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Title: THE GEOLOGY OF THE SOUTHERN PART OF THE PUEBLO MOUNTAINS, HUMBOLDT COUNTY, NEVADA

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The thesis area is in the northwestern part of the Basin and Range province and occupies an area of approximately 25 square miles in the Pueblo Mountains of Humboldt County, Nevada.

The area contains marine sedimentary strata of possible Permo-Triassic age which were subjected to regional metamorphism and intruded by diorites during Jurassic or Cretaceous time. These older rocks are unconformably overlain by a thick sequence of late Tertiary volcanic and sedimentary rocks. The basal unit of these younger rocks consists of basalt flows with minor interbedded ash flow and ash fall tuffs, and volcanic sandstones. The basalt unit is disconformably overlain by rhyolite flows in the southern part of the area. Both of these essentially volcanic units are unconformably overlain by interbedded volcanic sedimentary and welded and non-welded pyroclastic rocks. This sedimentary-pyroclastic unit is unconformably overlain by dissected gravel deposits on the west flanks of the mountains.

Major block faulting and tilting, which began in late Miocene or early Pliocene time, has continued into the Quaternary Period. The faulting and tilting produced the Pueblo Mountains, which are tilted to the west and bounded on the east by normal faults. The faulting produced undrained basins that received sedimentation from the eroded upthrown block. Structural and stratigraphic evidence suggests that the Pueblo and Pine Forest Mountains were originally a single fault block that was later separated by northeast-trending normal faults in late Pliocene or Pleistocene time, resulting in the draining of the basin developed west of the mountains and the partial erosion of the older basin filling.

The Geology of the Southern Part of the Pueblo Mountains, Humboldt County, Nevada

by

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THE GEOLOGY OF THE SOUTHERN PART OF THE PUEBLO MOUNTAINS, HUMBOLDT COUNTY, NEVADA

INTRODUCTION

Location and Accessibility

The area discussed in this report includes 25 square miles in northwestern Humboldt County, Nevada, including the southern end of the Pueblo Mountains and adjacent portions of the Pueblo and Bog Hot Valleys. The area is about one mile southwest of Denio, Nevada, and the northern boundary is within one mile of the Oregon-Nevada State line (see Figure 1).

The area may be reached from the west or the south via Nevada State Highway 8A, which skirts the Pueblo Mountains, or from the north by way of an unpaved road leading from Fields, Oregon to Denio.

All parts of the area are accessible either by vehicle or by foot. There are many dirt roads in Pueblo Valley leading to mining claims at the foot of the Pueblo Mountains. One of these roads also leads to the eastern part of the mountains. The western flanks of the mountains are accessible from dirt roads in Bog Hot Valley, one of which leads into the mountains from Bog Hot Ranch. All of the roads are easily negotiated during dry weather by pick-up truck with two-wheel drive, but they may be impassible during wet weather.

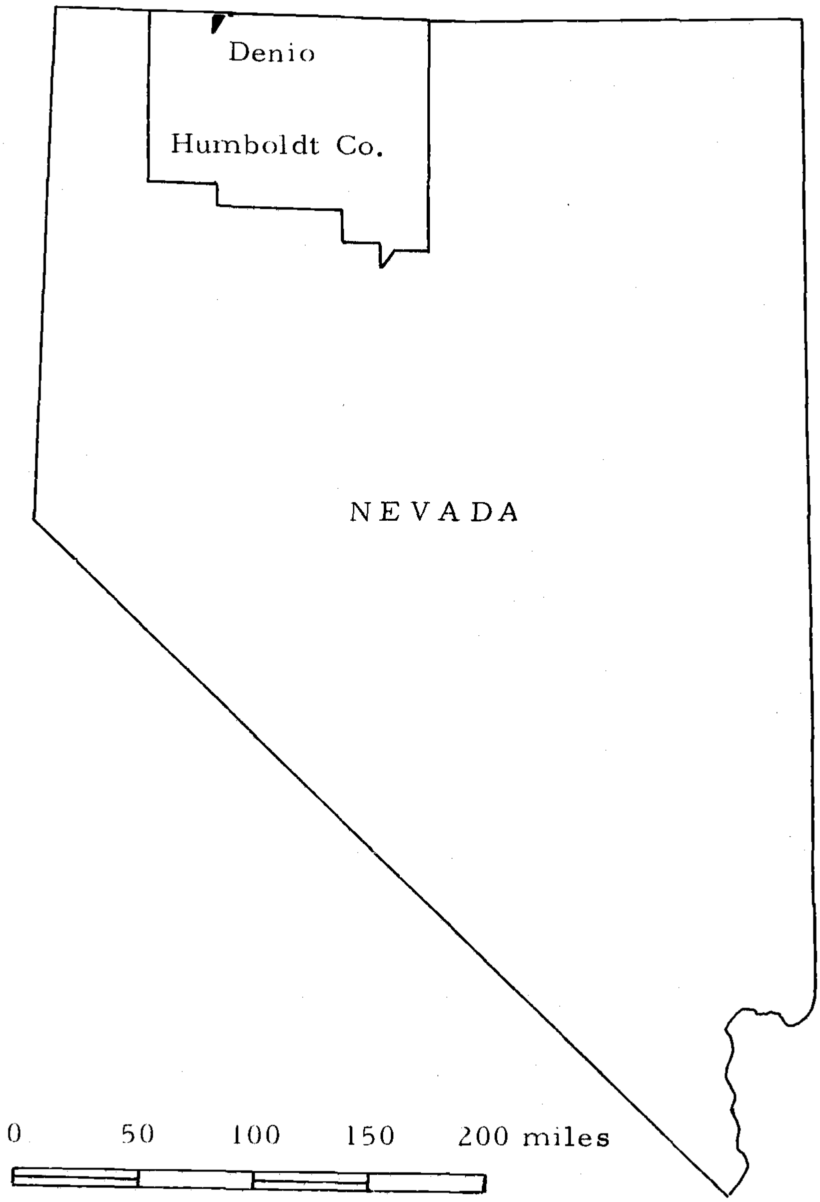

Figure 1. Index map showing the location of the area investigated.

Purpose and Methods of Investigation

The investigation was conducted in the area in order to describe and map lithologic units and structures only briefly mentioned or described in the literature and heretofore mapped only as part of a regional geologic reconnaissance.

Field work was conducted during the months of July, September, and November 1968 for a total of nine weeks, and involved the describing and measuring of lithologic units and structures and the plotting of their contacts directly on topographic base maps with a scale of 1:24000. The base maps are 7 1/2'' quadrangles published by the U. S. Geological Survey and included advance sheets of Ashdown 1 NW and Ashdown 2 NE, with contour intervals of 40 and 20 feet respectively. The final map, with a contour interval of 40 feet, was compiled from these base maps (See Plate 1). Aerial photographs with an approximate scale of 1:63000 were of limited use in the field for detailed mapping but were invaluable for determining structure and tracing some of the contacts. Structural attitudes were determined in the field with a Brunton compass; an Abney level mounted on a five foot staff was used for section measurements. Laboratory work involved the microscopic examination of hand specimens and thin sections with binocular and petrographic microscopes.

Previous Investigations

James Blake (1875), John C. Merriam (1907, 1910), and Richard E. Fuller (1931) briefly discussed the geology in the area of this investigation. Ronald Willden (1961, 1964) included the area in his reconnaissance geologic investigation of Humboldt County, Nevada. Investigations by workers in southeastern Oregon have helped to clarify the structure and stratigraphy within the area, especially the investigations of R. E. Fuller and A. C. Waters (1929), and G. W. Walker and C. A. Repenning (1965).

Topography and Drainage

The Pueblo Mountains are a southern continuation of the much higher Steens Mountains of Oregon and extend eight miles into the State of Nevada. They rise abruptly above adjacent valleys and have an asymmetrical cross profile, the east side of the range being much steeper than the west side. The mountains are about six miles wide in the northern part of the area but narrow rapidly toward their southern end.

The maximum relief in the area is approximately 2,100 feet. Pueblo Valley, with an average elevation of about 4,200 feet, lies to the east of the mountains, and Bog Hot Valley, with slightly higher elevations, lies to the south and west. The east side of the mountains rises abruptly from Pueblo Valley and forms a steep northeast-trending mountain front dominated by Strawberry Butte, the highest point in the area, which has an elevation of 6, 326 feet.

The mountains consist of two major ridges. The north-trending west ridge extends the length of the mountains and reaches elevations of over 6, 000 feet in the northern part of the area. The slightly higher east ridge, containing Strawberry Butte, trends to the northeast and occupies only part of the mountain mass in the area but becomes the higher main ridge of the Pueblo Mountains in Oregon.

The area is in a region of internal drainage. Bog Hot Valley is drained by Thousand Creek, an intermittent stream which has some surface flow for short distances contributed by hot springs. The creek drains into Continental Lake in the southern part of the area, and the lake overflows into Pueblo Valley by way of Pueblo Slough. Pueblo Valley has no drainage outlet. The lake is dry except during times of heavy surface runoff from the surrounding mountains.

The mountains are drained by many short, deep, canyon-like valleys, which are occupied by intermittent streams. The major canyons draining the steeper east slopes into Pueblo Valley have gradients between 500 and 600 feet per mile, whereas those draining the gentler west slopes have gradients between 300 and 400 feet per mile. Cowden Canyon, which drains Alberson Basin, is the most prominent canyon in the area.

Climate and Vegetation

The area has a desert climate resulting from the rain shadow created by the Sierra Nevada and Cascade Range to the west of the Great Basin. Weather data recorded at Denio (elevation 4,185 feet) are either incomplete or lacking except for the years from 1951 through 1960, but the temperature and precipitation averages during this period of time are regarded as the "normal" for the area.

The mean annual temperature is 48.6° F. and the annual precipitation is 8.31 inches. Hot dry summers and moderately cold wet winters are typical. Prevailing winds are from the west, but local topography occasionally causes their prevailing direction to be from the south or southwest. Although high winds are uncommon, they usually produce dust and sandstorms.

Mean daily maximum temperatures during the summer months are above 80° F., with July usually the hottest month of the year. A large daily range of temperature amounting to as much as 40° during the summers usually results in cool nights, even following the hottest days. Frosts usually begin early in the fall and continue late into the spring. The mean temperature during the winter months is 32.5° F., with January the coldest month of the year. Although low temperatures are occasionally recorded, prolonged periods of extreme cold are rare.

Little or no precipitation may be recorded during the summer months, but thunder storms occasionally develop into heavy local downpours of rain. Heavy rain late in the fall may cause some flooding in the valleys. Precipitation increases during the winter months, but the greatest amount of precipitation comes during the spring. May is usually the wettest month of the year. Mountain snowfall is the main source for stream flow, and the melting of snow during the spring commonly causes some flooding in the valleys. Snowfall records are incomplete, but the total for 1955 was 27.0 inches and is comparable to the "normal" annual total of 27.4 inches at Winnemucca airport located about 98 miles southeast of Denio.

Sagebrush and various other shrubs, flowers, and grasses tolerant of alkaline soil and low precipitation grow in the region. Sagebrush occurs from the lowest to the highest elevations. Grasses are concentrated mainly in Pueblo Slough but provide some summer forage for cattle in the mountains. There are no trees in the area except for a few occurrences of small desert willow growing around some of the springs in the mountains.

Culture and Land Uses

There is no industry in the area other than open range livestock grazing. Mining has been carried on in the past, but none of the mines are now in operation. The area is used extensively for recreation, mainly hunting for game, semi-precious stones, and Indian artifacts.

Geologic Setting

The Pueblo Mountains are located in the northwestern part of the Basin and Range province. The mountain range is a westward tilted fault flock bounded on the east by normal faults. The area of investigation is underlain by Late Paleozoic and Early Mesozoic meta-sedimentary and meta-igneous rocks, Mesozoic diorite plutons, and late Tertiary volcanic and sedimentary rocks. The Tertiary volcanic rocks are the dominant rock type making up the mountains.

STRATIGRAPHY

The general stratigraphy of the region is known only from reconnaisance mapping, for detailed investigations have been made only in widely scattered areas. Correlation and age of most rock units are in doubt, for the fault block mountains are chiefly Tertiary volcanic rocks that contain few or no fossils.

The stratigraphy of the area investigated is summarized in Table 1. The oldest rocks exposed are schists and minor interbedded quartzites and greenstone, which are collectively mapped as a metasedimentary unit of possible Permo-Triassic age. These metamorphic rocks have been intruded by two diorite plutons of possible Jurassic or Cretaceous age and mapped as biotite diorite and diorite porphyry units, respectively. An angular unconformable relationship exists between these older rocks and the overlying basalt unit of probable middle Miocene age that contains minor interbedded tuffs, sandstone, and cinder beds in its upper part. The basalt unit is disconformably overlain by a rhyolite unit, also of probable middle Miocene age. Both of these volcanic units are unconformably overlain by a sedimentary-pyroclastic unit of probable middle to late Miocene age. The unconformity is one of disconformable to low angular relationship. This unit includes interbedded volcanic conglomerates, sandstones, silty mudstones, and ash flow tuffs. Five of the ash flow tuff beds are welded and are differentiated as members of the unit. The sedimentary-pyroclastic unit is in turn overlain with angular unconformity by gravel deposits of probable Pliocene age. Alluvial fan, stream, and playa deposits of Quaternary age are the youngest deposits in the area.

Table 1. Stratigraphic Summary

Age	Map Unit	Thickness in feet
Quaternary	Alluvium, playa, and dune deposits	?
- - - - - - - - - - - - - -	(angular unconformity)	- - - - - - - - - - - - -
Pliocene ?	Dissected gravel deposits	0-250 ?
- - - - - - - - - - - - - -	(angular unconformity)	- - - - - - - - - - - - -
Middle to late Miocene ?	Sedimentary-pyroclastic unit	1200-1300
- - - - - - - -	(disconformity to low angular unconformity)	- - - - - -
	Rhyolite unit	300-400
Middle Miocene ? - - - - -	(disconformity)	- - - - - - - - - - - - - - -
	Basalt unit	2863-3200
- - - - - - - - - - - - - -	(angular unconformity)	- - - - - - - - - - - - -
Permo-Triassic ?	Metasedimentary unit (intruded by diorite porphyry and biotite diorite units of possible Jurassic or Cretaceous age)	1800

Pre-Tertiary Metamorphic Rocks

Metamorphosed sedimentary rocks containing a subordinate amount of greenstone are collectively described in this report as the metasedimentary unit. Willden (1964) described the metamorphic rocks in the area as an undivided metamorphic sedimentary and volcanic unit (TrPu). A large part of his metamorphic unit includes a diorite pluton within the area investigated.

Field Relationship

The metasedimentary unit underlies the length of the east ridge (See Plate 1) cropping out in a narrow northeast-trending band that ranges in width from 1/5 to 3/5 of a mile. The unit separates the intrusive diorite porphyry underlying the higher part of the ridge from the biotite diorite underlying the lower southeast slopes. Except at its southern end, where it is a ridge-former for a short distance, the unit is expressed in the topography only by the gentler mountain slopes developed between the more resistant intrusive igneous rocks. Poorly exposed and regolith-covered on the mountain slopes, the metamorphic rocks are best exposed in some of the deeper southeast-trending canyons draining the east side of the mountains.

Contacts of the unit with adjacent intrusive or volcanic units are not exposed. The foliation strikes to the northeast, paralleling the trend of the intrusive igneous rocks, and dips to the southeast throughout most of its extent; however, the unit becomes tightly folded in the SW 1/4 sec. 6, T. 47 N., R. 30 E. The metamorphic rocks are intruded, more or less concordantly, by the biotite diorite, and more or less discordantly, by the diorite porphyry. At its southern area of outcrop it is overlain by the west-dipping basalt unit with angular unconformity. The metasedimentary unit is in fault contact with the basalt unit in sec. 1, T. 46 N., R. 28 E.

An estimated maximum thickness of 1,800 feet is exposed in the area investigated. Since the schistosity parallels lithologic differences, the schistosity is believed to have developed parallel to the original bedding.

Closely spaced fractures with variable attitudes intersect the schistosity, but none of the fractures noted have a preferred orientation that could be regarded as fracture cleavage. Most of the fracturing parallels the attitude of the schistosity. Elongate segregations of micaceous minerals locally produce a lineation in the plane of schistosity that could be measured in the field. As shown on the geologic map, those few lineations measured trend to the southeast.

Lithology and Petrography

The metasedimentary unit predominantly consists of finely crystalline quartz-muscovite and quartz-chlorite-muscovite schists and subordinate amounts of metaquartzite, muscovite-garnet schist, and greenstone. Although the texture is locally so fine that some of the metamorphic rocks could be properly termed phyllites, most are classified as schists, for the texture is usually coarse enough to differentiate the dominant minerals with the unaided eye or with the aid of a hand lens. Except for color differences between the quartz-muscovite and the quartz-chlorite-muscovite schists, these rock types are not readily differentiated in the field into distinct beds. They appear to grade one into the other both vertically and laterally and probably represent minor differences in composition of the original rock. Where these schists are exposed in sec. 1, T. 46 N., R. 28 E., they appear to alternate with one another in definite beds 10 to 20 feet in thickness. All gradations exist in the field, however, between those quartz-muscovite schists containing little or no chlorite and those containing considerable chlorite.

The quartz-muscovite schist is light gray (N7) to medium light gray (N6) in color. The weathered surface is not appreciably different in color from the fresh surface, but a pinkish-gray (5 YR 8/1) regolith is commonly formed. The muscovite occurs in plates usually less than 5 mm in diameter, and, because the schists cleave along the planes of schistosity where the muscovite is concentrated, it appears to be the dominant mineral making up the rock. The high amount of quartz is only revealed on surfaces perpendicular to the schistosity.

The average modal analysis of a representative sample (266-264) of quartz-muscovite schist examined microscopically is 70% quartz, 18% muscovite, 4% albite, 4% iron oxide, 2% calcite, 1% epidote, and 1% sphene. The schist has a porphyroblastic texture not readily noted in hand specimens. The crystals range from less than 0. 05 to 3 mm, and the porphyroblasts comprise about 5 per-cent of the rock. The porphyroblasts are subhedral to anhedral albite (An8) and range in size from 0. 25 to 3 mm. They are commonly fractured, and their long dimensions are usually oriented subparallel to the schistosity. The fractured crystals are healed with muscovite. The albite is partly altered to epidote and calcite. The matrix consists of lensoid aggregates, ranging from 0. 25 to 0. 5 mm in width and 2 to 4 mm in length, of fine to coarsely crystalline anhedral quartz alternating with discontinuous bands of lamellar muscovite. The quartz in the aggregates has sutured contacts. The muscovite bends smoothly around the albite porphyroblasts and quartz lenses. Anhedral crystals of iron oxide form "trains" or are elongate parallel to the schistosity. Although in part replacing the albite, the calcite also occurs in discrete anhedral grains in the quartz lenses. The matrix contains a minor amount of anhedral yellowish-green epidote that is probably derived from the alteration of plagioclase. Anhedral sphene occurs in the matrix as discrete crystals, and it also forms a narrow granular rim partly bordering some of the larger crystals of iron oxide.

The quartz-chlorite-muscovite schist is greenish-gray (5 G 6/1) in color and weathers to a pale-reddish-brown (10 R 5/4) color. The green color of the chlorite often masks the colorless muscovite and may appear to be the only micaceous mineral in some hand specimens. The dominance of quartz, like that of the quartz-muscovite schists, is apparent only on sections perpendicular to the schistosity. The estimated mineral mode determined by microscopic examination of a representative sample (13-14) is 56% quartz, 20% chlorite, 15% muscovite, 4% magnetite, 3% epidote, 1% sphene, and less than 1% plagioclase feldspar and calcite combined. The rock has a lepidoblastic texture, individual flakes ranging from 0.05 to 2 mm in length. Lensoid aggregates, ranging from 0.5 to 1 mm in width and 3 to 4 mm in length, of fine and coarsely crystalline anhedral quartz alternate with bands of fibro-lamellar green chlorite and muscovite. The micaceous minerals bend smoothly around the quartz lenses and anhedral yellowish-green epidote crystals that are probably derived from the alteration of feldspar. Magnetite octahedra displaying square and rhombic sections are widely disseminated and commonly form "trails" parallel to the schistosity. The sphene occurs in small euhedral to anhedral crystals, and the plagioclase occurs in anhedral crystals displaying indistinct albite twinning. The plagioclase is partly altered to sericite. The small amount of calcite present is associated with the quartz lenses in anhedral crystals.

Muscovite-garnet schist is exposed in a prospect pit in sec. 1, T. 46 N., R. 28 E. The schist is weathered and is very pale orange (10 YR 8/2) in color. Minute porphyroblasts of red garnet, less than 1 mm in diameter, are megascopically discernible. Thin section examination of a representative sample (30-24) reveals that the schist consists of 95% fibro-lamellar muscovite, 3% yellowish-brown limonite, 1% garnet, and 1% quartz. The garnet, which is anhedral and averages 0.5 mm in diameter, is commonly fractured; fragments from some of the larger grains appear to be dragged out parallel to the schistosity. The limonite, which occurs in streaks parallel to the schistosity, is probably an alteration product of iron oxide. The quartz occurs in lenticular aggregates whose anhedral grains have sutured or straight interlocking contacts.

Very hard, light gray (N7) or pinkish-gray (5 YR 8/1), finely crystalline metaquartzite is exposed in small discontinuous outcrops in the upper part of the metasedimentary unit. The contacts with adjacent rocks are not exposed. The nature of the outcrops suggests lenticular beds ranging from 5 to 15 feet in thickness and from 20 to 150 feet in length that are within the schists. The thicker beds locally display subparallel reddish-orange (10 R 6/6) and dark yellowish-orange (10 YR 6/6) color bands ranging from 1 mm to as much as

6 cm in width. The color bands parallel the contacts as well as the schistosity developed in the metaquartzite. The mineral mode of a representative sample (29-22) determined in thin section examination consists of 95% quartz, 4% iron oxide, and 1% muscovite. The crystals range in size from less than 0.05 to 0.5 mm. The quartz occurs in alternating discontinuous parallel layers of finer and coarser crystalline anhedral quartz with either straight or sutured interlocking contacts with adjacent crystals. The quartz is clear and has straight or undulatory extinction. No relict detrital grains with secondary overgrowth of quartz were noted. The iron oxide, variously altered to limonite and hematite, occurs in minute anhedral crystals more or less concentrated in layers paralleling the schistosity and is responsible for the color banding seen in hand specimens. Relict bedding is suggested by the concentration of the iron oxide into layers. The minor amount of muscovite occurs in small isolated plates oriented parallel to the schistosity.

The metasedimentary unit also contains a subordinate amount of greenstone, which forms isolated less easily eroded outcrops locally protruducing from the regolith that covers the mountain slopes. The greenstone appears to be in beds ranging from 10 to 20 feet in thickness. None of the beds can be traced more than 100 feet along strike. The rocks are dark greenish-gray (5 G 6/1) in color on the fresh surface and weather to a pale reddish-brown (10 R 5/4). They are hard and dense and except for epidote and a minor amount of quartz no other minerals are megascopically discernible. The epidote occurs in euhedral to anhedral crystals as large as 1 cm in length and imparts a porphyroblastic texture to some of the rock. Much of the epidote is fractured and occurs as pseudomorphs after plagioclase feldspar. Outcrops are commonly cut by numerous variously oriented epidote veinlets ranging from one-sixteenth to one-half inch in width. The foliation is not well developed, and parts of some outcrops appear massive in structure.

Petrographic examination of a representative sample (214-219) from the apparently massive part of one of these greenstones reveals that it is microscopically foliated. Porphyroblasts, 0.25 to 1 mm in size, composed of epidotized anhedral albite (An6) displaying albite twinning are set in a matrix with an average crystal size of less than 0.05 mm. Because of the fine texture of the matrix, the percent of minerals present cannot be estimated with any degree of accuracy. The albite porphyroblasts are commonly bent and fractured, and their long dimensions are oriented subparallel to the foliation. The matrix is dominantly euhedral to anhedral yellowish-green epidote, fibro-lamellar chlorite, and anhedral iron oxide, with a lesser amount of anhedral quartz and calcite in lenticular aggregates, and anhedral plagioclase feldspar displaying indistinct albite twinning.

The metasedimentary unit contains a few quartz veins that range from less than 1 inch to as much as 8 feet in width. A few of the veins are cross-cutting, but most of the veins are dilation veins that parallel the schistosity. The larger veins form resistant outcrops that usually cannot be traced more than 15 or 20 feet. At the Hall Mine in sec. 1, T. 46 N., R. 28 E., at least two closely spaced dilation veins form a resistant outcrop extending for a distance of about 40 or 50 feet. Many of the veins contain small irregular accumulations of bornite and chalcopyrite. Minute fractures cutting the mineralized quartz are commonly filled with chrysocolla and less commonly with malachite. The quartz cropping out at the Hall Mine is variously stained yellow, brown, and red by iron oxide minerals.

Origin

The greenschist facies of low grade regional metamorphism is suggested by most of the mineral assemblages. The isolated occurrence of muscovite-garnet schist suggests higher localized temperatures. There is no evidence suggesting contact metamorphism adjacent to the intrusive bodies.

The schists are believed to have been derived from fine-grained sedimentary rocks, and the subordinate amount of metaquartzite probably was derived from fine-grained, well-sorted quartz-arenite sandstone containing little or no argillaceous material. The original sedimentary rocks are most likely of marine origin, for marine invertebrate fossils have been collected elsewhere in Humboldt County from similar but unmetamorphosed sedimentary rocks of comparable age (Willden, 1964).

The greenstones may be in part what Willden (1964) refers to as metavolcanic rocks that occur in the unit. No relict structure was noted that would suggest vesicles, pillow structure, or any volcanic structures. If the greenstones indeed represent mafic igneous rocks, they are either very thin areally restricted flows or are concordant sill-like intrusions. Their apparent restricted lateral extent may be due to poor exposures on the mountain slopes. North of the area investigated, metasedimentary rocks containing greenstones presumed to have been mafic volcanic rocks are reported by Williams and Compton (1953), and Walker and Repenning (1965) to occur in the Pueblo Mountains of Oregon.

Correlation and Age

Rocks lithologically resembling known Triassic rocks, either unfossiliferous or containing fossils of broad age designation, are widespread in Humboldt County (Willden, 1964). The rocks generally consist of fine-grained clastic material, sandstone generally being the most coarse-grained. Contact and regional metamorphism has affected all pre-Cretaceous rocks in the county, and the degree of metamorphism varies from mountain range to mountain range.

Although the metamorphic rocks of the Pueblo Mountains are lithologically similar to known Triassic rocks occurring elsewhere in the county, the presence of interbedded greenstones suggests that these rocks are more closely related to interbedded sedimentary and mafic volcanic rocks of Permian to Triassic age in the Jackson Mountains (Willden, 1964; Walker and Repenning, 1965). The metasedimentary unit of this report is therefore assigned a Permo-Triassic age.

Pre-Tertiary Intrusive Igneous Rocks

Willden (1964) originally mapped the pluton underlying Strawberry Butte as part of his granodiorite unit (TKg), which included all quartz-bearing pre-late Tertiary intrusive rocks of Humboldt County. An additional major intrusive body also occurs in the area investigated, which may be differentiated from Willden's (1964) undivided metamorphic and sedimentary unit (TrPu). Both intrusive units are diorites and intrude the metasedimentary unit of this report, but they differ from each other in their texture as well as in their intrusive relationships. Because of important mineralogical and textural characteristics, these major plutons are described as the biotite diorite unit and the diorite porphyry unit, respectively.

Pre-Tertiary dike rocks mainly include numerous small undifferentiated porphyritic andesite dikes intruding the biotite diorite.

These mafic dikes also intrude the metasedimentary unit. Small aplite dikes cut both the biotite diorite as well as the mafic dikes intruding this unit.

Biotite Diorite Unit

Field Relationship

The biotite diorite underlies the lower mountain slopes adjacent to Pueblo Valley in the northeastern part of the area investigated. The intrusive body trends approximately N. 40° E. and crops out in an area about two and one-half miles in length and about three-fourths of a mile in width. It does not extend north of the area investigated, for its northeast trend is truncated by one of the inferred normal faults bounding the east side of the mountains. Two small isolated knolls bordering Pueblo Valley south of Spring Canyon Creek are also composed of biotite diorite and form erosional remnants of the intrusive body. The pluton is extensively covered by regolith, and exposures on the mountain slopes are confined to small isolated outcrops. It is best exposed in the southeast-trending canyons cutting across the unit. The pluton is less easily eroded than the adjacent metasedimentary unit, and small canyons tend to parallel the contact.

Although the contact with the metasedimentary unit is not exposed, the biotite diorite is regarded as being more or less concordant in its intrusive relationship with the originally unmetamorphosed rocks. The contact of the pluton parallels the schistosity developed in the metasedimentary unit. As previously discussed, the schistosity of the metasedimentary unit is believed to have developed parallel to the original bedding of the unmetamorphosed rocks. The contact with the basalt unit is not exposed. The pluton has an unconformable relationship with this younger, west-dipping volcanic unit.

The pluton locally contains small isolated outcrops of schist and metaquartzite near the contact with the metasedimentary unit in sec. 1, T. 46 N., R. 28 E., and in the SW 1/4 sec. 12, T. 47 N., R. 28 E. that are too small to differentiate. Their contacts with the biotite diorite is not exposed, but they are presumed to be xenoliths of the intruded country rock. Schists are also exposed in some of the prospect pits far from the contact in the NE 1/2 SE 1/2 sec. 12, T. 47 N., R. 29 E. All of the included country rock noted has a northeast strike and southeast dip similar to that of the metasedimentary unit.

The biotite diorite has a foliated structure formed by a subparallel orientation of the biotite and feldspar minerals. Because of this structure, the rock commonly has a gneissoid appearance. The attitude of the foliation parallels the contact with the metasedimentary unit, and it is believed to be a primary structural feature, because it is best developed along the contact. The foliation is obscure or fails to show megascopically in the eastern half of the pluton.

A major joint system is developed in the pluton by subparallel joints that strike northeast and dip southeast. These joints parallel the attitude of the foliation developed in the pluton and appear to be controlled by this structure. Rhomboid or rectangular shaped blocks are formed by northwest-dipping cross joints that intersect these major southeast-dipping joints at oblique to nearly right angles. The joints are regarded as tension joints, because no evidence of shear was noted along joint surfaces. Evidence of movement along joints was observed at a small outcrop of included metaquartzite in the SW 1/4 SW1/4 sec. 12, T. 47 N., R. 29 E. The schistosity of the metaquartzite strikes N. 30°E. and dips 55° southeast. The metaquartzite is intruded by mafic dikes ranging from 0.5 to 7 feet in width that have the same attitude as the schistosity. Many closely spaced fractures parallel the attitude of the dikes and the schistosity of the metaquartzite. A rhomboid joint pattern is formed by the intersection of these fractures by fractures that dip only 10° to 15° southeast. These less inclined fractures pass uninterrupted through both the dikes and metaquartzite, and small thrust faults are formed by some of these fractures that have offset the dikes as much as a foot to the northwest.

Lithology and Petrography

The biotite diorite is medium dark gray (N4) or dark greenish-gray (5 GY 4/1) in color on the fresh surface and has a medium-grained hypidiomorphic-granular texture. It weathers to a pale or moderate reddish-brown color (10 R 4/4-4/6). Plagioclase feldspar, biotite, and epidote are easily seen in hand specimens. Although the rock contains quartz, it is usually so fine-grained that it may be easily overlooked. The plagioclase commonly appears fractured and displays various degrees of epidotization. Epidote veinlets, generally less than one-eighth inch in width, commonly cut the outcrops. The epidote veinlets and epidotized feldspar are less readily weathered than the biotite and generally stand out in relief on outcrop surfaces.

Petrographic examination of four samples from the pluton indicates that it varies in composition from a diorite to a quartz diorite, because the amount of quartz in two of the samples exceeds 10 percent (See Table 2). Biotite is present in sufficient amounts to be regarded as a varietal accessory mineral in naming the rock. Since the amount of quartz present could not be adequately determined in the field, the name biotite diorite is preferred.

The plagioclase feldspar ranges from 1 to 4 mm in length and consists of euhedral to anhedral andesine (An32-An38) that commonly displays albite twinning. Pericline twinning and combined albite and carlsbad twinning is less common. Some of the andesine is zoned. Many of the crystals are bent and fractured, and their borders are commonly corroded and embayed by adjacent quartz, biotite, and epidote minerals. The andesine is commonly altered to epidote, and less commonly sericite, kaolin, and calcite.

Table 2. Modal analyses of samples from the biotite diorite unit.

	6-6	219-225	245-241	244-240
Andesine	52.3	54.5	51.1	47.5
Biotite	26.8	23.0	25.8	28.5
Quartz	8.3	13.0	10.1	6.3
Orthoclase	1.0	0.1	-	-
Hornblende	1.0	-	-	2.5
Sphene	0.1	-	-	0.2
Apatite	-	0.1	0.7	-
Zircon	0.1	-	-	0.1
Magnetite	0.9	1.6	1.7	0.5
Epidote	9.5	7.5	6.0	14.3
Calcite	-	0.2	4.6	0.1

Clear, unaltered, anhedral quartz occurs in discrete intergranular grains ranging from 0.25 to 1 mm in diameter, but more commonly in finer granular aggregates. The quartz aggregates are up to 1 mm in diameter. The grains within the aggregates average 0.1 mm in diameter and have straight or sutured contacts with adjacent grains. The smaller quartz grains generally have undulatory extinction.

The biotite is brown in color and commonly occurs in segregated finely lamellar aggregates as much as 6 mm in diameter. Plates within the aggregates average 0.1 mm in diameter. The biotite aggregates commonly corrode the borders of the andesine and fill fractures in this mineral. A small amount of biotite occurs in large discrete plates as much as 2 mm in diameter.

Minor accessory minerals include orthoclase, hornblende, sphene, apatite, zircon, and magnetite. Anhedral orthoclase was identified in only two of the samples. Green hornblende, present in only two of the samples, has largely been eliminated by deuteric alteration, for it occurs only in severely corroded anhedral cores within a few of the biotite aggregates. The sphene occurs as subhedral inclusions in the biotite but more commonly as a narrow rim partly bordering anhedral magnetite grains. Some of the larger biotite plates have euhedral to subhedral inclusions of zircon, and some of the larger quartz grains have inclusions of euhedral apatite. The magnetite is disseminated in the biotite aggregates in anhedral to euhedral grains.

Epidote is the most common alteration mineral. Colorless or yellowish-green in color and only slightly pleochroic, it occurs in euhedral to anhedral grains within the biotite and quartz aggregates or as inclusions in the feldspar. It is commonly concentrated near the outer edges or along twin lamellae in the andesine, and the long dimension of crystals are frequently oriented parallel to the twinning. Calcite partly replaces the feldspar minerals, but more commonly occurs as discrete anhedral grains associated with the quartz aggregates. The occurrence of both the epidote and calcite suggests hydrothermal alteration.

Diorite Porphyry Unit

Field Relationship

The diorite porphyry underlies the prominent east ridge dominated by Strawberry Butte. The exposed part of the pluton trends approximately N. 30° E. and occupies an area about one and a half miles in length and about three-fourths of a mile in width. The pluton extends an unknown distance north of the area investigated. The diorite porphyry is very resistant to erosion and forms the very steep slopes and cliffs bounding Strawberry Butte.

The pluton has a discordant intrusive relationship with the originally intruded rocks of the metasedimentary unit that borders the pluton to the southeast. The contact with this unit is not exposed. The pluton's northeast trend parallels the strike of the schistosity developed in the metasedimentary unit. The contact of the western part of the pluton with the basalt unit is also not exposed, but an unconformable relationship with these west-dipping basalt flows is indicated, for the latter have not experienced metamorphism.

The diorite porphyry is generally not foliated, but there are a few isolated outcrops on the crest of the ridge and in Cowden Canyon that have a foliated structure. The foliation ranges in strike from 5° to 40° northeast and ranges in dip from 50° to 80° southeast. The foliated rocks appear as indistinct northeast-trending zones ranging from 25 to 50 feet in width and as much as 200 feet in length. Their actual extent could not be determined, however, because of precipitous cliffs. Epidote is commonly concentrated in these zones, and thin section examination reveals that the feldspar is commonly fractured and has experienced considerable sericitization. Lenticular aggregates of sericite and biotite produce the foliation. These foliated zones are interpreted as possible fracture zones that acted as channelways for hydrothermal solutions.

Unoriented, rounded inclusions sporadically occur throughout the intrusive body. They have a composition similar to the enclosing diorite, but owe their much darker color to an abundance of biotite. They range in size from 0.5 inch to 2 feet in diameter and have sharp contacts with the enclosing rock. They are easily eroded and commonly leave rounded cavities in the outcrops marking their former location. It was not determined if the inclusions represent autoliths from early segregations or cognate xenoliths formed as an earlier part of a multiple intrusion.

Blocky jointing, formed by the intersection of nearly right angle joint planes, is common in the unit. The joints are spaced from 4 to 10 feet apart and are regarded as tension joints, for the walls of the blocks are generally separated 1 to 2 inches where they have not been obviously widened by weathering. The jointing appears to be dominated by a steeply dipping northeast-trending joint system that parallels the long direction of the pluton. These joints range in dip from 60° to 85° toward either the southeast or northwest and impart a linear appearance to the outcrops.

Lithology and Petrography

The diorite porphyry is greenish-gray in color (5 GY 6/1) on the fresh surface and weathers to a moderate reddish-brown color (10 R 4/6). The phenocrysts are composed of very light gray or light greenish-gray epidotized plagioclase feldspar with euhedral to anhedral crystal outlines. They range from 2 to 6 mm in length and range in amount from 15 to 35 percent. The average grain size of the groundmass is about 1 mm, and the only minerals megascopically discernible are plagioclase feldspar, biotite, epidote, and quartz. Epidote commonly fills minute fractures in the rock that generally are only 1 to 2 mm in width.

Petrographic examination was made of two representative samples collected from the pluton, whose modal analyses are listed in Table 3. The samples contain less than 10 percent quartz and no potash feldspar was identified in either sample. The groundmass of both samples has xenomorphic-granular texture.

Table 3. Modal analyses of samples from the diorite porphyry unit.

	216-221	37-31
Andesine	76.6	70.2
Quartz	6.0	8.9
Biotite	10.4	16.8
Magnetite	1.0	1.3
Hornblende	-	0.3
Sphene	-	0.2
Epidote	6.0	2.2
Calcite	-	0.1

The andesine phenocrysts are very corroded, and they are highly altered to epidote, sericite, kaolin, and less commonly calcite. They commonly display albite twinning and less commonly combined albite and carlsbad twinning. The twin lamallae are indistinct, because of the extensive alteration. The andesine in the groundmass is anhedral and is also highly altered.

Biotite is the most common accessory mineral, but, unlike that of the biotite diorite unit, it is commonly green in color. It occurs in segregated finely lamellar aggregates and as minute discrete plates in the groundmass. It commonly corrodes the borders of the andesine. The biotite has inclusions of euhedral to anhedral magnetite and euhedral to anhedral, light yellowish-green epidote. Green hornblende was identified in only one of the slides and occurred only as very corroded cores in some of the biotite aggregates. The magnetite inclusions in the biotite are commonly bordered by a narrow rim of anhedral sphene.

Clear anhedral quartz occurs in the groundmass in discrete intergranular grains or in granular aggregates. The quartz also fills microscopic fractures in the thin sections. It commonly has an undulatory extinction and sutured contacts with adjacent minerals.

Undifferentiated Dikes

Porphyritic Andesite Dikes

The biotite diorite unit has been intruded by numerous undifferentiated porphyritic andesite dikes ranging from 6 inches to as much as 8 feet in width. Most however, are only 2 to 3 feet in width. None of the dikes could be traced far enough to be adequately shown on the geologic map. Except for two, or possibly three that cut the metasedimentary unit near the base of the mountains in sec. 6, T. 47 N., R. 30 E., the dikes are confined to the biotite diorite unit. Because the dikes are poorly exposed where they have intruded the metasedimentary unit, the actual number of dikes involved was not determined. Much larger dikes with similar composition, but differing attitudes, were also observed to intrude the metasedimentary unit immediately north of the area investigated.

All of the dikes noted range in strike from 25° to 45° northeast and range in dip from 35° to 75° southeast. Those dikes that intrude the biotite diorite have even and sharp contacts, but their contacts with the metasedimentary unit are not exposed. Because these dikes commonly parallel the dominant northeast-striking and southeast-dipping joint system developed in the pluton, it seems possible that their emplacement may have been controlled by this fracture system.

The porphyritic andesite dikes are dark greenish-gray (5 GY 3/1) or greenish-black (5 GY 2/1) in color on the fresh surface and weather to a pale or moderate reddish-brown color (10 R 4/4-4/6). Outcrops are commonly cut by minute epidote veinlets. Light green epidote or epidotized plagioclase feldspar phenocrysts, ranging from 0.1 to 1 cm in diameter, are set in an aphanitic groundmass. The phenocrysts make up 5 to 10 percent of the rock. The estimated mineral mode, determined by thin section examination of a single sample (6-5), consists of 66% andesine, 23% biotite, 9% epidote, 1% quartz, and 1% iron oxide. Those phenocrysts not completely altered to epidote contain cores of albite twinned andesine (An34). The groundmass has an average grain size of 0.25 mm and is composed of corroded andesine laths with indistinct albite twinning, brown fibro-lamellar biotite, euhedral to anhedral epidote, anhedral quartz filling fractures, and subhedral to anhedral iron oxide. Besides being altered to epidote, the andesine is also partly altered to kaolin and sericite. The biotite is only slightly altered to chlorite. The epidote, and the quartz as well, was most likely introduced by hydrothermal solutions.

Aplite Dikes

Small aplite dikes with various attitudes locally cut both the biotite diorite and the intruding porphyritic andesite dikes with sharp contacts, ranging from 0.25 to 6 inches in width. They range in strike from 20°NW. to 70°NE. and dip 15° to 70° toward either the northwest or southeast. The larger dikes are usually tabular in shape, but the smaller dikes commonly bifurcate and are very irregular in shape.

The aplite dikes are light gray in color (N7-N8) and are commonly stained a pale reddish-brown (10 R 5/4) from the weathered enclosing rock. Thin section examination of a representative sample (245-242B) reveals a fine xenomorphic-granular texture with an average grain size of 0.75 mm. The grain size ranges from 0.5 to 1 mm. The estimated mineral mode consists of 63% potash feldspar, 29% quartz, 5% biotite, 2% oligoclase, and less than 1% epidote, zircon, and magnetite combined. The potash feldspar is anhedral microcline. The quartz occurs in clear anhedral grains that show undulatory extinction. The biotite, which contains inclusions of euhedral zircon with pleochroic halos, is brown in color and occurs in lamellar aggregates. The magnetite is associated with the biotite in euhedral to anhedral grains. The oligoclase (An14) is anhedral and displays albite twinning. The epidote is light yellowish-green in color and occurs in subhedral to anhedral grains associated with the biotite. The biotite is only partly altered to chlorite and the feldspar minerals are only slightly altered to kaolin and calcite.

Age of Pre-Tertiary Intrusive Igneous Rocks

The age of the pre-Tertiary intrusive rocks cannot be closely determined. The relative difference in age, if any, between the biotite diorite unit and the diorite porphyry unit is unknown. The intrusive rocks may be as old as Jurassic in age, because they intrude the metasedimentary unit of possible Permo-Triassic age. They are unconformably overlain by the basalt unit of possible middle Miocene age and could be as young as early Tertiary. A potassium-argon age of 96 m.y. obtained by J. G. Smith (cited in Bryant, 1969) on the youngest pluton in the Pine Forest Mountains suggests that the intrusive igneous rocks in the area investigated are no younger than Late Cretaceous in age. In view of the possible ages of the intrusive

Figure 2. Northeasterly view from the west ridge showing the massive diorite porphyry cropping out on Strawberry Butte. The diorite has a discordant intrusive relationship with the lighter-colored southeast-dipping metamorphic rocks. The biotite diorite intruding the metamorphic rocks crops out on the ridge to the right. The intervening valley and foreground is underlain by west-dipping basalt flows.

igneous rocks, they are arbitrarily assigned a Jurassic-Cretaceous age.

Late Tertiary Volcanic and Sedimentary Rocks

Basalt Unit

The basalt unit of this report consists of the basalt flows and minor interbedded tuffs that Merriam (1910) suggested were a division of his Pueblo Range Series.

Field Relationship

The basalt unit extends into the area from the north and underlies most of the west ridge of the mountains. It is best exposed in the southeast-facing escarpment bounding the southern end of the ridge where usually only the more massive, less easily eroded, basalt flows crop out in a series of step-like benches. Exposures are relatively poor on the gentler west slopes of the ridge where the unit is mostly covered by regolith.

The unit overlies the northeast-trending metasedimentary, diorite porphyry, and biotite diorite units. Although the contact with these underlying metamorphic and intrusive igneous is not exposed, an angular unconformable relationship is indicated by the generally north-striking and west-dipping attitude of the lava flows. The unaltered character of the basalts indicates that they have not been intruded by the diorite plutons and are much younger than these rocks.

The unit is unconformably overlain by both the rhyolite and the sedimentary-pyroclastic units. The rhyolite unit evidently has a disconformable relationship with the uppermost ash flow tuff member of the basalt unit, for the member shows evidence of having been eroded. The contact with the overlying sedimentary-pyroclastic unit is not exposed, but a dominance of basalt clasts in conglomerates adjacent to the contact and its somewhat irregular trace suggests a disconformable relationship between these two units. A slight angular discordance is suggested along at least part of the contact in the E 1/2 sec. 3, T. 46 N., R. 28 E. where ash flow tuffs occurring in the upper part of the basalt unit are truncated along their strike to the northwest by the overlying sedimentary-pyroclastic unit.

Section measurement in the N 1/2 secs. 1, 2, and 3, T. 46 N., R. 28 E. indicates that the basalt unit is at least 2,863 feet thick (See Appendix, Section 1). The unit increases in thickness to the north, and it is estimated to be about 3,200 feet thick in the northern part of the area investigated.

The unit consists predominately of numerous parallel basalt flows ranging from 5 to 95 feet in thickness. The average thickness of the flows is about 24 feet. The lower 2,078 feet consists entirely of lava flows, but the upper 785 feet includes minor interbedded ash flow and ash fall tuffs, cinder beds, and volcanic sandstone (See Appendix).

Five interbedded ash flow tuff beds that range from 3 to 19 feet in thickness are exposed in the escarpment that bounds the southeast side of the west ridge (See Appendix, Section 2). One of these tuff beds is unwelded, but the others display various degrees of welding. Three welded tuff beds that are only 4 to 5 feet thick locally crop out on the steeper front slopes of the west ridge in sec. 2, T. 47 N., R. 28 E., and in secs. 26 and 35, T. 47., R. 28 E. (See Appendix, Section 1). Three ash flow tuff beds that range from 12 to 30 feet in thickness locally crop out on the gentler back slopes of the west ridge in the W 1/2 secs. 2 and 11, T. 46 N., R. 28 E., and each of these tuff beds have welded and unwelded zones. Because of different stratigraphic positions and discontinuous exposures, none of the ash flow tuff beds cropping out north of the escarpment can be correlated with those ash flow tuff beds occurring in the escarpment. An ash fall tuff bed, two cinder beds, and a bed of volcanic sandstone that are interbedded with the basalt flows are also exposed in the escarpment.

A lack of flow breccia and sharp undulating or crenulated contacts suggests that most of the basalts are pahoehoe lava flows. Flow wrinkles are locally exposed on the upper surface of some of the flows, and flow wrinkle casts are locally preserved on the under-surface of flows where they form small overhanging cliffs. None of these upper surface features are well enough exposed to be used in determining possible flow directions. A few of the basalts are as lava flows whose upper and lower zones of flow breccia are composed of angular scoriaceous blocks as large as 10 inches in diameter. The flow breccia at the top of these basalts is always much thicker than any flow breccia occurring at their base.

Most of the basalt flows have very vesicular chilled margins, but many flows are so vesicular throughout that no massive or less vesicular central zone may be apparent. The lower vesicular zone is usually much thinner than the upper vesicular zone and rarely exceeds 6 inches in thickness. The thicker upper vesicular zone is usually no more than 1 to 2 feet in thickness. The vesicles in these chilled margins are generally ovoid in shape and less than one-fourth inch in diameter. Scattered vesicles in the more massive central parts of the flows, mostly ovoid in shape, range up to 3 cm in diameter. Elongate vesicles somewhat flattened parallel to the top and bottom of flows are rare.

Many of the more vesicular basalt flows are amygdaloidal. The amygdules are ovoid to irregular in shape and range from 0.2 to 3 cm in diameter. The mineral filling may consist entirely of calcite, stilbite, or natrolite, but commonly there is a combination of these minerals. In amygdules containing both zeolite minerals and calcite, the calcite appears to have formed later than the zeolite minerals, for it generally occupies a central core within the amygdules. The amygdules in a few of the basalts are more or less concentrated into zones 1 to 3 feet in thickness, which parallel the top and bottom of the flows. Pipe amygdules and amygdule cylinders, attributed to the upward streaming of gases, commonly arise from the base of many of the flows. The pipe amygdules are somewhat cone shaped and generally taper upward. They range from 0.5 to 6 inches in length and from 0.125 to 0.5 inch in diameter. Many of the larger pipe amygdules bifurcate with their branches pointing toward the base of the flow. Bent pipe amygdules trending S. 60° W. were noted at the base of a flow located in the NE 1/4 NE 1/2 sec. 2, T. 46 N., R. 28 E. No bent or inclined pipe amygdules were noted in any of the other flows; therefore this isolated occurrence cannot be considered indicative of flow direction for the basalt unit as a whole. Amygdules are commonly concentrated into cylindrical zones 1 to 5 inches in diameter and 2 to 4 feet in length. These amygdule cylinders are spaced 1 to 5 feet apart and rise vertically from the base of the flows.

Many of the thicker flows have a poorly developed columnar jointing oriented perpendicular to their top and bottom surfaces. The columns are four to six sided and range from 2 to 6 feet in width. Cross joints intersecting the columns form stubby polygonal blocks that commonly form large sub-rounded residual boulders on the eroded and weathered surface of the flows.

Figure 3. Northerly view from near the top of the west ridge showing the underlying west-dipping lava flows of the basalt unit.

The basalts were observed to be intruded by a single small diabase dike traced for a distance of 300 feet in sec. 2, T. 46 N., R. 28 E. that strikes N. 85° W. and dips 88° NE. The dike, whose width is 8 feet, has a sharp even contact with the enclosing rock. It is less easily eroded than the intruded vesicular basalt flows, and it stands out in relief 4 to 5 feet above the surface of the ground. It was not determined if the dike is a feeder dike, for overlying flows have been eroded away. Columnar jointing, resembling stacked cord wood, is developed perpendicular to the walls of the dike. The columns are four to six sided and range from 4 to 8 inches in width and from 1 to 2 feet in length.

Lithology and Petrography

The basalt flows as well as their interbedded subunits are megascopically described in the Appendix. Petrographic examination was made of four samples of basalt, and the modal analysis of each of these samples is listed in Table 4.

Samples A101 and B13 are from megascopically dense, aphanitic basalt flows. They are holocrystalline and have an intergranular to subophitic texture, whose grain size ranges from 0.25 to 1.5 mm. The average grain size is 0.75 mm. The labradorite (An57-An65) is unaltered and occurs in euhedral to subhedral laths displaying albite twinning. The augite is also unaltered and is a pale purplish-brown titaniferous variety. It is weakly pleochroic and occurs in subhedral to anhedral intergranular crystals that partly enclose smaller laths of labradorite. Colorless or pale green, anhedral olivine is irregularly fractured and partly altered to iddingsite. The iron oxide is partly altered to hematite and includes both magnetite and ilmenite. It occurs in euhedral to anhedral intergranular crystals or as inclusions within both the labradorite and augite. Sample B13 differs from sample A101 only in having a larger amount of olivine, a lesser amount of iron oxide, and a minor amount of radiating fibrous zeolite that fills cavities.

Table 4. Modal analyses of basalt samples from the basalt unit.

	A101	B13	A98	A102
Labradorite	77.0	81.0	73.0	79.0
Augite	15.0	10.0	10.0	10.0
Olivine	1.0	6.0	1.0	2.0
Iron Oxide*	7.0	2.0	16.0	8.0
Zeolite	-	1.0	-	-
Nontronite	-	-	-	1.0

* Includes both magnetite and ilmenite

Sample A98 is from a megascopically dense aphanitic basalt flow, but petrographic examination reveals a microporphyritic texture. The plagioclase is so dark in color in the hand specimen that it is practically indistinguishable from the augite. Phenocrysts make up

20 percent of the sample and range from 0.5 to 1 mm in size. Most of the phenocrysts consist of euhedral to subhedral, corroded and partly fractured labradorite (An60) displaying albite twinning. Only a few of the phenocrysts consist of anhedral colorless olivine that is partly altered to iddingsite. The phenocrysts are set in a holocrystalline groundmass with a pilotaxitic texture. The minerals making up the groundmass are less than 0.05 mm in size and consist of microlites of pale green augite, laths of labradorite (An57), and disseminated grains of magnetite.

Sample A102 is a sample of a vesicular porphyritic basalt containing plagioclase phenocrysts as much as 2 cm in length. The phenocrysts are composed of labradorite (An60) and are set in a holocrystalline groundmass with an average grain size of 0.75 mm. The groundmass has an intergranular texture and consists of euhedral to subhedral laths of labradorite (An57), subhedral to anhedral augite, anhedral olivine, and disseminated iron oxide minerals. The augite is pale purplish-brown in color and weakly pleochroic. The olivine is colorless or pale green in color and largely altered to iddingstie. The iron oxide minerals consist of euhedral to anhedral magnetite and ilmenite. The vesicles are partly filled with a minor amount of yellowish-brown nontronite.

The diabase dike that intrudes the basalt unit is dark gray (N3) in color on the fresh surface and weathers to a moderate reddish-brown color (10 R 4/6). Megascopically, it has an aphanitic texture and a submetallic luster. Petrographic examination of a representative sample (154-158B) reveals a subophitic texture with an average grain size of 0.25 mm. The estimated mineral mode is 65% labradorite, 26% augite, 6% iron oxide, and 3% olivine. The labradorite (An60) occurs in euhedral to anhedral laths and is partly altered to kaolin. The augite is a pale purplish-brown titaniferous variety that is only slightly pleochroic. It partly envelopes some of the feldspar laths and is partly interstitial between them. Interstitial grains of euhedral to anhedral olivine are partly altered to chlorite along their outer margins. Finely disseminated iron oxide consists of both magnetite and ilmenite.

All of the interbedded ash flow tuffs in the basalt unit are vitric tuffs that generally contain small amounts of crystals and volcanic lithic constituents. The vitric material in each of these tuff beds consists mainly of pumice fragments rather than glass shards. Only one of these tuff beds is unwelded and is distinguished from an ash fall type deposit by its poor sorting and unstratified internal structure (See Appendix, Section 2). All the welded tuff beds appear to be simple cooling units, but they generally lack any upper partially welded or unwelded zones. The lack of these expected zones and the occurrence of baked soil zones at the top of most of these welded tuff beds indicates that they had experienced erosion prior to the eruption of overlying basalt flows. A vitrophyre that represents the densely welded zone generally caps each of these welded tuff beds. These vitrophyres are probably the obsidian sills that Fuller (1931) mentions as having intruded the basalt flows.

Petrographic examination was made of three samples of ash flow tuff. The modal analysis of each of these samples is listed in Table 5. Sample 175-170 is from a vitrophyre at the top of the uppermost ash flow tuff bed that underlies the rhyolite unit (See Appendix; Section 2, interval 654-645). Sample 188-181 is from the partially welded zone of a thick ash flow tuff bed exposed in the escarpment that bounds the southeast side of the west ridge of the mountains (See Appendix; Section 2, interval 606-620). Sample A6C is from a thick unwelded ash flow tuff bed that is also exposed in this escarpment (See Appendix; Section 2, interval 586-605). The minerals in these samples do not indicate the composition of the tuff, because the samples each contain a substantial amount of vitric material. The refractive indices of the vitric material are 1.511 ± 0.001 (sample 188-181), 1.507 ± 0.001 (sample 175-170), and 1.499 ± 0.001 (sample A6C). These refractive indices suggest silica contents of 67, 68, and 72 percent, respectively (George, 1924), and they are within ranges of indices recorded for glasses of dacitic (samples 188-181 and 175-170) to rhyolitic (sample A6C) composition (Grout, 1932).

Table 5. Modal analyses of samples of interbedded ash flow tuff in the basalt unit.

	A6C	188-181	175-170
Crystals			
Andesine	8.0 (An35)	14.0 (An36)	15.0 (An46)
Sanidine	-	3.5	3.0
Augite	0.1	0.3	2.0
Hypersthene	-	1.0	0.5
Biotite	0.3	0.4	0.8
Magnetite	-	1.0	1.0
Volcanic lithic grains	0.4	3.0	0.5
Matrix			
Vitric	91.0	75.8	76.6
Magnetite	0.2	1.0	0.6

Microscopically, the densely (175-170) and the partially (188-181) welded samples have similar mineralogy but different structure. Both samples contain anhedral to euhedral crystal fragments or phenocrysts of andesine, sanidine, hypersthene, augite, biotite, and magnetite. The phenocrysts in the densely welded sample range in size from 0.5 to 1 mm, and they are set in a colorless to light brown, partly devitrified glass that has a perlitic structure. The glass has poorly preserved pumice tube structures. The crystals in the partially welded sample range in size from 0.5 to 2 mm, and they are set in a partly devitrified matrix that has well-preserved pumice tube structures. The matrix of this sample also contains small lenses of light brown glass similar to glass in the densely welded sample. The andesine in both samples is unaltered and displays albite twinning. The andesine is commonly embayed by the vitric matrix and contains small irregular patches of light brown glass. The vitric matrix of these samples also contains fine disseminated grains of anhedral to euhedral magnetite. Alteration of the magnetite to hematite in the partially welded sample imparts a red color to the vitric material. The lithic grains in both samples range from 0.5 to 2 mm in diameter and consist of sub-rounded volcanic rocks with pilotaxitic textures of plagioclase microlites and anhedral grains of iron oxide with interstitial cryptocrystalline material.

The sample from the unwelded tuff (A6C) is composed mainly of angular pumice fragments with only a few scattered angular glass shards. The pumice fragments range from 0.125 to 0.25 mm in diameter, but they range up to 3 cm in diameter in the hand specimen. The pumice is partly devitrified and contains finely disseminated anhedral to euhedral magnetite. The magnetite is partly altered to hematite and imparts a pinkish color to the pumice as seen in outcrops. The crystals range from 0.25 to 2 mm in size and consist mostly of euhedral to anhedral, unaltered andesine that is commonly fractured and corroded. A minor amount of reddish-brown biotite in pseudohexagonal plates and green anhedral augite also occurs as crystals.

Rounded volcanic lithic grains range from 1 to 2 mm in diameter.

Origin

The lava flows making up the basalt unit are believed to have been erupted from fissures, for there is no evidence of central vent type eruptions. Although only one small possible feeder dike occurs in the area investigated, several large basalt dikes cut the lava flows immediately north of the area investigated. Except for a few flows of aa lava, the structure of most of the flows suggests that they were very hot, fluid, gas charged pahoehoe lavas, which generally spread out into relatively thin flows when erupted.

The minor interbedded ash flow tuff beds in the upper part of the unit are attributed to nuées ardentes type eruptions that were hot enough for most of these tuffs to become welded. The development of baked soil zones and incomplete zonation of what are believed to be simple cooling units are indicative of erosion of the welded tuff beds.

Correlation and Age

The basalts of the Pueblo Mountains have been lithologically correlated by Fuller (1931), Baldwin (1964), and Walker and Repenning (1965) with the thick series of parallel, commonly porphyritic, basalt flows of the Steens Basalt of Oregon. According to Fuller (1931) and Baldwin (1964), the Steens Basalt can be traced the full length of the

Steens and Pueblo Mountains.

Fuller (1931) assigned the Steens Basalt a late Miocene to possibly early Pliocene age, an assignment based on fossil flora collected from underlying tuff beds at Alvord Creek, Oregon. Wallace (1946) considered the basalts to be late Miocene in age, a dating based on vertebrate fossils found in tuff beds overlying the basalts near Beatys Butte, Oregon. A fossil flora from the underlying Alvord Creek Formation were considered by Axelrod (1957) to be lower Pliocene or younger in age, but a similar or younger age for the overlying Steens Basalt has been discounted by Baldwin (1964). Absolute age determinations by the potassium-argon method range from 14.5 to 15 m.y. for samples collected from near the top of the Steens Basalt (Evernden, et al., cited in Baldwin, 1964) and suggest a middle to late Miocene age.

In view of the foregoing discussion of the age of the Steens Basalt, the oldest possible age of the basalt unit is middle Miocene. The youngest possible assigned age, however, is based on the correlation and dating of overlying units. Merriam (1910) correlated the overlying rhyolite unit of this report with the Canyon Rhyolite, which in turn is overlain by the Virgin Valley Formation that contains middle Miocene vertebrate fossils. Fuller (1931), however, considered the Virgin Valley Formation to correlate in age with the Alvord Creek Formation that underlies the Steens Basalt. The writer of this report agrees with Merriam's (1910) correlation, for regional structural interpretation based on Willden's (1961) reconnaissance map of Humboldt County suggests that, owing to block faulting, the basalt flows of the Pueblo and Pine Forest Mountains probably physically underlie the Canyon Rhyolite but are not exposed because of insufficient uplift along normal faults west of these mountains. This conclusion is supported by the finding of W. Wendell,[1] who reports that basalt flows with interbedded tuffs and sedimentary beds resembling the upper part of the basalt unit of this report underlie the Canyon Rhyolite on the east side of McGee Mountain adjacent to Bog Hot Valley. The youngest possible age of the basalt unit is therefore believed to be middle Miocene.

Rhyolite Unit

The rhyolite in the Pueblo Mountains was first mentioned by Blake (1875) and later by Merriam (1910), who considered it as part of his Pueblo Mountain Series. The rhyolite was not differentiated by Willden (1961, 1964), who included it in his rhyolitic and dacitic volcanic rocks (Trd).

Field Relationship

The southern half of the west ridge of the mountains is underlain by rhyolite, which crops out in a nearly continuous narrow band on the

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[1] Oral communication, 1969.

gentler west slopes and forms the rim rock of the prominent escarpment bounding the southeast side of the mountains. Rhyolite also caps the downthrown blocks of the faults in secs. 11 and 14, T. 46 N., R. 28 E. The unit is very resistant to erosion and the sharp crest of the west ridge is formed on its eroded upturned edge. Although very resistant to erosion and generally free from vegetation, it is commonly covered on the west slopes of the ridge by a thin veneer of rock debris. The rhyolite is best exposed along the escarpment, but the steepness of its slopes usually makes the unit inaccessible for close inspection. Investigation was mainly confined to less satisfactory exposures at lower elevations along the escarpment and in canyons draining the west side of the ridge. The unit is partially buried by gravel deposits near its southern end, but rhyolite underlies a small, isolated knoll forming the southern most end of the Pueblo Mountains.

As previously discussed in the description of the underlying unit, the rhyolite has a disconformable relationship with the uppermost tuff member of the basalt unit. This unconformable relationship can be observed in the escarpment, but the tuff member is unconformably overlain by intervening basalts north of the rhyolite unit. Although talus largely conceals the lower contact in the escarpment, the contact appears to be roughly parallel with the underlying tuff bed, for little or no appreciable relief has been developed along the erosion surface. The trace of the lower contact along the escarpment is generally marked in the topography by a change from steep to nearly vertical cliffs. To the north however, the trace of the contact is marked only by a thin flow breccia, which has been almost completely stripped by erosion from the west slopes of the ridge.

The rhyolite unit is disconformably overlain by the sedimentary-pyroclastic unit. Adjacent overlying sedimentary rocks contain rhyolite clasts believed to have been derived by erosion of the unit, and the sedimentary rocks appear to have filled in irregularities or valley-like depressions developed on its upper surface. The contact with the overlying unit is not exposed, but it is easily traced in the field because of the very light gray pumiceous regolith developed on the overlying unit.

The rhyolite unit is estimated to range from 300 to 400 feet in thickness. The rhyolite forming the rim rock along the escarpment is estimated to be at least 200 feet thick and appears to consist of a single flow largely composed of flow breccia. Much of the rhyolite exposed on the back slope of the west ridge displays flow structure, and minor topographic breaks suggest one or more additional flows of undetermined thickness and extent.

The flow structure is represented by alternating color bands ranging from 0.5 to 5 mm in thickness and from 2 inches to 2 feet in length. The color bands commonly overlap one another. The flow structure is gently undulating. Folded or highly contorted flow structure was noted only in blocks occurring within flow breccia. Even where the flow banding is well developed, the rhyolite generally contains small scattered breccia fragments 1 to 2 mm in size. Platy fracture is commonly developed parallel to the flow structure. The plates are either straight or gently curved and range from 0. 25 to 4 inches in thickness and from 1 to 12 inches in length. At those few localities in the field where the attitude of the flow structure could be measured it dips to the southwest, but not necessarily at the same inclination as the rhyolite unit itself. This difference in attitude is probably due to individual flows conforming to the irregular surface of underlying flows, especially that of the flow breccia that composes much of the lower part of the unit.

The lower three to four feet of the rhyolite that forms the rim rock along the northern half of the escarpment consists of vesicular flow breccia composed of angular blocks less than 1 inch to as much as 8 inches across. This basal flow breccia grades upward into a zone 50 to 95 feet thick that displays poorly developed flow banding oriented subparallel to the base of the flow. Above this zone the rhyolite grades into a breccia, and the remainder of the rim rock appears to consist only of flow breccia composed of angular blocks as much as 5 feet across set in a dense felsic matrix. The upper flow breccia is generally all that is exposed along the southern half of the escarpment. Widely spaced vertical jointing formed in the breccia somewhat resembles the columnar jointing of basalt flows, but it does not appear to have a polygonal pattern. Much of the vertical jointing appears to be spaced at 30 to 40 foot intervals. The top of the rhyolite that forms the rim rock is very vesicular and has a reddened oxidized appearance. The vesicles at the top and bottom of this flow are ovoid or slightly elongate in shape and mostly are less than 1 cm in diameter. Small scattered vesicles elsewhere in the rhyolite are commonly ovoid in shape and are generally less than 1 mm in diameter. No flow direction could be determined from any of the elongate vesicles or the flow banding.

Lithology and Petrography

The rhyolite is very hard and tough and rings when struck with a hammer. Except for the flow banding and a few scattered phenocrysts, the rhyolite is megascopically dense. The flow banding consists of alternating color bands of pale red purple and grayish-red purple hues (5 RP 4/2-8/2). The flow breccia consists of grayish-red purple (5 RP 4/2-5/2) angular fragments and blocks set in a pale red purple (5 RP 6/2-7/2) or very light-gray (N8) matrix. The fragments and blocks commonly display flow banding, but flow banding in the matrix can usually be detected only with the aid of a hand lens. Less commonly the matrix is so finely vesicular that it has a frothy appearance. The phenocrysts make up less than 1 percent of the rock and range from 0.5 to 5 mm in length. They are usually feldspar or, more rarely, quartz. The rhyolite weathers to a moderate reddish-orange (10 R 6/6) and reddish-brown (10 R 4/6) color.

Petrographic examination of two representative samples (51-43; 100-110) reveals that the feldspar phenocrysts are composed of euhedral to anhedral sanidine whose borders are commonly embayed and corroded. No quartz was noted in either of the thin sections examined. The phenocrysts are set in a yellowish-brown, somewhat devitrified, glassy groundmass displaying flow banding and containing very small microlites of feldspar and disseminated iron oxide. The feldspar in the groundmass has an index of refraction less than balsam and may consist of potassic and (or) sodic feldspar. The groundmass also contains a few small cavity fillings of radial chalcedony and tridymite in wedge-shaped twins.

A sample of the rhyolite collected by Fuller (1931) from the flow capping the escarpment was chemically analyzed by W. H. and F. Herdsman (cited in Fuller, 1931). The analysis and norm is listed in Table 6.

Origin

There are no vents or volcanic structures within the area investigated to suggest that the rhyolite was locally derived. Unfortunately, no structures were noted which suggest a direction of movement. The only rhyolite of comparable stratigraphic occurrence in the general vicinity is the Canyon Rhyolite cropping out on the west side of Bog Hot Valley. The flow banding and thick flow breccia indicates a very viscous lava that certainly did not flow as much as 12 miles from the west or southwest. The source area is believed to be from the west, however, possibly from a vent or vents now underlying Bog Hot Valley.

Table 6. Chemical analysis and normative minerals of a sample from the rhyolite unit (modified after Fuller, 1931).

Analysis	Wt. %	CIPW norm	Wt. %
SiO_2	73.80	quartz	30.06
TiO_2	0.12	orthoclase	31.14
Al_2O_3	12.45	albite	31.44
Fe_2O_3	1.53	anorthite	1.67
FeO	0.93	diopside	2.26
MgO	0.28	wollastonite	0.12
CaO	0.96	magnetite	2.09
Na_2O	3.72	ilmenite	0.15
K_2O	5.35	water	0.70
H_2O	0.70		99.63
MnO_2	T		
P_2O_5	T		
S	T		
CO_2	none		
	99.84		

Correlation and Age

Merriam (1910) suggested that the rhyolite exposed in the Pueblo Mountains correlates with the Canyon Rhyolite. Fuller (1931) discounted such a correlation, for he considered the overlying Virgin Valley Formation to be equivalent in time with the Alvord Creek Formation that underlies the Steens Basalt. Since the supposedly younger basalts of the Pueblo Mountains do not crop out west of Bog Hot Valley, he viewed the Canyon Rhyolite as a barrier that kept the overlying Virgin Valley Formation from being flooded. The close proximity of the two rhyolites suggests that Merriam's (1910) correlation is correct and that the reason the basalts do not crop out west of Bog Hot Valley is because they are older and physically underlie the Canyon Rhyolite. Regional structural interpretation suggests that displacement along boundary faults has not been great enough to expose the underlying basalts as they have been in both the Pueblo and Pine Forest Mountains.

In view of the foregoing stratigraphic considerations, the rhyolite unit is assigned a middle Miocene age, for the Canyon Rhyolite is overlain by the Virgin Valley Formation containing middle Miocene vertebrate fossils (Merriam, 1910).

Figure 4. Northern part of the prominent fault scarp that bounds the southeast side of the mountains as viewed from Pueblo Valley. Continental Lake is in the foreground. The basalt unit with light-colored interbedded tuffs underlies most of the escarpment, and the rhyolite unit forms the resistant cap rock. Note the repetition of strata on the downthrown fault blocks that form the sharp ridges on the right.

Sedimentary-Pyroclastic Unit

Interbedded rhyolitic or trachytic flows, tuffs, and sedimentary deposits overlying the thick sequence of lava flows in the Pueblo Mountains were mentioned by both Blake (1875) and Merriam (1910). The rhyolitic and trachytic flows mentioned by these investigators are undoubtedly the welded tuffs of this report. Willden (1964) included these rocks in his rhyolitic and dacitic volcanic unit (Trd).

Field Relationship

The sedimentary-pyroclastic unit underlies the lower north-trending asymmetrical ridges and valleys flanking the west side of the mountains. It extends continuously from the northern boundary of the area investigated southward to the S 1/2 sec. 15, T. 46 N., R. 38 E. South of this locality the unit has been stripped by erosion from the west flanks of the mountains and crops out only in a small isolated area in sec. 27, T. 46 N., R. 28 E.

The unit as a whole is poorly exposed, for it is extensively covered by regolith, and slopes underlain by the unit are commonly slumped. The valleys are underlain by easily eroded sedimentary and pyroclastic strata that only locally crop out. The ridges are underlain by less easily eroded welded tuffs that generally crop out along their crests and back slopes. Because of their topographic expression and more continuous exposure, the welded tuffs can be traced in the field and in this report are differentiated as mappable members of the unit.

The unit overlaps both the rhyolite and basalt units. Although the lower contact is not exposed, erosion prior to deposition is suggested by local irregularities along the contact and the common occurrence of basalt and rhyolite clasts within the unit. Discordant structural attitudes in the central part of the area suggest a slight angular unconformable relationship where the strike of the rhyolite unit and tuff beds in the upper part of the basalt unit appear to be truncated by the overlying sedimentary-pyroclastic unit. The unit underlies the dissected gravel deposits with an obvious angular unconformable relationship. These younger deposits truncate the structure of the unit wherever they are in contact.

The actual thickness of the unit is unknown, for it is unconformably overlain by either the dissected gravel unit or Quaternary alluvium. The unit has a maximum thickness of 1,200 to 1,300 feet in the northern part of the area investigated. The maximum thickness of individual welded tuff members ranges from 20 to 80 feet. They are usually separated from one another by 70 to 150 feet of interbedded sedimentary strata. Strata occurring below the oldest welded tuff member ranges from about 500 feet in thickness in the northern part of the area to as little as 150 feet in thickness near the southern end of the mountains.

Lithology and Petrography

The unit consists of interbedded volcanic conglomerates, sandstones, silty mudstones, pumice flows, and vitric welded tuffs. Five welded tuff members are differentiated as members A1, A2, B, C, and D, in ascending stratigraphic position. The designation A1 and A2 are necessary, for these members appear to converge in the northern part of the area and because of poor exposure could not be separated from one another in the field.

Interbedded, very light gray (N8), poorly to moderately indurated, silty volcanic mudstones are variously exposed, but appear to be more concentrated in the lower part of the unit. Individual beds range from 1 inch to as much as 6 feet in thickness. The thicker mudstones are generally evenly bedded, but the thinner beds are lenticular. The contacts with adjacent sandstones or conglomerates are either sharp or gradational. The weathered and fresh surface are similar in color, and the only constituents megascopically discernable are plates of biotite and fragments of carbonized wood. Petrographic examination of a representative sample reveals that they are composed essentially of clay and silt size, partly devitrified, vitric constituents derived from pumice and shards. About 5 percent of the silt size fraction in the sample consists of angular, unaltered feldspar and quartz.

The interbedded sandstones are light to medium light gray in color (N6-N7) and friable. Their weathered surface, like that of the mudstones, is similar in color to the fresh surface. The texture ranges from fine- to very coarse-grained and poorly- to moderately well-sorted. All textural gradations exist both vertically and laterally between sandstones and pebbly sandstone. The sandstones generally occur in even beds from 1 inch to 2 feet in thickness and commonly have a crude laminated internal structure paralleling the contacts. No inclined current laminae were noted. The laminae range from 1 to 8 mm in thickness and are due to difference in either color or grain size among the constituents. Contacts may be sharp or gradational with overlying or underlying sandstone or conglomerate beds. Contacts with overlying conglomerates are generally irregular and display small cut and fill structures. The sandstones are classified as volcanic arenites, for the matrix consists entirely of finely divided vitric material and the framework consists predominately of constituents of volcanic origin. The framework consists mainly of feldspar and volcanic lithic grains, with either predominating in amount. Quartz, pyroxene, iron oxide, and biotite are common minor constituents. Mineral grains are commonly sub-angular to angular and bounded by crystal faces displaying little or no evidence of abrasion. The lithic grains are mostly rounded, less commonly sub-angular, suggesting a much longer abrasion history. Petrographic examination was made of a representative sample (82-76) of the most commonly occurring sandstone type exposed in the unit. The framework consists of 65% feldspar, 29% lithic grains, 2% quartz, 2% iron oxide, 1% augite, and 1% biotite. The matrix makes up 15 percent of the rock and consists of finely divided, partly devitrified, angular pumice fragments with relatively few broken glass shards. The feldspar displays only minor clay alteration and consists of sanidine and plagioclase. The lithic grains have intergranular and pilotaxitic textures suggestive of basalts and andesites.

Poorly indurated, very fine to coarse, pebble conglometerates in lenticular beds that range from 0.5 inch to 1 foot in thickness are commonly interbedded with the sandstones below the oldest welded tuff member. Pebbles included in the regolith overlying the unexposed intervals between these members suggests that conglomerates occur widely throughout the unit. The pebbles are sub-rounded to rounded and have subequent shapes. They consist predominately of dense, medium dark-gray (N4) basalt, although minor amounts of rhyolite and pumice pebbles are also present, with the pumice locally occurring in individual beds forming pumice pebble conglomerates. The pebbles are loosely or tightly packed in a volcanic sandstone matrix. A pebble conglomerate bed exposed for a distance of about 75 feet in the SW 1/4 SE 1/4 sec. 34, T. 47 N., R. 28 E. contains very loosely packed well-rounded cobbles as large as 8 inches in diameter. The cobbles are composed of greenish-gray (5 G 6/1) and moderate orange-pink (10 R 7/4) welded tuff.

A 22 foot thick interbedded unwelded pumice flow about 75 feet above the base of the unit is exposed for about a half mile in the SE 1/4 sec. 34, T. 47 N., R. 28 E. The pumice is mottled moderate orange-pink (5 YR 8/4) and dark yellowish-orange (10 YR 6/6) in color and has a case-hardened surface that is light brown (5 YR 6/4) in color. The pumice is poorly consolidated but has enough cohesion to produce a few small isolated outcrops. It is poorly sorted and consists of angular ash to block size pumice as large as 3 inches in diameter. The pumice is in complete disaray and displays no flattening or orientation. Crystals range from 0.5 to 5 mm in size and are commonly broken. The deposit also contains sub-rounded basalt pebbles as large as 1 inch in size, which make up between one and 15 percent of the rock. The pebbles are more concentrated in the lower three feet of the deposit and appear to have been derived from underlying pebble conglomerate beds. Petrographic examination of a representative sample (82-73) reveals that a minor amount of the ash size vitric material is composed of broken glass shards. The crystals in the sample consist of 6% unaltered anorthoclase and sanidine, 1% brown biotite, 0.5% anhedral quartz, and 5% anhedral to euhedral disseminated magnetite grains less than 0.5 mm in size that are partly altered to hematite. The alteration of the magnetitie is apparently responsible for the mottled pink and orange color of the deposit. The refractive index of the vitric material (1.499 ± 0.001) suggests a silica content of about 72 percent (George, 1924).

A pumice flow deposit 60 to 75 feet thick, which displays incipient welding and occurs 50 to 100 feet below the oldest welded tuff member, crops out intermittently on protected south-facing slopes from the northern boundary of the area investigated southward as far as the SE 1/4 sec. 3, T. 46 N., R. 28 E. The infrequent nearly vertical cliffs formed by the deposit display a crude columnar jointing. The deposit's cohesiveness appears to be due to both the angularity and incipient welding of the constituents. The deposit is easily eroded however, and small caves, windows, and pinnacles have been formed by differential erosion. The weathered surface is case-hardened and is pale brown (10 R 5/4) in color. Desert varnish commonly stains the weathered surface a dark-gray (N3) color. The deposit is poorly-sorted and is composed predominately of angular ash to block size pumice fragments as large as 18 inches in diameter. The pumice also contains 2 to 3 percent subhedral to euhedral feldspar crystals and 5 to 10 percent pebbles up to 3 inches in size of sub-rounded to rounded basalt and well-rounded pumice. The pebbles appear to be more concentrated in the lower one-fourth of the deposit, and although the contacts are concealed, the pebbles are believed to have been derived from underlying pebble conglomerates. The pumice in about the lower half of the deposit is very light gray (N8) in color and grades upward

Figure 5. Northwesterly view of Bog Hot Valley and the lower west slopes of the mountains. The rhyolite unit in the foreground is unconformably overlain by the sedimentary-pyroclastic unit with its welded tuff members capping the north-trending ridges.

into a light gray (N6) or medium light-gray pumice (N7) in which the larger blocks tend to be somewhat flattened subparallel to the top and bottom of the deposit. The deposit generally displays only incipient welding, however, for fractures pass around rather than through the pumice fragments. The refractive index of the vitric material (1.499 ± 0.001) suggests a silica content of about 72 percent (George, 1924).

The differentiated welded tuff members contain the zones of partial and dense welding of a simple cooling unit. Their unwelded zones grade into the interbedded deposits separating each member. The thickness and character of their upper unwelded zones are unknown, for tuffs attributable to these zones are not exposed. Tuffs attributed to the lower unwelded zones are rarely exposed, and their actual thicknesses are also unknown.

The welded tuff members have a eutaxitic structure formed by a streaky foliated appearance of deformed shards and pumice fragments. The pumice fragments are commonly disk-shaped and flattened subparallel to the top and bottom of each member. The fragments range from 2 to 60 mm in length and from 1 to 10 mm in thickness. The pumice appears to be more commonly flattened near the bottom of each member, but this feature is usually not apparent at any one locality, for the members are always incompletely exposed and vapor-phase activity has largely destroyed the pumice in the upper part of each member. Crystal fragments range from 0.5 to 5 mm in size, and angular to sub-rounded lithic fragments range from 0.2 to 20 mm in size. Volcanic lithic fragments are widely distributed and generally appear to be neither larger nor more concentrated in the lower than in the upper part of each member. The textures of the volcanic lithic grains are so fine that their composition could not be determined. Microscopically, they all have felty or pilotaxitic textures that are characteristic of andesites and (or) basalts.

The upper zone of partial welding makes up most of each member and has experienced considerable devitrification. The vitroclastic texture of the matrix is generally obscure, and crystals and lithic constituents are now set in a dense groundmass that largely consists of spherulites less than 0.5 mm in diameter composed of probable alkali feldspar and cristobalite. Most of the pumice in the upper three-fourths of this upper zone is poorly preserved and consists of drusy, porous growths of vapor-phase minerals. Numerous elongate cavities, as large as 8 inches in length and 4 inches in height, are formed from the destruction of the pumice. Relict pumice tube structure is commonly displayed by the aggregate of minerals lining the walls of these cavities. The smaller cavities tend to conform in shape to that of the flattened pumice, but the larger cavities are very irregular in shape and appear to have become distended during vapor-phase activity. The cavities become progressively smaller and less numerous in the lower one-fourth of this zone and probably mark decreasing vapor-phase activity. The dense matrix also becomes darker in color in the lower part of this zone and more of the pumice occurs in obsidian-like lenses rather than in drusy growths. A crude columnar jointing is commonly developed in the lower, less porous part of this zone. The columns are four to five sided and range from 3 to 7 feet in width and 6 to 8 feet in length.

The partially welded zone in most of the members grades downward into a dark-gray (N3) vitrophyre that represents the densely welded zone. The zone contains only a few scattered ovoid vesicles that are less than 2 mm in diameter. The vitrophyre is relatively free of devitrification. It is very brittle, and a platy fracture is commonly developed subparallel to the top and bottom of the zone. Deformed shards and pumice tube structures can easily be seen with the aid of a hand lens. The shards and pumice have a subparallel orientation and commonly bend around crystal and lithic fragments. The shards especially have noticeably rounded corners and appear to be fused to adjacent shards and pumice tube structures. Many of the crystals tend to have their long dimensions oriented subparallel to the plane of flattening. Wherever the zone is completely exposed, it ranges from 1 to 3 feet in thickness. The zone is never well enough exposed to compare its thickness with the local thickness of each member or to determine the proximity or direction of possible source vents.

The lower zone of partial welding is rarely completely exposed, but where observed it ranges from 0.5 to 1.5 feet in thickness. The welded tuff of this zone is light gray (N7) in color and has a foliated appearance owing to the flattening of the pumice and subparallel orientation of the shards. The zone is gradational with the overlying densely welded zone where the welded tuff becomes progressively darker and more obsidian-like in appearance. It becomes lighter in color and loses its foliated appearance where it grades downward into the unwelded zone. The unwelded tuff is very light gray (N8) in color and displays no flattening of the pumice. It also differs from the partly welded tuff in fracturing around rather than across crystals and pumice fragments. Only the upper few inches of this lower unwelded zone is ever exposed.

Welded tuff member A-1. Welded tuff member A-1 ranges from 50 to 80 feet in thickness. The member extends into the area from the north and is traced continuously southward for a distance of about four and a half miles. An isolated outcrop of welded tuff near the southern end of the mountains in sec. 27, T. 46 N., R. 38 E., is regarded as an erosional remnant of this member, because it has similar lithology and stratigraphic position. The rocks are so poorly exposed in the NE 1/4 sec. 34, T. 47 N., R. 28 E. that the member could not be separated from member A-2.

The upper partially welded zone is greenish-gray (5 G 6/1) to yellowish-gray (5 Y 8/1) in color on the fresh surface and weathers moderate reddish-brown (10 R 4/6). The upper 2 to 3 feet is dark reddish-brown (10 R 3/4) in color and commonly has a fused vesicular appearance. Cristobalite and riebeckite occur in this member as vapor-phase minerals. Drusy cavities locally contain euhedral riebeckite in crystals as much as 3 mm in length. The cristobalite does not occur in large enough crystals for positive megascopic identification.

Table 7. Modal analyses of samples from the welded tuff members in the sedimentary-pyroclastic unit.

	A-1 (213-211)	A-2 (199-194)	B (84-85)	C (76-60)	D (83-81)
Crystals:					
Anorthoclase	3.5	5.0	5.0	5.0	4.0
Quartz	10.0	14.0	3.0	0.5	1.0
Biotite	1.0	1.0	0.5	4.0	2.0
Riebeckite	0.5	-	-	-	-
Aegirine	-	-	-	1.0	-
Magnetite	-	1.0	0.5	0.5	-
Lithic frags:	1.5	1.0	-	0.5	-
Matix:					
Vitric	-	78.0	-	-	-
Devitrified	53.5	-	90.0	86.5	87.0
Quartz	28.0	-	-	-	1.0
Iron oxide	2.0	-	1.0	2.0	5.0

The modal analysis of a representative sample collected from the upper partially welded zone indicates that the member is of rhyolitic composition (Table 7). Crystal fragments range from 0.5 to 2 mm in size, and make up 15 percent of the sample. Sub-rounded volcanic lithic grains range from 0.5 to 4 mm in diameter. The crystal fragments are mainly anhedral quartz, and anhedral to euhedral, unaltered anorthoclase. A minor amount of subhedral yellow biotite also occurs as crystal fragments. A minor amount of subhedral, strongly pleochroic, dark-blue riebeckite is in crystals ranging from 0.5 to 0.75 mm in length. The crystal fragments and lithic grains are set in a crystallized matrix with grain size less than 0.5 mm. The matrix is mainly anhedral quartz, and devitrified glass occurring in feldspar spherulites less than 0.5 mm in diameter. The matrix also includes a minor amount of disseminated anhedral iron oxide, and euhedral cristobalite occurring interstially with the feldspar spherulites.

Welded tuff member A-2. Welded tuff member A-2 is as much as 35 feet thick and extends only about a mile into the area from the north. It thins toward the south and appears to join member A-1 in the NE 1/4 sec. 34, T. 47 N., R. 28 E., where intervening strata separating the two members also thin toward the south and appear to pinch-out. The two welded tuff members are so poorly exposed in the locality where they appear to join that their true relationship is unknown. The thinning and lack of a densely welded zone toward the south suggests that member A-2 dies-out.

Member A-2 is greenish-gray (5 G 6/1) in color on the fresh surface and weathers to a moderate reddish-brown (10 R 4/6) color. It is megascopically identical to member A-1, and petrographic examination of a representative sample collected from the densely welded zone indicates that it is also of rhyolitic composition (Table 7). Phenocrysts range from 0.5 to 2 mm in size and make up 21 percent of the sample. Volcanic lithic fragments range in size from 0.5 to 3 mm and make up only one percent of the sample. The phenocrysts consist of anhedral to subhedral quartz, subhedral unaltered anorthoclase, subhedral yellow biotite, and subhedral magnetite. The quartz and anorthoclase are partly resorbed by the vitric matrix. The phenocrysts and lithic fragments are set in a yellowish-brown, partly devitrified matrix of deformed glass shards and pumice tube structure less than 0.5 mm in size. The vitric constituents are aligned in the same direction and bend around phenocrysts and lithic fragments.

Welded tuff member B. Welded tuff member B extends nearly four miles into the area from the north and is sporadically exposed where overlying gravel deposits have been eroded away on the lower west flanks of the mountains. The member is as much as 70 feet thick and dies-out toward the south in the N 1/2 sec. 15, T. 46 N., R. 28 E.

Member B is light greenish-gray (5 G 8/1) to greenish-gray (5 G 6/1) in color on the fresh surface and weathers to a moderate reddish-brown (10 R 4/6) color. Petrographic examination of a representative sample collected from the upper partially welded zone indicates that it is of trachytic composition (Table 7). Crystal fragments range in size from 0.125 to 2 mm and make up 9 percent of the sample. Most of the crystal fragments consist of anhedral to subhedral, unaltered anorthoclase, and anhedral quartz. Many of the anorthoclase crystals are fractured. Only a minor amount of yellow biotite and subhedral magnetite occur as crystal fragments. No volcanic lithic grains happened to be included in the sample examined. The crystal fragments are set in a yellowish-brown matrix of spherulitic devitrified glass. The spherulites are less than 0.125 mm in diameter and are composed of radiating, acicular feldspar crystals.

Welded tuff member C. Welded tuff member C extends about four and a half miles into the area from the north, and it is sporadically exposed where overlying gravel deposits have been eroded away. The member ranges from 30 to 60 feet in thickness and thins toward the south.

The member is more varied in color on the fresh surface than any of the other welded tuff members. It is orange-pink (10 R 7/4) or mottled orange-pink (10 R 7/4) and greenish-gray (5 GY 6/1) in color in the southern half of its extent, but is light olive-gray (5 Y 6/1) to greenish-gray (5 GY 6/1) in color in the northern half of its extent. The weathered surface is pale reddish-brown (10 R 5/4) to moderate reddish-brown (10 R 4/6) in color. The member is of trachytic composition as revealed by petrographic examination of a representative sample (Table 7). Crystal fragments range in size from 0.25 to 3 mm and make up 11 percent of the sample. The crystal fragments are mainly anhedral to euhedral, unaltered anorthoclase and yellowish-brown biotite. A minor amount of euhedral magnetite, and anhedral quartz also occur as crystal fragments. A minor amount of subhedral, strongly pleochroic, dark-green aegirine occurs in crystals ranging from 0.25 to 0.5 mm in size. The aegirine and biotite are both partly replaced by iron oxide. Volcanic lithic fragments range in size from 0.5 to 2 mm. The matrix is completely devitrified and consists of iron oxide stained feldspar spherulites less than 0.25 mm in diameter, and disseminated, anhedral iron oxide. The iron oxide is apparently responsible for the pink colors of this welded tuff member.

Welded tuff member D. Welded tuff member D is as much as 55 feet thick and is poorly exposed in two small isolated areas in secs. 10 and 15, T. 46 N., R. 28 E. The member appears to die-out toward the south.

The member is moderate orange-pink (10 R 7/4) in color on the fresh surface and weathers pale reddish-brown (10 R 5/4). The modal analysis of a representative sample collected from its partially welded zone indicates that it is trachytic welded tuff (Table 7). Crystal fragments, ranging from 0.25 to 3 mm in size, make up 7 percent of the sample and consist mainly of anhedral to euhedral, unaltered anorthoclase and subhedral yellow biotite. A minor amount of anhedral quartz also occurs as crystal fragments. The sample examined happened to contain no lithic fragments. The crystal fragments are set in an iron oxide stained, devitrified matrix of feldspar spherulites less than 0.125 mm in diameter. Disseminated, anhedral iron oxide in the matrix is considerably altered to hematite, and this alteration product is most likely responsible for the pink and red colors of the member.

Origin

The texture and structure of the interbedded sandstones and pebble conglomerates suggests a fluvial environment of deposition. The interbedded silty mudstones may represent either flood-plain or lacustrine deposits. The poorly sorted pumice beds as well as the welded tuff members are believed to have been laid down by nuées ardentes type volcanic eruptions.

Correlation and Age

The sedimentary-pyroclastic unit unconformably overlies the rhyolite unit believed to correlate with the Canyon Rhyolite of Merriam (1910). The Canyon Rhyolite is unconformably overlain by the Virgin Valley Formation containing middle Miocene vertebrate fossils, but this formation is believed by Willden (1964) to extend into late Miocene time. Except for lack of welded tuff members, the Virgin Valley Formation is similar in lithology to the sedimentary-pyroclastic unit. Correlation with the Virgin Valley Formation is therefore suggested by somewhat similar lithology and stratigraphic position, and a middle to late (?) Miocene age is assigned to the unit.

Dissected Gravel Deposits

Unconsolidated to poorly consolidated sedimentary deposits occurring in Bog Hot Valley have been mapped by Willden (1964) in Nevada as the Thousand Creek beds (Ttc) and by Walker and Repenning (1965) in Oregon as a sedimentary-tuff unit (Tst) that includes boulder-bearing slope wash and fanglomerates. Merriam (1910) referred to fossiliferous sandstones cropping out along Thousand Creek as the Thousand Creek beds. He considered these beds to be essentially horizontal and to unconformably overlie the lava flows of the Pueblo Mountains, but Fuller (1931) concluded that they curve up into the mountains and have a conformable relationship with the lava flows. A definition of the Thousand Creek beds is in doubt, and the name has not been used by all investigators; therefore, sedimentary deposits of apparently similar stratigraphic position occurring in the area investigated are described as dissected gravel deposits.

Field Relationship

Gravel deposits discontinuously underlie the lower west flanks of the mountains adjacent to Bog Hot Valley. Although these deposits have been eroded, they are rarely exposed because of extensive slope wash. They are expressed in the topography by steeper slopes that rise above the general level of the valley alluvium.

The gravel deposits have an angular unconformable relationship with the underlying sedimentary-pyroclastic and rhyolite units as well as overlying Quaternary alluvium. The contact with these overlying and underlying units is not exposed. The deposits dip to the west, but they appear to merge with nearly horizontal volcanic sandstones cropping out immediately west of the area investigated. The unit ranges in thickness from 0 to 250 feet, and its eastern edge generally appears to thin to extinction.

Lithology

The gravels are so poorly exposed that their lithologic character is largely inferred from slope wash material. The gravels are poorly sorted and consist of angular to rounded pebble to boulder size clasts that are tightly to loosely packed in a coarse-grained sand matrix. The boulders are as large as 4 feet in diameter. The texture is so coarse that bedding cannot be detected in the limited exposures. Basalt clasts predominate, but thyolite clasts are common adjacent to the underlying rhyolite unit and welded tuff clasts are common adjacent to the underlying sedimentary-pyroclastic unit. The sand matrix consists predominately of volcanic lithic grains with a minor amount of sub-angular to sub-rounded grains of feldspar and quartz.

Origin

The texture, composition, and structural attitude of these deposits indicates that they are mainly older alluvial deposits derived from the erosion of the Pueblo Mountains. Their general west-dipping attitude and apparent grading into finer textured, nearly horizontal sediments to the west suggest that they are a coarse-grained marginal facies of the Thousand Creek beds of Merriam (1910).

Correlation and Age

The dissected gravel deposits are believed to correlate at least in part with the Thousand Creek beds of Merriam (1910). Vertebrate fossils collected from these beds were dated as early Pliocene by Merriam (1910) and late Pliocene by Stock (cited in Fuller, 1931). The gravel deposits are therefore assigned a Pliocene age.

Quaternary Alluvium, Playa, and Dune Deposits

Quaternary sedimentary deposits are undifferentiated in the area investigated and include alluvium, playa, and dune deposits. The alluvium consists of stream channel deposits within the mountains, alluvial fan deposits bordering the mountains, and the flood-plain deposits of Thousand Creek. Playa deposits are formed by Continental Lake, and dunes are locally formed in the valleys by drifting sands.

Figure 6. Southerly view from the lower west slopes of the mountains showing the truncation of one of the welded tuff members by the overlying dissected gravel deposits.

STRUCTURAL GEOLOGY

The Basin and Range province is regarded by most investigators as characterized by fault block structure. Some of the fault block mountains and valleys are graben and horst structures displaying little or no tilting, but many indicate tilting by the inclination of one or more datum planes. Structural interpretation of the mountains and adjacent valleys in the area investigated concurs with the generally held fault block hypothesis and suggests that the Pueblo Mountains and Bog Hot Valley were formed on a tilted upthrown fault block, whereas Pueblo Valley was formed on a downthrown block.

The internal structure of the mountains is dominated by the homoclinal structure of the north-striking and west-dipping volcanic and sedimentary rocks that underlie the west ridge and lower west flanking ridges of the mountains. The average westerly dip of these rocks is approximately 20°. The east ridge of the mountains is underlain by older northeast-trending intrusive igneous and metamorphic rocks, whose structural discordance with the overlying volcanic rocks indicates their angular unconformable relationship.

The schistosity of the metamorphic rocks has developed parallel to their original bedding. These rocks strike N. 20° - 40° E. and generally dip S. 35° - 80° E., but they are tightly folded in the SW

1/4 sec. 6, T. 47 N., R. 30 E. The folds are poorly exposed in gullies and small canyons on the lower mountain slopes, and consist of small, plunging, symmetrical and asymmetrical, anticlines and synclines that range from 15 to 30 feet in width and trend N. 30° - 40° E. Although they have dips as high as 75° on their limbs, none are overturned and their axial planes have no preferred inclination. Local seepages and crushed zones suggest that the folding is related to faulting of undetermined extent.

The structural relationships of the plutons with that of the originally intruded rocks can be determined, because the schistosity of the metamorphic rocks has developed parallel to their original bedding. The diorite porphyry is a discordant intrusive body that trends approximately N. 30° - 40° E. The structural trends of both intrusive bodies suggests that their emplacement was structurally controlled by the intruded rocks. The foliated structure of the biotite diorite is most likely a primary structural feature, because the attitude of this structure closely parallels the attitude of the originally intruded rocks, and it is better developed near the contact with these rocks.

All the faults within the area investigated are normal faults. The range-bounding faults diagonally truncate the internal structure of the mountains in a northeasterly direction, and they are responsible for the extreme narrowing of the mountains toward the south. The amount of displacement along most of the faults cannot be determined, because of lack of datum planes. All the faults are concealed and any scarps that have been formed are eroded; therefore, the dip of only a few faults could be determined by their trace.

Some of the faults have westerly trends and relatively small displacement. The sedimentary-pyroclastic unit is displaced by the larger of these west-trending faults in sec. 27, T. 47 N., R. 28 E. It is about a mile long and has a throw of approximately 160 feet. Its approximate trace is within an east-west valley whose course it has apparently influenced. Welded tuff members north of the fault have been downthrown relative to those members south of the fault. The rhyolite and basalt units are displaced by a fault in the S 1/2 sec. 22, T. 46 N., R. 28 E. that trends nearly due west and whose trace is within a narrow mountain gap that is about one-half mile long. The throw of this fault is approximately 80 feet, and its downthrown side is to the south. A nearly vertical fault in the SE 1/4 sec. 1, T. 46 N., R. 28 E. trends N. 20° E. and displaces the rhyolite and basalt units in the prominent escarpment that bounds the southeast side of the mountains. This fault has an estimated throw of only 40 or 50 feet, and its downthrown side is to the north. A small, conspicuous fold that appears to be a drag fold is formed on the downthrown side of this fault.

All the faults with more northeasterly trends are confined to the east side of the mountains. These normal faults have their upthrown blocks to the northwest, and all but one are range-bounding faults. The southern four miles of the mountains are bounded on their east side by a fault that trends N. 5° - 20° E. and forms a prominent fault scarp on its upthrown side. The height of its escarpment suggests that it has a minimum throw of 1000 feet. The rhyolite and underlying basalt units as well as the Pliocene gravel deposits at the southern end of the mountains are displaced by this fault. This range-bounding fault extends northeastward into the mountains by way of Bobcat Canyon in the W 1/2 sec. 14, T. 46 N., R. 28 E., where it forms a hinge fault along the northern one mile of its extent that dips approximately 50° S.E. The rhyolite and basalt units are displaced by another hinge fault in the E 1/2 of secs. 11 and 14, T. 46 N., R. 28 E. that strikes N. 20° E. and dips 55° S.E. This fault is about a mile long and dies-out toward the north. The maximum throw of this fault at its southern end is approximately 800 feet. A fault in sec. 1, T. 46 N., R. 28 E. trends N. 50° E. and is about a mile long. The southern half of this fault is within the mountains and places the basalt unit in fault contact with the metasedimentary and biotite diorite units. The height of its fault scarp along the northern half of its extent suggests that this fault has a minimum throw of 640 feet. The linearity of the mountain front for a distance of four miles northeastward from the NE 1/4 sec. 14, T. 46 N., R. 28 E. to the SW 1/4 sec. 7, T. 47 N., R. 30 E. suggests another range-bounding fault. The height of its eroded fault scarp along the northern mile of its extent suggests that this fault has a minimum throw of 660 feet. A minor offset of the mountain front in sec. 7, T. 47 N., R. 30 E. suggests an additional normal fault bounding the mountains that extends north of the area investigated.

Bog Hot Valley has been formed on the westward-tilted fault blocks of the Pueblo and Pine Forest Ranges. This valley is bounded on its west side by the escarpment of a normal fault (Merriam, 1910; Willden, 1964). West-dipping basalts and tuffs on the lower west side of the Trout Creek Range (Carlton, 1968) suggest that Pueblo Valley was also formed on a westward-tilted fault block. The structure and the Tertiary stratigraphy of the Pine Forest Range is like that of the Pueblo Range (Willden, 1964), but the Pine Forest Range is offset to the southeast from the Pueblo Range by the narrow drainage outlet of Bog Hot Valley. The local and regional structure suggests that these two ranges were originally joined as a single north-trending fault block that was later separated by northeast-striking normal faults that were downthrown to the southeast.

The initial faulting and tilting of the Pueblo Mountains took place after the deposition of the sedimentary-pyroclastic unit, possibly in late Miocene or early Pliocene time, and the eroded sediments from the uplifted mountains were deposited in adjacent basins during Pliocene time. These older basin deposits within the area investigated are buried by younger deposits in Pueblo Valley, but they are exposed by erosion in Bog Hot Valley. The erosion of these older basin deposits in Bog Hot Valley could only have taken place after the separation of the originally joined Pueblo-Pine Forest fault block by northeast-striking normal faults that produced the drainage outlet for this valley. The faulting of these deposits by the southern most range-bounding fault of the Pueblo Mountains suggests that these ranges were separated from one another in late Pliocene or Pleistocene time.

The height of the various fault scarps indicates only the most recent minimum amount of displacement that has occurred along any one of the range-bounding faults. The local maximum relief suggests that repeated faulting has uplifted the mountains 2,100 feet relative to Pueblo Valley, but this suggested amount of uplift by faulting does not take into account the eroded beds on the west side of the mountains as well as the possible dip of the range-bounding faults. Although the dip of the southernmost range-bounding fault is approximately 50° where it extends into the mountains, the dips of the other range-bounding faults are unknown. According to Willden (1964), faults in Humboldt County range in dip from 45° to 70°. If the average dip of these range-bounding faults is assumed to be 60° and the exposed top of the sedimentary-pyroclastic unit is extended to the east side of the mountains in the northern part of the area, a minimum throw of 6,000 feet would be required for the uplift of the mountains by faulting relative to Pueblo Valley.

GEOMORPHOLOGY

Running water, aided by weathering and mass wasting, has been the principal geomorphic agent responsible for the reduction of the mountain slopes and deposition in the adjacent valleys. Even though the area has a desert climate, there is sufficient precipitation during the fall and spring to provide runoff in the mountains in the form of stream flow and sheet wash. Erosion is enhanced during periods of runoff by lack of vegetation and steepness of the mountain slopes. Although runoff is of short duration, it is usually severe and is capable of transporting very coarse-grained material to the adjacent valleys.

Mechanical weathering is predominant in the area, because of lack of moisture and vegetation in a desert climate where chemical weathering is not favored. The prevalence of mechanical weathering is responsible for a thin mantle of coarse, angular regolith that covers much of the bed rock in the mountains. Weathering, with the aid of mass wasting, has formed many talus accumulations that have temporarily blocked the drainage in some of the smaller canyons on the steeper east side of the mountains.

Reduction of the mountains slopes by rock creep is less important than slumping, because of the angularity of the regolith and lack of moisture aiding its downhill movement. Slumping is common along the sides of valleys and canyons underlain by the weaker pyroclastic and sedimentary rocks as well as along the steep escarpment bounding the southeast side of the mountains that is underlain by lava flows.

The topography of the mountains reflects their structure and lithology. Their asymmetrical cross profile and northerly trend is largely controlled by the west-dipping homoclinal structure of the volcanic and sedimentary rocks that underlie the west ridge and lower west-flanking ridges and valleys of the mountains. The west ridge of the mountains is underlain by lava flows that are relatively resistant to erosion. Interbedded pyroclastic and sedimentary rocks underlie the small homoclinal ridges and valleys flanking the west side of the mountains, with the valleys underlain by easily eroded pumice flows and sedimentary rocks, and the ridges underlain by less easily eroded welded tuff beds. Dip slopes are formed on the west side of the mountains where slopes coincide with the dip of the less easily eroded volcanic rocks. The northeasterly trend of the east ridge of the mountains is controlled by the structural trend of underlying intrusive igneous and metamorphic rocks. The higher, steeper slopes of this east ridge are underlain by a massive diorite pluton, and the lower slopes are underlain by more easily eroded intrusive igneous and metamorphic rocks.

Most of the faults within and those bounding the mountains are expressed in the topography by valleys or scarps. Fault-line valleys have been formed along the trace of a small normal fault in the S 1/2 sec. 27, T. 47 N., R. 28 E. and another small normal fault in the S 1/2 sec. 22, T. 46 N., R. 28 E. Fault valleys are formed on the downthrown side of two normal faults in secs. 11 and 14, T. 46 N., R. 28 E. The southern three miles of the mountains are bounded on the east side by a prominent fault scarp that is as much as 1000 feet in height. This scarp is formed on the upthrown side of a normal fault and is capped by rhyolite that is very resistant to erosion. The inferred normal faults bounding the east side of the mountains to the north of this prominent fault scarp have more eroded, less continuous scarps. The inferred normal fault in secs. 6 and 7, T. 47 N., R. 30 E. has faceted spur ends along part of its scarp.

The mountains have a subparallel drainage pattern controlled by their dominant homoclinal structure and steep slopes. The numerous short, narrow, stream valleys and canyons with typical V-shaped cross profiles and steep gradients place the range in the youthful stage of the cycle of erosion. Both sides of the mountains are drained by many transverse valleys whose courses appear to have been influenced by initial slopes developed on a westward-tilted fault block. These transverse valleys are regarded as resequent valleys, because their courses are in the same direction as the inferred consequent drainage, but at lower topographic elevations. The homoclinal valleys developed on the lower west-flanks of the mountains as well as those separating the two main mountain ridges are subsequent valleys formed by partial adjustment to lithologic variations. The subsequent valleys separating the east ridge from the west ridge of the mountains are underlain by more easily eroded basalt flows, and they are separated from one another by low interstream divides. All of these mountain valleys should drain southward to Pueblo Valley, but most drain southeastward to this valley by way of narrow superposed canyons that cut across the less easily eroded intrusive igneous and metamorphic rocks that underlie the east ridge of the mountains.

The internal drainage of the region has been responsible for the dominant depositional characteristics of the valleys. Pueblo Valley, being slightly lower in elevation than Bog Hot Valley, is the local base level to which canyons and valleys are being deepened. Although Bog Hot Valley partly owes its existence to erosion, it is nearly at base level and displays depositional features. Coarser-grained sediments eroded from the mountains are rapidly deposited upon reaching the gentler gradient of the valleys and form alluvial fans adjacent to the valleys and canyons draining the mountains. Alluvial fans bordering the faulted east front of the mountains are better-formed than those on the gentler west side of the mountains. Spring and Cowden Canyon have especially large alluvial fans that extend about a mile into Pueblo Valley. Finer-grained sediments transported from the mountains are carried further into the valleys and tend to level their central parts. The deposits of Continental Lake and Thousand Creek are nearly horizontal. Continental Lake is dry except during times of heavy runoff and is a typical shallow, desert playa, whose surface when dry is mudcracked and covered with an efflorescent of alkali salts. The lake owes its existence to a low sand dune barrier on its northeast side that impedes drainage into Pueblo Valley.

Although erosion and deposition has modified the landscape, diastrophism is believed to have been the dominant geomorphic process controlling its development. The mountains are in a youthful stage of the cycle of erosion, and the topographic expression of the westward-tilted fault block has been little altered by degradation. The parallel drainage pattern of the mountains appears to have been controlled by initial slopes originated by the faulting and tilting. Recurrent uplift of the mountains along the range-bounding faults is suggested by faceted spur ends and the occurrence of well-formed alluvial fans. The formation of the mountains and adjacent valleys cannot be explained by erosion, especially in a region of internal drainage.

GEOLOGIC HISTORY

The geologic history begins during Permo-Triassic time with deposition of clastic sediments in a sea that occupied the area. The marine sediments consisted predominately of muds, but there was also deposition of fine quartz sands. Greenstones associated with these now metamorphosed sedimentary rocks may represent small localized submarine eruptions or intrusive bodies. The record of these early formed rocks is incomplete, but deposition ceased with uplift of the area and retreat of the sea, and they were subsequently deformed, metamorphosed, and intruded by diorite plutons during Jurassic or Cretaceous time. This orogenic event is probably related to the Nevadan orogeny.

The uplifted metamorphic and intrusive igneous rocks were laid bare by erosion during early Tertiary and the beginning of late Tertiary time. By middle Miocene time, fissure eruptions poured out numerous basalt flows that eventually accumulated to a thickness of 2,863 feet. Not all of the volcanic activity consisted of the eruption of lava, for there were also episodes of ash eruption. Most of these pyroclastic eruptions were nuées ardentes type eruptions in which the ash was usually hot enough to become welded upon deposition. There were also periods of quiet when no volcanic activity took place, and the terrain was eroded and the volcanic materials were reworked by running water.

These periods of quiet were long enough so that the welded tuff beds were largely destroyed by erosion and thin soils were formed before renewed outpourings of lava. At least four such periods of erosion and soil formation are recorded in the basalt unit. The eruption of basalt finally ceased and 300 to 400 feet of very viscous rhyolite consisting of only two or three individual flows were erupted in the southern part of the area. These rhyolite flows are believed to be related in time with the eruption of rhyolite in the vicinity of Virgin Valley.

The basalt and rhyolite lavas underwent erosion during the middle Miocene, and sediments derived from the volcanic terrain were deposited on their eroded surface. The volcanic sediments were probably flood-plain and lacustrine deposits that continued to be deposited into late Miocene time. However, sedimentation was interrupted by seven episodes of nuées ardentes volcanic eruptions in which the ash of five of the eruptions was hot enough to become welded.

The originally joined Pueblo-Pine Forest Mountain fault block was undergoing uplift and westward tilting during Pliocene time, and debris eroded from the rising mountains was deposited in adjacent basins. This fault block was separated in late Pliocene or Pleistocene time by northeast trending normal faults that produced a drainage outlet for Bog Hot Valley. Block faulting, possibly initiated as early as late Miocene, has continued into the Quaternary Period and is the dominant geomorphic process in the evolution of the present landscape.

ECONOMIC CONSIDERATIONS

The quartz veins occurring in the biotite diorite and meta-sedimentary units have been extensively prospected for gold, but only small amounts of gold have been produced. None of the mines are in operation at the present time, and only the Cowden and Hall claims have had any reported production. Although bornite and chrysocolla are associated with the quartz veins, the veins are economically unimportant for their copper content, because these minerals occur in only minor amounts. The veins are relatively small, rarely occur in close proximity with one another, and have no appreciable extent. The difficulty in locating additional mineralized veins has apparently been a deciding factor in discouraging development of the mines.

The Nevada Highway Department and local residents obtain sand and gravel from the Pueblo Slough as well as from the older gravel deposits exposed at the southern end of the Pueblo Mountains. These deposits are extensive and are within easy access from existing roads, but are of little economic value at the present time, because they are located too far from existing marketing centers.

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APPENDIX

Measured Sections of the Basalt Unit

The measured sections include one complete and one incomplete stratigraphic section of the basalt unit. Subunits of the measured sections include mainly dense basalt flows and porphyritic basalt flows with subordinate interbedded ash flow tuffs, ash fall tuff, cinder beds, and sandstone.

Dense Basalt Flows: Medium gray (N5) to dark gray (N3), aphanitic basalts that weather reddish-brown (10 R 4/6), and are commonly only slightly vesicular, but the degree of vesicularity varies from flow to flow as well as within a single flow. Vesicles are commonly ovoid in shape and are less than 1 cm in diameter. Calcite and zeolite amygdules are commonly present. Blocky fracture is common.

Porphyritic Basalt Flows: Vesicular, medium dark gray (N4), porphyritic basalts that weather pale reddish-brown (10 R 5/4) or grayish-red (10 R 4/2). Vesicles are commonly less than 1 cm in diameter. Lath shaped plagioclase phenocrysts as large as 3.5 cm are set in an aphanitic groundmass. Vesicles are locally filled with calcite or zeolite minerals.

Ash Flow Tuffs: Non-welded to densely welded vitric tuffs that have gradational vertical zonation and eutaxitic structure. All the ash flow tuffs have been eroded and only the lower non-welded and welded zones remain. The top of these tuffs commonly has a baked soil zone.

Ash Fall Tuff: Only one interbedded vitric tuff is classified as an ash fall deposit, because it is moderately sorted. (See section 2, interval 572-567).

Cinder Beds: Poorly consolidated, moderate red (5 R 4/6), lapilli and block size cinders as much as 4 cm in diameter. Cinders are set in a scanty matrix of reddish-brown (10 R 4/6) vitric tuff composed mainly of glass shards.

Volcanic sandstone: Only one thin bed of pebbly volcanic sandstone is included in the measured sections (see section 2, interval 606-605).

Section 1

Initial Point: Top of the underlying metasedimentary unit in the SW 1/4 NE 1/4 NW 1/4 sec. 1, T. 46 N., R. 28 E.

Terminal point: Base of the overlying sedimentary-pyroclastic unit in the SW 1/4 NE 1/4 NW 1/4 sec. 3, T. 46 N., R. 28 E.

2863'-2508': Contact with overlying sedimentary-pyroclastic unit is covered. Interval mostly covered, but includes an undetermined number of dark gray (N3), vesicular, basalt flows that weather reddish-brown (10 R 4/6).

2508'-2503': Welded Tuff. Partially welded vitric tuff with eutaxitic structure of black obsidian-like lenses of pumice up to 3 cm in length and 4 mm in width set in a moderate red (5 R 4/6), vitric matrix of deformed shards with an average grain size of 2 mm. Crystal fragments of feldspar (3%) and quartz (1%). Four to five sided polygonal columnar jointing 3 to 4 feet in width. Upper contact covered; lower contact sharp and irregular.

2503'-2483': Dense basalt as in subunit description. Scattered ovoid vesicles 1 to 5 mm in diameter. Upper 2 feet has ropy structure. Upper contact sharp and irregular; lower contact sharp and slightly irregular.

2483'-2479': Welded tuff. Partially welded tuff with eutaxitic structure of black obsidian-like lenses of pumice up to 2 cm in length and 5 mm in width set in a moderate reddish-brown (10 R 4/6) matrix of deformed shards less than 1 mm in length. Crystal fragments of feldspar (5%); Volcanic lithic grains (1%) 1 to 2 mm in diameter. Lower 6 inches has a platy fracture. Upper 1 to 2 inches consists of a moderate red (5 R 4/6) soil zone that is baked by the overlying basalt flow. Upper contact sharp and slightly irregular; lower contact sharp and irregular.

2479'-2473': Dense basalt as in subunit description. Upper 2 feet very vesicular and has ropy structure. Upper contact sharp and irregular; lower contact covered.

2473'-2248': Covered. Interval contains float of partially and densely welded tuff.

2248'-2203': Porphyritic basalt as in subunit description. Plagioclase phenocrysts 1 to 3.5 cm in size. Interval consists of intertonguing pahoehoe flow units 4 to 8 feet in thickness.

2203'-2177': Covered.

2177'-2082': Dense basalt as in subunit description. Upper 4 to 5 feet very vesicular and has red oxidized appearance; central part has only a few scattered ovoid vesicles and poorly developed columnar jointing; lower 4 to 5 feet consists of flow breccia containing scoriaceous angular blocks 3 to 10 inches in diameter. Contacts are covered.

2082'-2078': Welded tuff. Densely welded tuff consisting of medium-gray (N4) vitrophyre with perlitic structure containing euhedral plagioclase phenocrysts (8%) ranging from 1 to 2 mm in length. Contacts are covered.

2078'-2054': Dense basalt as in subunit description. Upper 4 feet is scoriaceous and has moderate red (5 R 4/6) oxidized appearance. Contacts are covered.

2054'-2028': Dense basalt as in subunit description. Contacts are covered.

2028'-1994': Covered.

1994'-1975': Dense basalt as in subunit description. Contacts are covered.

1975'-1894': Porphyritic basalt as in subunit description. Plagioclase phenocrysts (5 to 10%) are 1 to 6 mm in length. Columnar jointing not developed, but flow is cut by many vertical fractures spaced 3 to 8 feet. Contacts are covered.

1894'-1883': Dense basalt as in subunit description. Upper contact covered ; lower contact sharp and irregular.

1883'-1833': Dense basalt as in subunit description. Upper 12 feet very vesicular and amygdaloidal. Upper surface has ropy structure. Upper contact sharp and irregular; lower contact covered.

1833'-1818': Covered.

1818'-1810': Dense basalt as in subunit description. A few scattered elongate vesicles 2 cm in length and 1 cm in width oriented subparallel to the top and bottom of flow. Contacts are covered.

1810'-1775': Covered.

1775'-1761': Dense basalt as in subunit description. A few ovoid vesicles 1 to 3 cm in diameter. Poorly developed columnar jointing; columns 4 to 5 feet in width. Contacts covered.

1961'-1744': Covered.

1744'-1727': Dense basalt as in subunit description. Contacts are covered.

1727'-1624': Covered.

1624'-1608': Dense basalt as in subunit description. Contacts are covered.

1608'-1593': Covered.

1593'-1582': Dense basalt as in subunit description. Zeolite amygdules less than 1 cm in diameter are concentrated in cyclindrical zones 2 to 5 inches in width that extend perpendicularly 3 to 5 feet from base of the flow. Contacts are covered.

1582'-1567': Covered.

1567'-1558': Dense basalt as in subunit description. Vesicles are only 2 to 8 mm in diameter. Poorly developed columnar jointing; columns 3 to 4 feet in width. Contacts covered.

1558'-1531': Covered.

1531'-1461': Dense basalt as in subunit description, but zeolitized. Radiating zeolite mineral forms numerous irregular shaped amygdules less than 2 mm in diameter. Poorly developed columnar jointing; columns 3 to 5 feet in width. Contacts are covered.

1461'-1406': Covered.

1406'-1393': Porphyritic basalt as in subunit description. Numerous zeolite amygdules less than 1 cm in diameter. Plagioclase Phenocrysts (15%) are 1 to 8 mm in length. Contacts covered.

1393'-1334': Covered.

1334'-1327': Porphyritic basalt as in subunit description. Plagioclase phenocrysts (8 to 10%) range from 1 to 9 mm in length. Contacts are covered.

1327'-1168': Covered.

1168'-1043': Dense basalt as in subunit description. Very vesicular; interval consists of many intertonguing pahoehoe flow units 1 to 3 feet in thickness. Contacts are covered.

1043'-1032': Covered.

1032'-1027': Dense basalt as in subunit description. Contacts are covered.

1027'- 979': Covered.

979'- 967': Dense basalt as in subunit description. Contacts are covered.

967'- 956': Covered.

956'- 918': Dense basalt as in subunit description. Upper and lower 2 to 3 feet vesicular and containing many calcite and zeolite amygdules less than 1 cm in diameter; central part has poorly developed columnar jointing. Upper contact covered; lower contact sharp and irregular.

918'- 913': Dense basalt as in subunit description. Vesicular throughout; vesicles less than 5 cm in diameter. Numerous calcite amygdules in upper 3 feet of flow. Many calcite pipe amygdules averaging 0.25 inches in width and 6 inches in length extend perpendicularly from base of flow. Contacts sharp and irregular.

913'- 880': Dense basalt as in subunit description. Very weathered, vesicular, intertonguing flow units of pahoehoe lava ranging from 2 to 4 feet in thickness. Ropy upper surfaces exposed on some of the flow units. Contacts sharp and irregular.

880'- 865': Dense basalt as in subunit description. Upper 2 feet contains many ovoid vesicles less than 5 mm in diameter that are oriented in vesicle "trains" paralleling the top and bottom of the flow. Lower 1 foot very vesicular with reddened oxidized appearance; contains a few calcite and stilbite pipe amygdules as much as 0.25 inches in diameter and 7 inches in length that extend perpendicularly from the base of the flow. Upper contact sharp and irregular; lower contact covered.

865' - 811': Covered.

811' - 795': Dense basalt as in subunit description. A few ovoid vesicles less than 5 mm in diameter. Contacts are covered.

795' - 741': Covered.

741' - 710': Dense basalt as in subunit description. Contains a few scattered ovoid vesicles 0.4 to 2 cm in diameter; poorly developed columnar jointing. Upper contact covered; lower contact sharp and irregular.

710' - 673': Dense basalt as in subunit description. Upper 4 feet contains zeolite amygdules less than 1 cm in diameter oriented in "trails" that parallel the top and bottom of the flow. Central part has poorly developed columnar jointing; columns 4 to 5 feet in width. Ovoid zeolite amygdules ranging from 0.5 to 1 cm in diameter are concentrated in cylindrical zones 2 to 4 inches in width that extend perpendicularly 3 to 5 feet from base of flow. Upper contact sharp with undulating ropy surfaces; lower contact covered.

673' - 647': Dense basalt as in subunit description. Contains numerous ovoid and irregular shaped zeolite and calcite amygdules ranging from 0.1 to 1 cm in diameter. Upper 2 feet scoriaceous. Contacts are covered.

647' - 627': Dense basalt as in subunit description. Poorly developed columnar jointing; columns 3 to 4 feet in width. Zeolite amygdules 0.5 to 1 cm in diameter are concentracted into cylindrical zones 0.5 to 4 inches in width that extend perpendicularly 3 to 4 feet above base of the flow. Contacts are covered.

627' - 610': Dense basalt as in subunit description. Vesicular and amygdaloidal; vesicles and amygdules ovoid to irregular in shape and 0.1 to 1 cm in diameter. Amygdules consist of natrolite, stilbite, and calcite. Contacts are covered.

610' - 565': Covered.

565' - 559': Dense basalt as in subunit description. A few scattered ovoid vesicles 0.5 to 1 cm in diameter; natrolite, stilbite, and calcite amygdules 0.2 to 1.5 cm in diameter concentrated into cylindrical zones 2 to 3 inches in width that extend perpendicularly 2 to 3 feet from the base of the flow. Contacts are covered.

559' - 552': Dense basalt as in subunit description. Very weathered; only a few scattered ovoid vesicles less than 4 mm in diameter. Contacts are covered.

552' - 516': Covered. Surface of ground strewn with numerous zeolite amygdules as much as 3 inches in diameter.

516' - 508': Dense basalt as in subunit description. Ovoid and irregularly shaped zeolite amygdules 0.5 to 2 cm in size are concentrated into cylindrical zones 1 to 3 inches in width that extend perpendicularly 2 to 3 feet above the base of the flow. Contacts are covered.

508' - 463': Dense basalt as in subunit description. Poorly developed columnar jointing; columns 4 to 5 feet in width. Contacts are covered.

463' - 452': Dense basalt as in subunit description. Vesicular, vesicles 1 to 2 mm in diameter and commonly filled with a zeolite mineral. Contacts are covered.

452' - 338': Covered.

338' - 317': Dense basalt as in subunit description. Many natrolite and calcite amygdules 0.3 to 2 cm in diameter. Flow is cut by many irregular fractures 1 to 3 mm in width that are filled with calcite. Contacts are covered.

317' - 224': Covered.

224' - 205': Dense basalt as in subunit description. Contains many natrolite and calcite amygdules 0.5 to 2 cm in diameter. Contacts are covered.

205' - 0': Covered. Contact with the underlying metasedimentary unit is covered.

Total thickness: 2,863 feet.

Section 2

Initial Point: Base of the escarpment in the SW 1/4 NW 1/4 SW 1/4 sec. 14, T. 46 N., R. 28 E.

Terminal Point: Base of the overlying rhyolite unit in the SE 1/4 NE 1/4 SE 1/4 sec. 15, T. 46 N., R. 28 E.

654'- 645': Welded tuff. Partially to densely welded. Upper 2 feet consists of a vitrophyre with perlitic structure containing feldspar phenocrysts (15 to 20%) that are less than 1 mm in diameter. Middle 5 feet consists of alternating layers of obsidian-like glass with perlitic structure and grayish-red (10 R 4/2) partially welded vitric tuff containing obsidian lenses of flattened pumice less than 1 cm in length and 2 mm in width. These alternating layers range from 0.25 to 10 inches in thickness. Lower 2 feet consists of light gray (N 7), partially welded, vitric tuff containing obsidian lenses of flattened pumice less than 1 cm in length and 2 mm in width. Upper contact is sharp and slightly irregular with the flow breccia of the overlying rhyolite unit; lower contact is covered.

645'- 620': Dense basalt as in subunit description. Very vesicular; vesicles ovoid and less than 5 mm in diameter. Flow breccia in upper 5 feet consists of scoriaceous blocks, 0.5 to 8 inches in diameter, set in a less vesicular matrix of basalt. Contacts are covered.

620'- 606': Welded and non-welded vitric tuff. Upper 5 feet is a vitrophyre with perlitic structure that contains euhedral feldspar phenocrysts (20%) 1 to 2 mm in length. Middle 8 to 12 inch zone consists of partially welded vitric tuff with a eutaxitic structure formed by flattened obsidian-like pumice less than 1 cm in length and 2 mm in width. Lower 8 to 9 feet consists of mottled grayish-orange-pink (10 R 8/2) and very light gray (N 8), poorly indurated, non-welded tuff composed mainly of ash and lapilli size pumice fragments up to 3 cm in diameter. Non-welded material contains less than 10% crystal fragments of feldspar and biotite that are less than 2 mm in diameter, and 1% volcanic lithic grains less than 3 mm in diameter. All of the zones are gradational with one another. Upper contact covered; lower contact sharp and even.

606'- 605': Pebbly volcanic sandstone, poorly indurated, pinkish-gray (5 YR 8/1), medium to very coarse-grained. Consists of 30% sub-rounded to sub-angular feldspar, 40% sub-rounded volcanic lithic grains, 20% vitric material consisting of broken glass shards and pumice, 10% rounded basalt pebbles up to 3 cm in diameter. Pebbles are more concentrated in the lower 4 inches producing a graded structure. Contacts sharp and even.

605'- 586': Non-welded ash flow tuff. Tuff is mottled grayish-orange-pink (10 R 8/2) and moderate orange-pink (10 R 7/4), poorly indurated, and is poorly sorted. Consists mainly of ash and lapilli size pumice in angular fragments less than 3 cm in size; 2 to 3% crystal fragments less than 2 mm in size of feldspar and pseudohexagonal plates of biotite; 1% rounded volcanic lithic grains 1 to 3 mm in diameter. Upper contact sharp and even; lower contact sharp and irregular.

586'- 572': Dense basalt as in subunit description. A few scattered ovoid vesicles, 1 to 2 cm in diameter, are locally filled with calcite. Upper 6 to 8 feet is scoriaceous. Upper contact sharp and irregular; lower contact is covered.

572'- 567': Ash fall tuff. Yellow gray (5 Y 8/1), poorly indurated, moderately sorted, vitric tuff with a vitroclastic texture less than 2 mm. Consists mainly of glass shards and angular pumice fragments; 5 to 8% euhedral to subhedral, partly broken feldspar crystals; 3% angular volcanic lithic grains. Contacts are covered.

567'- 532': Covered.

532'- 490': Dense basalt as in subunit description. Upper 8 to 10 feet very vesicular. Central part of flow is highly fractured with fractures spaced 0.5 to 3 feet and oriented both perpendicularly and horizontally to the top and bottom of the flow. Contacts are covered.

490'- 351': Covered.

351'- 346': Welded vitric tuff. Upper 1 to 3 inches consists of a moderate red (5 R 4/6), dense, baked soil zone that overlies 2 to 2.5 feet of vitrophyre containing feldspar phenocrysts (10 to 20%) that range from 1 to 3 mm in length. Lower 2.5 to 3 feet consists of a yellowish-gray (5 Y 8/1) partially welded vitric tuff. This partially welded zone has a eutaxitic structure formed by obsidian-like lenses of flattened pumice less than 6 mm in length and 1 mm in width that are set in a finer vitroclastic matrix less than 3 mm in size of slightly deformed shards and pumice fragments. This zone contains crystal fragments (5%) of feldspar and biotite, and rounded volcanic lithic grains (1%). Contacts are covered.

346'- 311': Porphyritic basalt as in subunit description. Interval consists of vesicular, intertonguing flow units of pahoehoe lava 2 to 6 feet in thickness. Plagioclase phenocrysts range from 1 to 2 cm in length and are either unoriented or have a swirled orientation. Contacts are covered.

311'- 301': Dense basalt as in subunit description. Flow is highly fractured. Contacts covered.

301'- 216': Dense basalt as in subunit description. Upper 6 to 15 feet consists of flow breccia composed of scoriaceous angular blocks up to 10 inches in diameter with small isolated patches of moderate red (5 R 4/6) vitric tuff. Central part of flow is highly fractured. Lower 5 to 10 feet consists of a flow breccia composed of angular scoriaceous blocks as large as 8 inches in diameter. Upper contact covered; lower contact sharp and slightly irregular.

216'- 213': Welded tuff. Upper 2 to 4 inches consists of a moderate red (5 R 4/6), baked, soil zone that contains a few sub-rounded basalt pebbles up to 3 cm in diameter. The baked soil zone is gradational with an underlying vitrophyre that is 1.5 feet thick and contains feldspar phenocrysts (8%) that range from 1 to 3 mm in length. Lower 1 feet consists of alternating layers of light gray (N7) and moderate reddish-brown partially welded vitric tuff that are in layers ranging from 1 to 2 cm in thickness. This lower partially welded tuff has small obsidian-like lenses of flattened pumice less than 5 mm in length and 1 mm in width. It includes 4% feldspar crystals less than 2 mm in length, and 1% volcanic lithic grains less than 3 mm in diameter. Upper contact sharp and slightly irregular; lower contact is covered.

213'- 189': Porphyritic basalt as in subunit description. Plagioclase phenocrysts (6%) range from 1 to 2 cm in length. Upper contact covered; lower contact sharp and slightly irregular.

189'- 173': Dense basalt as in subunit description. Intertonguing, very vesicular, flow units of pahoehoe lava 4 to 6 feet in thickness. Upper contact sharp and slightly irregular; lower contact covered.

173'- 156': Dense basalt as in subunit description. Vesicles less than 6 mm in diameter, and a few are filled with calcite or stilbite. Lower 3 to 4 inches of flow contains numerous calcite pipe amygdules averaging 0.25 inches in diameter and as much as 4 inches in length that extend perpendicularly from base of flow. A few pipe amygdules bifurcate downward. Upper contact covered; lower contact sharp and irregular.

156' - 118': Porphyritic basalt as in subunit description. Plagioclase phenocrysts (10%) range from 0.2 to 1 cm in length. Upper 6 to 7 feet contains many calcite amygdules less than 1 cm in diameter. Upper contact sharp and irregular; lower contact is covered.

118'- 110': Cinder bed as in subunit description. Contacts are covered.

110'- 98': Dense basalt as in subunit description. Upper contact covered; lower contact sharp and irregular.

98'- 73': Cinder bed as in subunit description. Upper contact sharp and irregular; lower contact slightly irregular.

73' - 10': Dense basalt as in subunit description. Contacts sharp and slightly irregular.

10' - 0': Exposed part of dense basalt as in subunit description that is at the base of the escarpment.