jurassic metasedimentary rocks are preserved today as pendants in the Jurassic and Cretaceous plutons of the Sierra Nevada batholith.
- Peavine sequence metavolcanic rocks of the Reno area are calc-alkaline and possibly high-potassium; they appear to be entirely subaerial. Their age is uncertain, but probably best interpreted as Middle Jurassic.
- The presence of such rocks is compatible with an east-dipping subduction zone and a continental magmatic arc during their time of deposition.
- Peavine sequence rocks of the Reno area are not folded or strongly foliated, in contrast to Triassic and Jurassic(?) rocks to the south in the vicinity of Carson City. The significance of this is not clear; possibly Peavine sequence rocks postdate a deformation event recorded in the metavolcanic and metasedimentary rocks to the south.
- Correlation between pendants of metavolcanic rocks is difficult without isotopic age control, which is needed for more detailed studies.

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