AN ABSTRACT OF THE THESIS OF

WINTHROP ALLEN ROWE for the MASTER OF SCIENCE
(Name) (Degree)

in GEOLOGY presented on June 10, 1970
Major) (Date)

Title: GEOLOGY OF THE SOUTH-CENTRAL PUEBLO MOUNTAINS, OREGON-NEVADA

Abstract approved: Redacted for Privacy
Dr. Harold E. Enlows

The thesis area consists of 33 square miles in the south-central Pueblo Mountains of Humboldt County, Nevada and Harney County, Oregon. The Pueblo Mountains are tilted fault block mountains found in the extreme northwestern part of the Basin and Range province and were produced during Early Tertiary Basin and Range orogeny. Northwest and northeast trending faults of Late Tertiary time have since cut the entire stratigraphic sequence.

The oldest rocks exposed are metamorphosed Permian to Triassic eugeosynclinal sedimentary rocks. The metamorphic sequence is intruded by several granitic plutons of Late Jurassic to Middle Cretaceous age. A thick sequence of Miocene basalt flows unconformably overlies the pre-Tertiary rocks. A slight angular unconformity separates the basalt sequence from overlying Miocene tuffaceous sedimentary rocks, sillar flows, and welded tuffs. Unconsolidated deposits of Quaternary alluvium include alluvial fan and

lacustrine sediments.

Mineralization within the area includes several gold prospects, a mercury prospect, and a possible copper deposit. The copper prospect consists of a large gossan (6,000 feet by 3,000 feet). Mineralization and alteration from a Cretaceous porphyritic quartz monzonite intrusion has produced potassic and quartz sericite hydrothermal alteration in the host. Oxidation and weathering has removed the sulfides from the surface leaving goethite, hematite, and limonite residues.

Geology of the South-central Pueblo Mountains, Oregon-Nevada

by

Winthrop Allen Rowe

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

June 1971

APPROVED:

Redacted for Privacy

Associate Professor of Geology
in charge of major

Redacted for Privacy

Associate Professor of Geology
in charge of supporting field

Redacted for Privacy

Acting Chairman of the Department of Geology

Redacted for Privacy

Dean of Graduate School

Date thesis is presented June 10, 1970

Typed by Mary Jo Stratton for Winthrop Allen Rowe

ACKNOWLEDGEMENTS

The writer is especially grateful to Dr. Harold E. Enlows for suggesting the problem, conducting a final field check, for assistance and discussions on problems encountered, and for critically reading the manuscript and offering many helpful suggestions.

Appreciation is gratefully extended to Dr. Cyrus W. Field for helpful discussions on problems encountered with hydrothermal alteration and mineralization and for his suggestions and critical reading of the manuscript.

Special thanks is extended to Dr. Edward M. Taylor for providing chemical data for an ash flow tuff unit and for his suggestions and critical reading of the manuscript.

Special consideration must also be extended to my wife, Karen, for her assistance in typing the manuscript. The writer is grateful for her patience and moral support during the preparation of the thesis.

The writer extends thanks to his parents, Mr. and Mrs. W. A. Rowe, Sr. for financial assistance during the thesis preparation.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

GEOLOGY OF THE SOUTH-CENTRAL PUEBLO MOUNTAINS, OREGON-NEVADA

INTRODUCTION

Location and Accessibility

The Pueblo Mountains are in the north-central part of Humboldt County, Nevada, and in the south-central part of Harney County, Oregon. The area mapped includes approximately 33 square miles with 28 square miles in T. 41 S., R. 34 E., and R. 35 E. of Oregon and five square miles in T. 47 N., R. 29 E., and R. 30 E. of Nevada. The town of Denio, Nevada is included in the southeastern part of the thesis area.

Access to the area is provided by a graded gravel road paralleling the eastern front of the Pueblo Mountains. The central part is reached by unimproved dirt roads to cattle salt licks, reservoirs, water holes, and mineral prospects. The eastern part is accessible only by hiking or by traveling overland in off-highway vehicles from Oregon End Ranch, four miles east of the area.

Relief

The lowest elevation in the area is 4,202 feet at Denio, while the mountain just north of Denio Canyon has a maximum elevation of 7,200 feet. Thus the maximum topographic relief is slightly less than

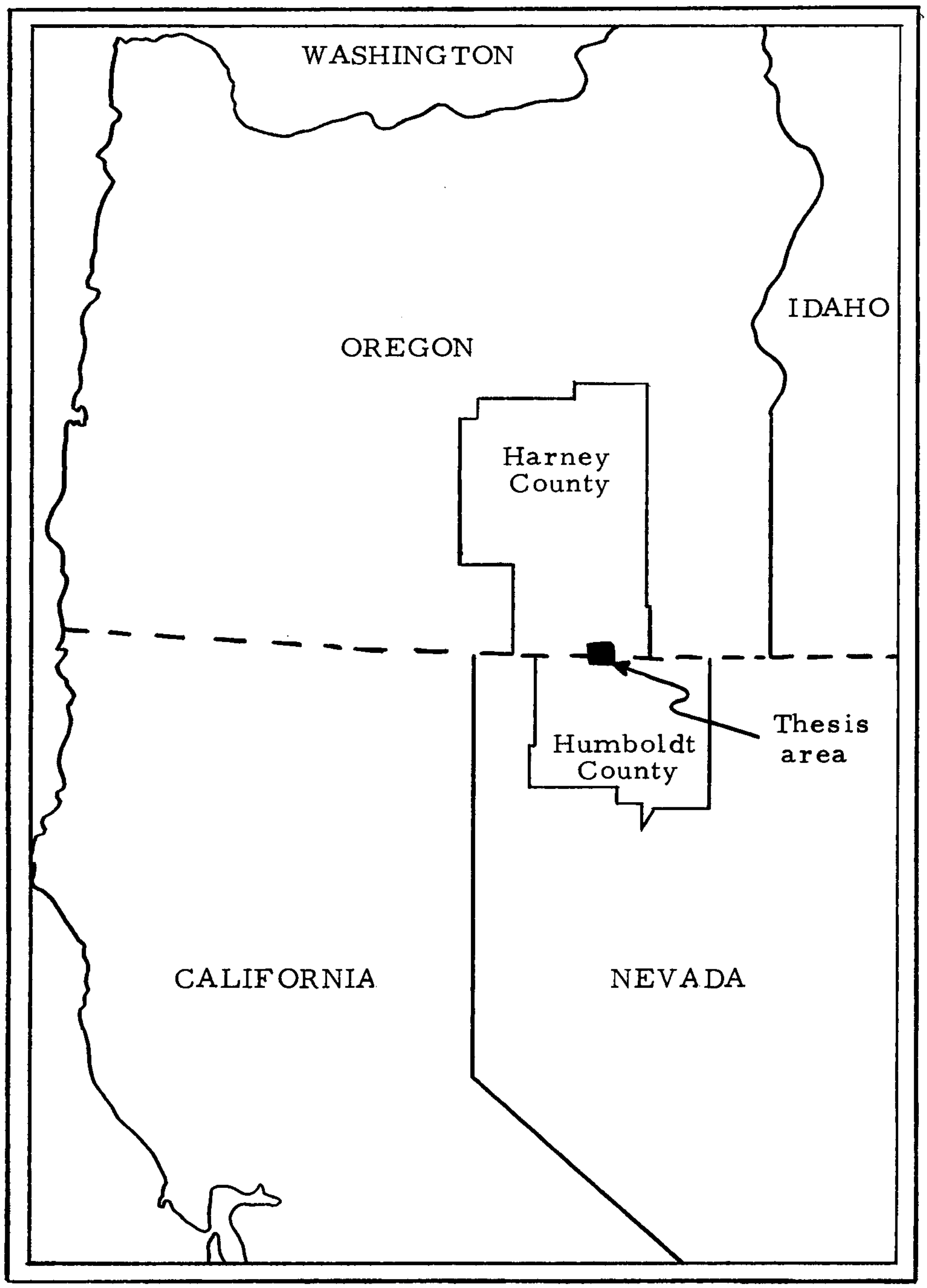

Figure 1. Regional location of thesis area.

3,000 feet.

Drainage

The drainage system is chiefly composed of intermittent streams that flow only during infrequent thunder showers or spring run-off of melting snows. Drainages are short and disappear into the alluvial fans at the foot of the mountains. Most drainage patterns are dendritic in nature.

The larger intermittent streams of the western Pueblo Mountains are tributaries to Rincon Creek, which ultimately drains into Continental Lake, an alkaline playa at the southern tip of the Pueblo Range. The drainages in the central and eastern Pueblo Mountains flow into Pueblo Valley.

Denio Creek is the only perennial stream in the area. Denio Creek flows six miles and terminates in alluvial fans at the eastern front of the Pueblo Mountains.

Climate

Annual precipitation in the area varies from five to ten inches with a maximum precipitation occurring in the months between October and March. A second maximum occurs in the months of May and June. Spring and early summer are characterized by numerous thunder showers. Winter months have moderate to heavy snow falls.

Snow often remains until spring in the higher mountain area.

Summers are characterized by hot days (generally 90 degrees or above), and cool evenings (generally 40 degrees or below). In late August of 1969, frequent westerly dust storms were observed in the late afternoons.

Vegetation

Up to an elevation of approximately 6,000 feet, the dominant plant life is sagebrush with a scattering of various types of grasses. Above 6,000 feet, the vegetation consists of various grasses and minor quantities of flowering plants. The flowering plants grow close to the ground with broad leaf patterns. The grass of the higher elevations provides adequate grazing for fairly large cattle herds.

Vegetation is more abundant and more varied in the moist creek beds. Denio Creek and Van Horn Creek support small groves of willow trees, cottonwood trees and several species of shrub-type plants, as well as a heavier growth of grass.

In alluvial fans and in large dry wash areas, the sagebrush is five to six feet high. The alkaline soil in Pueblo Valley supports short and scanty sagebrush and greasewood plants.

Purpose and Method of Investigation

The primary purposes of this study were to produce a detailed geologic map and to study the structures, stratigraphy, and petrography of the rock units of the area.

The base map used is after Oregon State Highway Base Maps Alvord Lake Three and Four at a scale 1:62, 500. Such drainage maps were not available for the Nevada Portion. The writer traced a drainage map from the United States Geological Survey Fifteen-Minute Quadrangle maps (1:62, 500) and attached this map to the southern border of the Oregon State Highway map. This newly formed base map was then enlarged to a scale of 1:25, 000. For field mapping and for topographic cross-sections, the contours from the Adel Quadrangle map (scale 1:250, 000) were superimposed on the base map. High altitude aerial photographs were also used in field mapping.

Seven weeks of the summer of 1969 were spent in the area constructing a geologic map and collecting samples. Thin sections were cut from samples collected, and two months were spent during the winter of 1969-1970 on a detailed petrographic study of rocks in the area.

The following is a discussion of laboratory techniques used. The Michel-Levy method was used for determining the anorthite content of plagioclase feldspar. Anorthoclase was classified on the basis of a medium 2V angle ($45-50^{\circ}$). Microcline was distinguished from orthoclase on the basis of cross-hatched twinning. Mesolite was recognised on the basis of high relief and low birefringence.

Nontronite and saponite were recognised as birefringent clay-like masses and separated on the basis of their respective colors of green and yellow. Phlogophite was classified on the basis of light yellow-gold color and "birds-eye" extinction. The 2V measurements were estimated. Modal analysis tables represent 600 point counts. Other percentages were estimated using volume percent illustrated tables as a guide. Chemical data were provided by Dr. E. M. Taylor (of Oregon State Geology Department) a sample fusion technique for X-ray florescence.

Previous Work

The earliest recorded work in south-central Oregon and northwestern Nevada was that of Blake (1873), who described the general geology, structures, and geomorphology of the Pueblo Mountain area. Russell (1884) made a general reconnaissance study of southeast Oregon. Later, Russell (1903) revisited the area and prepared a preliminary report on artesian basins. He briefly described the geology and structures of the Steens-Pueblo Mountains. Davis (1903) has also described the geology of these mountain ranges.

A geological and water reconnaissance map was constructed by Waring (1908-1909). The first stratigraphic dating was done by Merriam (1910) in studies of the geology and fauna of the Virgin Valley beds 20 miles southwest of the thesis area.

The first discussion of the structure of the area was written by

Smith (1927). He proposed high angle thrust faulting as the cause of Basin and Range structures in the Steens and Pueblo Mountains. Later, Fuller and Waters (1929) contended that Basin and Range structures in the area were produced by tension and not by compression. In 1931, Fuller published a paper on the geomorphology and the volcanics of the Steens Mountains. Piper, Robinson and Park (1939) made a study of the geology and ground water of Harney Basin. In 1943, Nolan published a paper on the Basin and Range Province of Utah, Nevada, and California.

A study was conducted by Ross (1941) on the geology and mercury deposits of the Steens and Pueblo Mountains. The study of Ross was so well received that Williams and Compton (1953) wrote a similar but more detailed paper on the same area. Van Houten (1956) did a reconnaissance study of the Cenozoic sedimentary rocks of Nevada.

More recent work was done by Willden (1961) with a reconnaissance map of the geology of Humboldt County, Nevada. Later Willden (1964) prepared a supplementary paper describing the geology and mineral deposits of Humboldt County. In 1965, Walker and Repenning prepared a reconnaissance map of the Adel Quadrangle of Oregon to supplement the geologic work of Willden in Nevada. Baldwin (1964) described the geology of the area in his book "Geology of Oregon."

Several masters and doctoral theses have been written on local areas of the region of which the following might be listed:

Wilkerson, W. L., 1958. The geology of Steens Mountain, Oregon. M.S. thesis, University of Oregon.

Fryberger, J. S., 1959. The geology of Steens Mountain, Oregon. M.S. thesis, University of Oregon.

Johnson, G. D., 1960. Geology of the northwest quarter Alvord Lake Three Quadrangle, Oregon. M.S. thesis, Oregon State University.

Maloney, N. J., 1961. Geology of the eastern part of Beaty Butte Four Quadrangle, Oregon. M.S. thesis, Oregon State University.

Avent, J. C., 1965. Cenozoic stratigraphy and structure of Pueblo Mountains region, Oregon-Nevada. Ph.D. thesis, University of Washington.

Carlton, R. W., 1968. The structure and stratigraphy of a portion of the Trout Creek Mountains, Harney County, Oregon. M.S. thesis, Oregon State University.

Wendell, W. G., 1969. The structure and stratigraphy of the Virgin Valley-McGee Mountain Area, Humboldt County, Nevada. M.S. thesis, Oregon State University.

Bryant, G. T., 1969. The general geology of the northern-most part of the Pine Forest Mountains, Humboldt County, Nevada. M.S. thesis, Oregon State University.

Apart from these theses, very little detailed work has been done in the Steens and Pueblo Mountains. It is hoped, that this thesis will aid in producing more accurate interpretations of regional stratigraphy, distribution, and description of the individual rock units.

Terminology and Definitions

Igneous, metamorphic, and sedimentary rocks are named after classifications defined by Williams, Turner and Gilbert (1954), Turner and Verhoogen (1960), and Travis (1955). Textural features are classified after the same authors. Hydrothermal alteration groups are classified after those proposed by Creasey (1959, 1966).

Foliation classifications are after Whitten (1965) and Turner and Weiss (1963), while metamorphic grades and facies classifications are after Turner and Verhoogen (1960) and Turner (1968). The term "foliation" is used repeatedly in the text. The writer prefers the definition proposed by Turner and Weiss (1963, p. 97) for foliation, being "...all types of mesoscopically recognizable s-surfaces of metamorphic origin." Turner and Weiss (1963, p. 28) define s-surface as "...any kind of penetrative planar structure in rocks."

REGIONAL SETTING

The Steens and Pueblo Mountains are in the northern-most part of the Basin and Range Province. The Pueblo Mountains are characteristically tilted block mountains, bounded on the eastern, or front face, by a fault scarp with a long gentle dip slope on the back side.

The oldest rocks in the area are the Permian-Triassic metamorphic sequence that crops out on the eastern front of the Pueblo Mountains. They consist of metavolcanics and metasediments. Rock types include greenstones and chlorite, biotite, sericite, and talc schists. In the Jackson Mountains, 45 miles to the south, weakly metamorphosed volcanic and sedimentary rocks are found which contain fossil evidence indicating a Permian-Triassic age. Despite the somewhat higher metamorphic rank of the rocks in the Pueblo Mountains, the close lithologic similarity suggests a correlation. The metamorphic rocks of the Pueblo Mountains are cut by granodioritic and monzonitic intrusive rocks of upper Jurassic to Cretaceous age.

A thick sequence of basalt was deposited in the Pueblo Mountain area in middle Miocene time. They can be correlated with the Steens Basalt to the north. These basalts are generally porphyritic and consist of non-vesicular flows intertonguing with vesicular amygdaloidal to glomeroporphyritic flows. The flows appear to have been derived in part from large fissures or feeder dikes that were mapped in the thesis area.

The Canyon Rhyolite Formation was named by Merriam (1910). The type section is found in the Virgin Valley area, 20 miles southwest of the thesis area. Detailed studies have shown the formation to be made up of a lower member with rhyolite flows and a upper member made up of rhyolite welded tuffs (Wendell, 1969). Merriam (1910) has dated the Canyon Rhyolite as middle to late Miocene age. Within the Pueblo Mountains, the Canyon Rhyolite is restricted to the southern tip of the range where it conformably overlies the Steens Basalt.

A sequence of tuffaceous sedimentary rocks, a thick sillar sequence, and several welded ash-flow tuffs (from bottom to top) overlie the Canyon Rhyolite and the Steens Basalt with a slight unconformity.

Quaternary alluvium occurs throughout the region as recent lacustrine, alluvial fan, and eolian deposits. Substantial thicknesses of alluvium form fans along the eastern front of the Pueblo Mountains and fill Alberson Basin.

STRATIGRAPHY

Little detailed geologic mapping has previously been done in the Pueblo Mountains. The units described in this study are essentially the same as those defined by Burnam (1970) in the area immediately to the south. However, this area contains several intrusive units not found to the south. The principal rock units defined by this study are listed in Table 1.

Permian-Triassic Metamorphic Rocks

Distribution and Topographic Expression

The largest exposures of basement rocks are to the north in the vicinity of Pueblo Mountain. At Pueblo Mountain, they have an east-west outcrop width of more than four miles. Within the thesis area, the largest outcrop is 2.3 miles along the northern border of the area. It narrows to 1.3 miles in width along the southern border. The total outcrop area of pre-Tertiary crystalline rocks is 10.3 square miles. Section measurements in the metamorphic sequence were considered impractical because of irregularities of foliation related to folding faulting, and the emplacement of intrusives.

The pre-Tertiary basement rocks form the highest features of the Pueblo Mountains. These crystalline rocks stand as bold jagged outcrops because of their resistance to erosion and differential

Table 1. Rock units found in the thesis area.

Age	Rock units	Thickness (feet)	Description
Quaternary	Alluvian		Lacustrine playa lake deposits, lacustrine gravels, alluvial fans, and fluviatile gravels, sands and silts.
Middle to Late Miocene	Welded tuffs	139	Four crystal rich ignimbrites. Poorly consolidated zones have been mostly removed by erosion, densely welded zones show prominent eutaxitic texture with flattened pumice fragments.
Middle to Late Miocene	Sillar	216	Poorly welded crystal rich tuff. Contains pumice fragments and basaltic fragments of cobble size.
Middle to Late Miocene	Tuffaceous sedimentary rocks	534	Stratified deposit of tuffaceous siltstones, sandstones, and conglomerates. Poorly consolidated.
	Probable Minor Unconformity		
Middle to Late Miocene	Steens Basalt	4,832	Vesicular and non-vesicular porphyritic basalts, often amygdaloidal or glomeroporphyritic.
	Marked Angular Unconformity		
Jurassic to Cretaceous (?)	Acidic intrusions		Medium to acidic intrusions forcefully emplaced into the metamorphic sequence. Three intrusions: quartz monzonite, biotite granodiorite, and quartz diorite. All three are porphyritic.
Permian to Triassic (?)	Metamorphic sequence		Metamorphosed eugeosynclinal sediments: greenstones, phyllites; phyllitic schists; chlorite, biotite and sericite schists; quartzite lenses; and carbonate rich metamorphic rocks.

weathering along foliation planes. Slopes in this terrain are invariably steep.

Field Relations

The Permian-Triassic metamorphic rocks weather to platy tabular slabs. Slopes are covered with a thin regolith made up of light-gray to light-brown soil rich in pebble-sized fragments of platy rock debris.

Quartz veins are common throughout the metamorphic terrain and especially near faults and intrusives. The veins are generally less than one inch thick and they may either cut or follow foliation planes. The quartz veins postdate all other types of veining.

Epidote-quartz veins, up to 0.75 inches wide, are also common near intrusive contacts. These veinlets seldom follow the foliation planes. They cross-cut both metamorphic and nearby younger intrusive rocks.

Two aplite dikes intrude the metamorphics on the ridge crest one mile south of Denio Canyon, and a third dike crops out half-way up the face of the fault scarp between Denio Canyon and the southern border of the thesis area. They range from 0.5 to two feet in width. Normally the aplite dikes are concordant with the foliation in the metamorphic host rock. However, the north-south trending aplite on the fault scarp is discordant to the northeast trending foliation pattern.

The pre-Tertiary crystalline rocks are bounded on the east by a normal fault. To the west, the Miocene basalt sequence caps the crystalline rocks.

Foliations in the metamorphic rocks strike N 15 - 30° E. and dip 45 - 65° SE. Although the trend is normally constant throughout the area, exceptions are found locally where the foliations have been disturbed by faulting or intrusive emplacement. Within the metamorphics, the foliation appears to be parallel to the original bedding as it is concordant with quartzite lenses that originally were beds of quartz rich sandstones.

Classification and Petrography

Metamorphic grade of the regionally metamorphosed rocks is middle to upper greenschist facies. The metamorphic grade of the contact metamorphosed rocks is albite-epidote hornfels facies. Contact aureoles are uncommon and seldom exceed 100 feet in width.

The metamorphic sequence is made up of interbedded greenstondes, semischists, various types of schists, and phyllites. Occasional lenses of quartzites are randomly distributed through the sequence.

Greenstones. Greenstones are the most abundant rocks in the metamorphic sequence. Petrographic studies indicate that albite, biotite, quartz, epidote, actinolite, and possibly sericite are typically the major minerals. Minor minerals are sphene, magnetite, ilmenite, chlorite, clinozoisite, carbonates, and apatite. Locally, microcline and rutile occur in minor amounts. The color of these rocks is dark greenish-gray (5GY 4/1) and is caused by an abundance of epidote, biotite, actinolite, and chlorite.

Metacrysts are albite. Infrequent twinning and aggregate textures of the metacrysts suggests replacement of the calcium rich plagioclase phenocrysts of the parent mafic volcanic rocks by albite. Biotite is green and occurs as fine-grained schistose aggregates. Chlorite and actinolite are commonly associated with biotite. Sericite may also be present in the fine-grained schistose masses. Quartz and albite occur as fine-grained aggregates in the greenstones. Epidote and clinozoisite are found as veinlets and disseminated minerals throught the host.

Sodium metasomatism as albitization is evident locally where the greenstones are in contact with the quartz monzonite intrusive. This alteration is gradational from the albitized rock near the contact to unaltered greenstone 300 feet from the contact. The mineral assemblage in altered rock is typically albite (An_8), sphene, apatite, clinozoisite, quartz, and anorthoclase. The anorthoclase is restricted to albite veinlets that cross-cut the altered rock. Clay minerals are predominantly concentrated in cores of the albite grains. The altered greenstone is light greenish-gray (5GY 8/1).

Semischists. Semischists are derived from the metamorphism of wacke sandstones. They are recognised by relics of rounded sand-sized grains of the original framework within a highly schistose groundmass. A crude fracture cleavage parallels the schistosity.

Metacrysts (replaced framework grains) are composed of sericite, quartz, chert, and albite. A typical mineral assemblage of the schistose groundmass contains quartz, albite, sericite, biotite or chlorite, epidote, and sphene. Opaque minerals include magnetite and ilmenite that are randomly disseminated throughout the host.

Schists. The schists are generally fine-grained and exhibit large variations in mineralogical compositions. Rock types include biotite, chlorite, sericite, and talc schists. Quartz and albite are stable and persistent minerals common to each of these rock types. Minor minerals include tremolite - actinolite, epidote, sphene, magnetite, ilmenite, and hematite. Rutile crystals are less commonly associated with sphene.

Mineral assemblages and schistose textures indicate the parent rocks were of sedimentary and volcanic origin. Many of the biotite and chlorite schists were probably originally fine-grained flows or pyroclastics of intermediate to mafic composition prior to regional metamorphism.

Phyllites. Phyllites typically have a mineral assemblage of quartz, sericite, chlorite, carbonates, albite, microcline, and epidote. Magnetite and rutile are sparcely disseminated in the rock. Quartz veins (less than 0.2 mm thick) parallel the schistosity. Microcrystalline mica oriented parallel to the schistosity gives the rock a sheen on fractured surfaces.

The fine-grained character and the alumina and silica rich mineral components of the phyllites suggest that the parent was a mudstone.

Quartzites. Quartzites consist almost entirely of quartz grains that display secondary overgrowths. A few randomly disseminated grains of magnetite and hematite are present. The monomineralic nature of the quartzites indicates the parent rocks were quartz-rich sandstones.

Hornfelses. Contact metamorphic rocks are characterized by an equigranular groundmass averaging 0.3 mm with occasional metacrysts averaging 2 mm in length.

Metacrysts consist of albite and quartz. The hornfelsic groundmass is composed principally of albite, quartz, sericite, and biotite. Minor minerals include epidote, cordierite, magnetite, and ilmenite.

Origin

The metamorphic sequence of greenstones, semischists, schists, phyllites, and quartzites was presumably derived from interbedded mafic lava flows and pyroclastics, wacke sandstones,

Figure 2. Looking northwest toward the mouth of Denio Canyon. The mountainous area is produced by resistant pre-Tertiary crystalline rocks.

mudstones, quartz sandstones, and cherts. The original rocks are typical deposits of a mobile eugeosynclinal belt. Regional metamorphism took place during subsequent late-stage destruction of the geosyncline. Incipient contact metamorphism occurred during later emplacement of plutons.

Age and Correlation

The metamorphic rocks of the Pueblo Mountains are similar to those in the Jackson Mountains 45 miles to the southeast. The Jackson Mountain sequence is less metamorphosed and is fossiliferous. It has been paleontologically dated as Permian to Triassic in age (Willden, 1964).

Pre-Tertiary Intrusive Rocks

Distribution

The pre-Tertiary intrusives crop out over an area of approximately 2.9 square miles. They include a quartz diorite, granodiorite, and a quartz monzonite. The largest intrusive consists of a quartz monzonite that covers an area of 2.0 square miles. Within the area is a small intrusion of granodiorite of about 0.1 square mile, and immediately east of Alberson Basin, a quartz diorite crops out over an area of 0.8 square mile.

Biotite Granodiorite

Distribution and Character. The biotite granodiorite is restricted to the eastern front of the Pueblo Mountains, about half-way between the mouth of Denio Canyon and Van Horn Canyon. The intrusive is nearly one half mile long and only 250 yards wide in the widest part, at the southern end. The elongate body trends northeast and was emplaced discordantly in a direction subparallel to the strike of pre-Tertiary metamorphic rocks. The intrusion exhibits strongly brecciated contacts against the adjacent metamorphic host rocks.

The igneous texture and lack of foliation distinguishes the granodiorite from the pre-Tertiary metamorphic rocks that it intrudes. The fresh surface is medium gray (N5) and weathers to a medium dark gray (N4). The biotite granodiorite is darker than any other rock type in the immediate vicinity.

Jointing is poorly developed, thus the biotite granodiorite has a more massive outcrop pattern than other intrusives in the area.

Within the intrusive, mafic minerals are oriented parallel to the contact to form a subtile banding effect. This crude gneissoid type banding can only be seen within the outermost 30 feet adjacent to the contacts.

Lithology and Petrography. The biotite granodiorite has a medium to fine-grained hypidiomorphic porphyritic texture. Phenocrysts of plagioclase and microcline attain a length of 2.0 mm and comprise six percent of the rock. Groundmass grains average 0.5 mm in length. Plagioclase, quartz, microcline, and biotite are major minerals. The dominant alteration minerals are epidote, clinozoisite, and sericite. Table 2 presents a modal analysis of typical biotite granodiorite.

Quartz is generally interstitial between the andesine and microcline grains. Fine-grained quartz aggregates are also found in small cross-cutting veins. Microcline anhedra occasionally have thin intergrowths of albite, forming microcline-microperthite. Andesine (An_{35}) phenocrysts comprise 90 percent of the total phenocrysts and are commonly fractured and bent.

In the groundmass, andesine grains are anhedral and have poorly developed twins. A thin zone of myrmekite (less than 0.1 mm wide) is sometimes developed in the andesine grains in contact with microcline. Andesine is altered to sericite and clay minerals, and is being replaced by epidote and clinozoisite. Green-brown books of primary biotite are characteristically replaced by green hydrothermal biotite, leaving an opaque residue along relic cleavage traces.

Accessory minerals are principally magnetite, ilmenite, sphene, apatite, and zircon. Disseminated anhedra of magnetite and ilmenite comprise 5.4 percent of the rock. Subhedral crystals of sphene are typically altered to leucoxene along fractures. Zircon and apatite as subhedral crystals are randomly disseminated throughout the rock.

Table 2. Modal analysis of sample WR-85-A from the porphyritic biotite granodiorite.

Mineral	Percent
Potassium feldspar[1]	5.2
Plagioclase (An_{35})	44.6
Quartz	11.6
Biotite	9.8
Sphene	0.8
Opaques	5.4
Epidote and clinozoicite	16.4
Apatite	1.2
Sericite	4.4
Chlorite	0.4
Zircon	0.2
Total	100.0

[1] Potassium feldspar includes microcline, microcline microperthite, and secondary orthoclase.

Quartz Diorite

Character and Distribution. The porphyritic quartz diorite weathers to form a blocky rubble as a consequence of three directions of jointing. In general, jointing includes a nearly vertical north-trending set, another set that intersects the first at right angles, and a third set that is nearly horizontal.

The weathered surface of this rock is a pale reddish-brown (10YR 5/6), and slopes are characterized by red-brown rock "streamers."

To the east and to the north, this intrusive is in contact with the pre-Tertiary metamorphic rocks. Although the distinction between these two rock types normally can be made on the basis of texture alone, hydrothermal effects have locally obscured the diagnostic schistose and igneous textures. Thus, the contact may be hard to locate precisely. However, the contacts are commonly marked by slight changes in slope and differences in weathering patterns.

Along the western margin the porphyritic quartz diorite is in contact with the Steens Basalt. The basalt-intrusive contact is sharp and easily recognised by a strong topographic break in slope. The more resistant intrusive forms steeper slopes relative to the less resistant basalt flows. A strong color difference between the two rock types is evident.

Lithology and Petrography. The porphyritic quartz diorite has a medium-grained hypidiomorphic inequigranular texture. Phenocrysts of plagioclase and hornblende attain a length of 3.0 mm and comprise eight to ten percent of the rock. Groundmass grains average 0.8 mm in length. Plagioclase, quartz, and orthoclase are the major minerals. The dominant alteration minerals include sericite, hydrothermal biotite, and epidote. Table 3 lists a modal analysis of this rock.

Quartz occurs as interstitial anhedra. Secondary quartz is present as small veinlets. Orthoclase occurs in euhedral to anhedral grains. Occasionally, orthoclase has minor intergrowths of albite forming a thinly laminated perthite. Secondary orthoclase of hydrothermal origin represents early stages of replacement of andesine, and is preferentially located along the albite twin planes. Andesine (An_{31}) phenocrysts have irregular crystal outlines. Andesine of the groundmass forms stubby subhedral crystals with well developed twins. Sericite has strongly replaced the andesine grains. Green-brown hornblende laths attain a length of 3.0 mm and have been partially altered to biotite, especially along cleavage traces.

The accessory minerals are principally apatite, sphene, and magnetite. Disseminated euhedra of apatite and magnetite occur in small quantities. Small quantities of anhedral sphene have partially altered to leucoxene along fractures and grain boundaries.

Quartz Monzonite

Distribution and Character. The porphyritic quartz monzonite

Table 3. Modal analysis of sample WR-8 from porphyritic quartz diorite.

Mineral	Percent
Orthoclase	5.0
Plagioclase (An_{31})	56.2
Quartz	10.6
Biotite	6.2
Hornblende	6.2
Sphene	0.2
Opaques	3.0
Epidote	3.8
Apatite	0.2
Sericite	8.2
Chlorite	0.4
Total	100.0

crops out over a surface area of 2.0 square miles between Denio Canyon and Van Horn Canyon. The intrusion cuts the pre-Tertiary metamorphic rocks and, in part, is capped by the Steens Basalt to the west. The contact between the basalts and the intrusive is an eriosional contact indicating an unconformity between the two rock types.

Three-directional jointing produces a coarse blocky weathering pattern. Individual blocks range from two to ten feet on a side. The quartz monzonite has a light-gray (N7) fresh surface and weathers to a moderate reddish-brown (10R 4/6).

An intrusion breccia is often present along the quartz monzonite-metamorphic contact. Fragments of the metamorphic rocks were torn away from the wall and incorporated in the intrusion forming a highly irregular contact. The intrusive has partially assimilated these blocks forming a poorly defined border around the individual fragments. The included fragments comprise nearly 60 percent of the intrusive at the contact. Small xenoliths (two and three inches in diameter) are present throughout the intrusive.

Lithology and Petrography. The quartz monzonite has a coarse grained hypidiomorphic porphyritic texture. Phenocrysts of plagioclase, microcline, and hornblende attain a length of 6.5 mm and comprise ten percent of the rock. Groundmass grains average 1.7 mm in length. Plagioclase, microcline, and quartz are the major minerals. The dominant alteration minerals include hydrothermal biotite, epidote, and sericite. Table 4 lists a modal analysis for two samples of the quartz monzonite. These two samples were chosen to demonstrate the large compositional variations caused by hydrothermal alterations. The more altered sample (WR-53) shows an increase in introduced biotite, quartz, and secondary orthoclase and a decrease in hornblende and plagioclase.

Quartz occurs as intestitial anhedra. Secondary quartz is present as small veinlets and as small anhedral grains localized along fractures. Anhedral grains of microcline fill the intersticies between the plagioclase grains. Albite intergrowths produce microcline-microperthite complexes in 15 percent of the total microcline grains. The plagioclase varies from calcic albite to sodic oligoclase (An_{9-12}), but is dominantly oligoclase. Phenocrysts of plagioclase are euhedral and often show normal zoning. Thin zones of myrmekite (0.2 mm or less) are generally developed along the plagioclase-microcline contacts. Plagioclase alters to sericite and is being strongly replaced by secondary orthoclase.

Accessory minerals are principally hornblende, sphene, magnetite, and apatite. Green-brown hornblende laths are strongly altered to hydrothermal biotite, leaving opaque residues along relic cleavage traces. Small anhedra of sphene have leucoxene alteration along fractures. Magnetite and apatite subhedra are disseminated in

Table 4. Modal analysis of porphyritic quartz monzonite (samples WR-38 and WR-53, respectively.

Mineral	WR-38 Percent	WR-53 Percent
Potassium feldspar[1]	20.2	26.8
Plagioclase (An_{9-12})	34.8	23.8
Quartz	14.2	24.4
Biotite	8.8	13.8
Hornblende	11.6	0.6
Sphene	0.6	0.4
Magnetite	1.4	0.2
Epidote and clinozoisite	4.8	7.8
Apatite	0.6	0.8
Sericite	1.8	1.4
Chlorite	1.2	0.4
Total	100.0	100.0

[1] Potassium feldspars include microcline, microcline-micropethite, and secondary orthoclase.

small quantities throughout the rock.

Mode of Emplacement

The biotite granodiorite and the quartz diorite are discordant intrusions. The direction of elongation of the biotite granodiorite intrusive is parallel to the strike of metamorphic foliations but the contacts dip more steeply than the dip of foliations. The quartz diorite contacts do not parallel the strike or dip of metamorphic foliations. Both intrusives have brecciated the metamorphic host rock, indicating forceful emplacement.

Extensive brecciation, distortion, and displacement of metamorphic rocks demonstrates the forceful emplacement of the quartz monzonite intrusion to form discordant contacts with the metamorphic country rocks. Numerous roof pendants of the metamorphic rocks were distorted during the emplacement of the intrusive.

Correlation and Age

Because none of the intrusives are in contact with other intrusives of the area, no relative ages were determined. In the text, the intrusives are listed in order of increasing size.

The youngest pluton in the Pine Forest Range (near Duffer Peak), 15 miles south of the thesis area, is dated by K-Ar methods as 96 million years or Middle Cretaceous in age (Smith, 1969). The Pine

Forest plutons cut metamorphic rocks similar to those in the Pueblo Mountains, and have similar lithologies to the Pueblo Mountain plutons. Thus, the plutons of the Pueblo Mountains are correlated with the plutonic activity of the Pine Forest Range and are considered Late Jurassic to Middle Cretaceous in age.

Steens Basalt

Distribution and Topographic Expression

The Steens Basalt is the most abundant rock type in the area of study. The outcrops cover a 12 square mile area. The thickest section of basalt is along the northern border of the thesis area where 4,832 feet of basalts were measured in an east-west traverse. In the southern part of the area, less than 3,000 feet of basalts are present.

The basalt sequence characteristically produces a series of north-south trending cuestas and valleys. Resistant flows form prominent cuestas that are locally cross-cut by streams, whereas flow breccias and less resistant vesicular flows weather more rapidly to form valleys. The cuestas dip 21° to 25° to the west. Inface slopes of the cuestas are often bold cliffs of pseudo-columnar basalts. Much of the inface slope is made up of talus at the foot of the basalt cliffs.

Stratigraphic Relationships

An angular unconformity separates the pre-Tertiary crystalline rocks from the Steens Basalt flows. Foliations of the underlying metamorphics strike northeast and dip steeply to the southeast, whereas the basalt flows strike north-south and dip 20° to 25° to the west. Topographic highs within the pre-Tertiary rocks existed during the early deposition of these basalt flows. Interbedded between the first and second flows of the basalt sequence is an arkosic sandstone more than 20 feet thick that is composed of pre-Tertiary crystalline rock and Miocene basalt detritus. The metamorphic and intrusive detritus was derived from the erosion of topographically higher terrain that consisted of pre-Tertiary crystalline rock. The thinner section of basalt in the southern part of the area suggests the pre-Tertiary crystalline rocks had to have been as much as 1,800 feet higher in elevation than in the northern part at the time the basalts were extruded.

The Steens basalt is overlain by tuffaceous sedimentary rocks.

Approximately 90 percent of the lower 1,900 feet of Steens Basalt consists of intertonguing vesicular, amygdaloidal basalt flows, whereas the remainder consists of non-vesicular varieties. Vesicular amygdaloidal flows comprise only 25 percent of the upper 3,000 feet of this basalt sequence, and dense non-vesicular flows comprise the remainder. Near the top of the section, several aa flows are present, and are characterized by a clinkery surface grading downward to a platy non-vesicular basalt at the base. On several flows where the clinkery rubble occurs at the base, it is inferred that the flow over-rode a fallen part of the clinkery upper surface. Where the aa lava flowed over bodies of water (such as small lakes or streams), the basalt was locally altered and leached to a pale red (5R 6/2) color.

Vesicular amygdloidal basalts are porphyritic to glomeroporphyritic and generally consist of more than 15 percent vesicles and vesicle fillings (calcite, zeolites, and chalcedony). Fresh surfaces are grayish-black (N2) and weathered surfaces are grayish-red (10R 4/2). Non-vesicular basalts are porphyritic with no vesicles. Fresh surfaces are grayish-black (N2) and weathered surfaces are dark reddish-brown (10R 3/4).

Several silicic ash flows are present in the upper 3,000 feet of the basalt sequence. Four ignimbrites were noted in the section measured along the northern border of the area studied. They exhibit compaction and extensive welding. The welded tuffs are normally of local distribution and they generally pinch out laterally within several miles.

The arkosic sandstone between the first and second flows is moderate red (5R 5/4) in color. The average grain size of the framework is 0.9 to 1.0 mm and a clay rich matrix makes up 20 percent of the rock. Pebble-sized grains are infrequently present. The sandstone is well-bedded and the presence of graded bedding, cross-bedding, scour and fill, and truncated bedding structures indicates

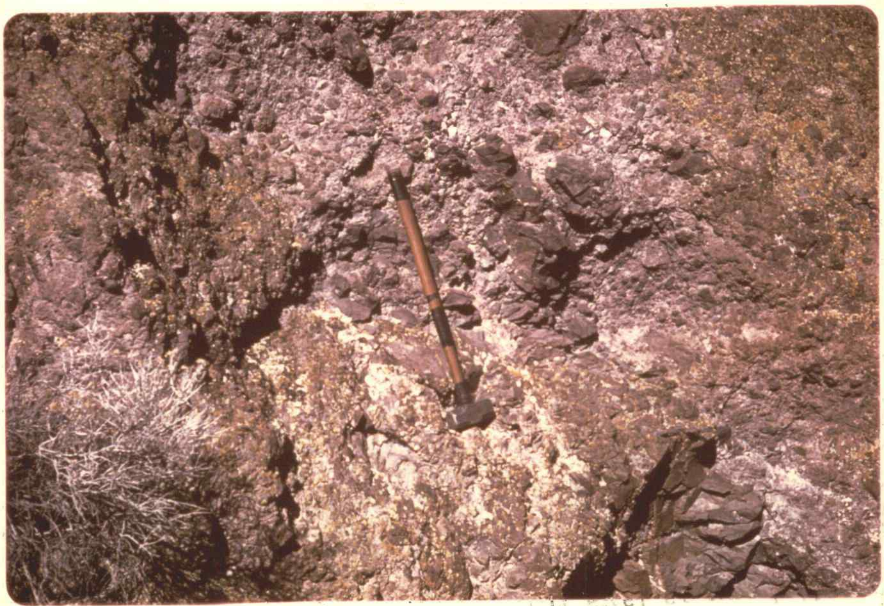

Figure 3. Clinkery aa lava flow showing local alteration from flowing over a small body of water.

fluviatile type deposition.

Several feeder dikes of basalt cross-cut the basalt unit. The dikes are nearly vertical, strike N 35 to 40° W, and exhibit well developed horizontal columnar jointing. They range from 10 to 20 feet in width. Where phenocrysts are abundant, they exhibit a weak flow texture parallel to the contacts of the dikes. The phenocrysts are most abundantly concentrated near the center of the dikes.

Lithology and Petrography

Non-vesicular Basalt. The non-vesicular basalts are characterized by a hypocrystalline porphyritic texture. Phenocrysts of plagioclase feldspar, olivine, and augite comprise up to 15 percent of the rock. Minerals of the groundmass include labradorite, olivine, augite, hypersthene, opaques, apatite, clay minerals, and glass. The dominant rock type is augite-olivine basalt. Olivine-rich basalt typically exhibits a pitted weathering surface caused by the selective removal of olivine crystals.

Euhedral labradorite (An_{54-68}) laths up to 18 mm in length make up more than 90 percent of the total phenocrysts. The large labradorite crystals are commonly bent and fractured. Labradorite has altered to clay minerals and sericite (minor), and infrequently is replaced by calcite. Olivine phenocrysts are subhedral and attain a length of 5.0 mm. The olivine is magnesium rich (2V ranges from about 83 to 89°). Pseudomorphs of iddingsite are not uncommon. Augite phenocrysts are anhedral, attain a length of 6.0 mm, and have 2V's of 60 to 65°. The pyroxene commonly exhibits a pinkish hue that suggests titaniferous augite.

The groundmass consists of randomly oriented labradorite laths that are often embedded in augite to form a sub-ophitic texture. Interstitial glass is present in small amounts and is invariably replaced by nontronite and saponite. Olivine of the groundmass is less altered than the phenocrysts. Hypersthene is uncommon in these basalts and where present, it occurs as microcrystalline anhedra. Small amounts of ilmenite and magnetite are disseminated throughout. Apatite is found locally as a minor accessory component.

Vesicular Amygdaloidal Basalt. The vesicular amygdaloidal basalts characteristically have greater than 15 percent vesicles and amygdules in a hypocrystalline porphyritic texture. Occasionally, phenocrysts cluster together to form a glomeroporphyritic texture. Plagioclase feldspar phenocrysts up to 28 mm in length comprise greater than 10 percent of the rock. Components of the groundmass include labradorite, augite, olivine, hypersthene, magnetite, ilmenite, and chalcedony. The most common rock type is augite basalt.

Phenocrysts consist exclusively of labradorite (An_{56-70}). These large crystals are bent, fractured, and replaced by groundmass plagioclase that suggests a possible disequilibrium during cooling.

Figure 4. Looking north at prominent outcrops of the Steens Basalt. Note the intracanyon flow in center of the picture and the prominent dike to the right.

nontronite and saponite are dominant alteration products of the feldspar as well as glass.

Labradorite (An_{52-63}) of the groundmass occurs as anhedral laths. Anhedral augite grains have 2V's ranging from 50 to 60°, extinction angles of 38 to 42°, and an "hour glass" type of undulatory extinction. Larger crystals of augite tend to produce a sub-ophitic texture where they enclose labradorite laths. Nearly all of the subhedral crystals of olivine have altered to iddingsite along fractures and grain borders. Occasionally nontronite replaces olivine. Anhedral crystals of hypersthene are present in small amounts. Magnetite and ilmenite are disseminated throughout the groundmass. The magnetite weathers to hematite producting the red surface of the rock. Minor amounts of interstitial glass have partially altered to saponite, nontronite, and zeolites.

Zeolites (mesolite, natrolite, and stilbite) are the most abundant vesicle fillings. Calcite is also abundant and botryoidal chalcedony is not uncommon. Cavities are occasionally lined with chalcedony around a central opaline core.

Arkosic Sandstone. The mineralogy of the framework reflects contributions from basalt, quartz monzonite, and metamorphic sources to the arkosic sandstone. Up to 15 percent of the sand grains are made up of sodic plagioclase, quartz, and microcline from the quartz monzonite intrusion; five percent of the rock is made up of sub-angular fragments of highly schistose metamorphic rocks; and the remainder consists of sand-sized grains of labradorite, magnetite, and highly weathered clinopyroxene. The clay-rich matrix comprises up to eight percent of the sandstone. The intersticies are filled by clays and argilic cement. The host also contains minor lenses of silt and clay-sized particles. Less commonly, magnetite lenses are present which weather to hematite and impart a red coloration to the rock.

Ash Flow Tuffs. The ash flow tuffs are thoroughly welded and display pronounced eutaxitic porphyritic textures. All vesicles have been flattened. Phenocrysts of plagioclase feldspar and sanidine up to 4 mm in length comprise two to five percent of the rock. The groundmass is dominantly glass with andesine needles, augite, magnetite, and hypersthene.

Andesine (An_{48-50}) phenocrysts range from 1 to 4 mm in length and are aligned perpendicular to the direction of flattening. They are predominantly euhedral and have been extensively altered to sericite. Subhedral sanidine phenocrysts are 2 to 4 mm in length and comprise 20 percent of the total phenocrysts. Much of the sanidine replaces andesine along fracture surfaces.

The groundmass contains more than 90 percent glass. Glass occurs as flattened and welded shards. Devitrification patterns in the altered shards has produced axiolitic structures. Fine grained disseminated opaque minerals give the fresh glass a grayish-black (N2) color. Highly weathered glass (found in zones of less intense welding) is moderate reddish-brown (10R 4/6) in color. Andesine needles in the groundmass are generally more calcium deficient (An_{44-48}) than their coarser phenocryst equivalent. Plagioclase microlites seldom exceed 0.2 mm in length. The needles have a preferred orientation parallel to flattened shards, or perpendicular to the direction of flattening. Both orthopyroxenes (hypersthene) and clinopyroxenes (augite) are present. The pyroxenes occur as subhedra 0.8 mm in length. Augite may exhibit both twinning and undulatory extinction.

Sericite is the most abundant alteration mineral as it comprises up to 35 percent of the individual andesine grains. Amorphous silica, opal, is an alteration product of glass. It is light-tan in color and is localized as vesicle fillings. In one specimen, a small amount of yellow birefringent montmorillonitic clay (probably saponite) was noted as an alteration product of glass.

On the basis of modal analyses, the tuffs would be classified as welded andesite tuffs. The chemical analysis (see Table 5) however, shows the welded tuffs to have a silica content of 65.7 percent. In accordance with Turner and Verhoogen (1960, p. 275), these rocks would be better classified as rhyolitic quartz latite welded tuffs.

Origin and Depositional Environment

The continuity and distribution of the basalt flows suggests that

Table 5. Chemical analysis of sample WR-113-A via X-ray emission spectroscopy.

Oxide	Percent
SiO_2	65.70
Al_2O_3	16.20
FeO	4.00
CaO	1.40
MgO	0.60
K_2O	6.00
TiO_2	0.83
Na_2O	*
Total	95.13

*Not determined.

they were produced by large fissure eruptions. Evidence for their derivation from fissures is based on the presence of feeder dikes within the area. However, direct visual evidence of a dike grading into a flow was not found.

Flat continuous contacts between flows suggests that the basalts were extruded on a topographically subdued terrain. However, the lowest flow in the sequence thickens and thins indicating a locally dissected terrain prior to volcanism. Erosion between flows was minimal and only one intra-canyon flow was noted in the entire sequence. This canyon is approximately 30 feet deep and 100 feet wide.

The fairly rapid succession of basalt flows is interrupted by local eriptions of silicic ash flow tuffs. In contrast to the basalts, ash flows were locally distributed because their lateral continuity is limited. These silicic eruptions may have been derived from residual differentiation of the original mafic (basaltic) magma. Moreover, the presence of calcic plagioclase in the silicic volcanic rock may indicate possible residual material from the mafic magma, or alternatively, they may represent xenocrysts.

Sedimentary rocks between the first and second flows were produced by weathering and erosion of the first flow and nearby pre-Tertiary rocks. Graded bedding, cross-bedding, and truncated bedding in the sandstone indicate a fluvialtile environment of deposition.

Age and Correlation

The thick basalt sequence can be traced 20 miles to the north into the Steens Mountains, where they were originally defined as Steens Basalt by Fuller (1931). Everden, Curtis and James (as cited by Baldwin, 1964), using potassium-argon dating techniques, determined the age of the Steens Basalt as late to middle Miocene (14.5 to 15 million years). The radiometric dates are in agreement with other investigators who have paleontologically dated the Steens Basalt as middle Miocene. Additionally, Waters (1962) correlates the Steens Basalt with the high-alumina basalts of the Oregon Plateaus.

Tuffaceous Sedimentary Rocks

Distribution and Topographic Expression

The tuffaceous sedimentary rocks crop out over a surface area of 1.9 square miles. The outcrop pattern trends north-south along the western part of the Pueblo Mountains, widening in the westerly trending valley floors and thinning along the easterly projecting ridges produced by overlying welded tuffs. The tuffaceous sedimentary rocks are prominent valley-formers because they are the least resistant rocks in the area. Outcrops are poor and the entire section could not be defined along any one traverse.

Stratigraphic Relationships and Thickness

The tuffaceous sedimentary rocks unconformably overlie the Steens Basalt. A 5 to 8° difference in dip is apparent between the two units. An erosional contact is indicated by the presence of abundant (up to ten percent) basalt fragments in the sedimentary rocks. The sedimentary rocks are conformably overlain by two sillar flows.

The sedimentary sequence consists of 534 feet of stratified tuffaceous conglomerates, sandstones, and siltstones. This unit is normally thin-bedded with individual beds ranging from 0.25 to six inches in thickness. Primary structures include cross-bedding, scour and fill, and graded bedding. A high permeability and porosity reflects the poorly consolidated nature of these rocks. Framework grains are sub-rounded and make up 95 percent of the rock. A clay rich groundmass provides the cement.

These sedimentary rocks are very light-gray (N8) in color and consist of 85 to 90 percent tuffaceous material (pumice fragments and glass shards), six to eight percent basaltic lithic fragments, and randomly dispersed grains of magnetite, micas, and pyroxenes.

Lithology and Petrography

Framework grains are sub-rounded to sub-angular and are most commonly 1.2 to 1.5 mm in diameter. Rock types consist of tuffaceous conglomerates, sandstones, and siltstones.

Greater than 85 percent of the tuffaceous sedimentary rock is composed of highly vesicular pumice fragments and broken glass shards. Numerous grains of basaltic fragments are included in the rock. Broken fragments of highly weathered plagioclase and anorthoclase are not uncommon. Infrequent grains of augite, hypersthene, and yellow-gold phlogophite are disseminated throughout the rock. Cementation stems from an argillaceous matrix.

Clay minerals are produced by alteration of plagioclase, glass, and basaltic fragments. Light yellow-brown opal is produced as an alteration product of pumice fragments.

Origin and Depositional Environment

The tuffaceous sediments were probably produced by reworking of air fall or ash flow tuffs in a fluviatile environment. The sequence probably represents several eruptive phases of the pyroclastic material.

Correlation and Age

The volcanic activity that produced the tuffaceous sedimentary rocks was probably related to the eruptive activity that produced the Steens Basalt sequence. This interpretation is indicated by the presence of silicic tuffs within the Steens Basalt. The age of the tuffaceous sedimentary rocks would then be considered middle to late Miocene.

Sillar Sequence

Distribution and Topographic Expression

The sillar sequence extends from the southern to the northern border of the thesis area. The outcrop width (map view) is narrow because the sillar produces a single bold outcrop and is overlain by the more resistant welded tuffs. Less than one square mile is covered by the surface expression of this rock.

Hoodoos are produced in the outcrop patterns as a result of irregular jointing in this unit. The hoodoos attain 75 feet in height and form bold jagged outcrops.

Stratigraphic Relationships and Thickness

The sillar sequence conformably overlies the tuffaceous sedimentary rocks. The contact is gradational. Sediments are overlain by eight feet of sillar, then 12 feet of sediments, which in turn are overlain by the sillar sequence proper. The contact is generally poorly exposed.

Conformably overlying the sillars is the welded tuff sequence. The contact is generally poorly exposed but can be mapped with ten feet stratigraphically, as the welded tuffs are more resistant and a slight topographic break is found at this zone.

The sillar sequence is 216 feet thick. In the northern part of the

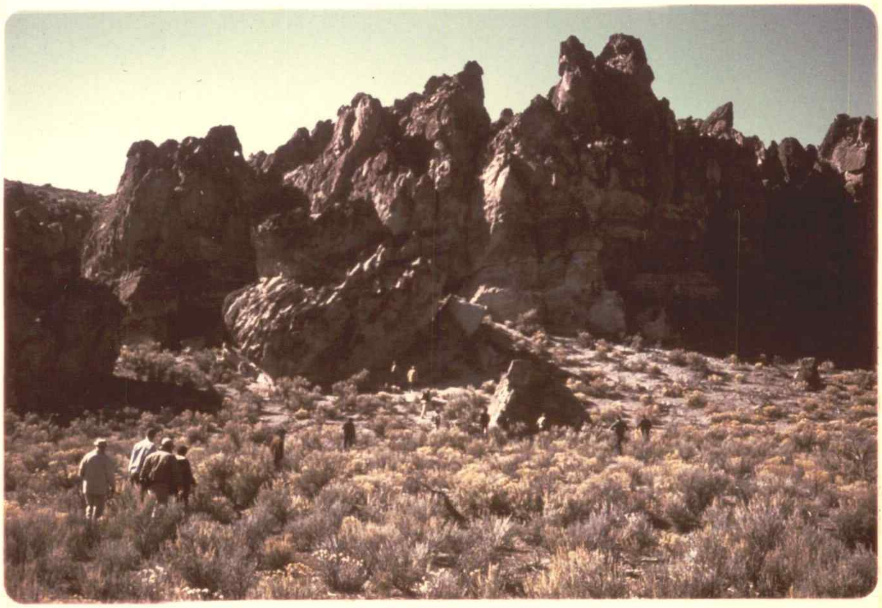

Figure 5. Prominent hoodoos developed in the sillar sequence. The readily eroded tuffaceous sedimentary rocks produced the topographically subdued area in the foreground.

area, the sequence consists of two separate sillar members. In the southern part of the area, only the lower member is present, and the unit is somewhat thinner. The lower member is light-gray (N7) and has one percent basalt fragments, 15 percent pumice fragments, and two percent phenocrysts. The upper member is dark yellowish-brown (10YR 4.2) and has two percent basalt fragments, 30 percent pumice fragments, and five percent phenocrysts.

Lithology and Petrography

The sillar exhibits a poorly welded porphyritic texture. Phenocrysts of anorthoclase and quartz attain a length of 5.0 mm and comprise two percent of the rock. Large fragments of pumice attain a length of 16 mm. The groundmass consists of glass shards, quartz, anorthoclase, augite, and magnetite. Fenner (1948) described poorly welded ash flow tuffs of this nature in Peru for which he proposed the name sillar.

Pumice fragments and glass shards comprise 80 to 90 percent of the rock. The pumice fragments invariably exhibit round vesicles. Subhedral crystals of anorthoclase commonly exhibit carlsbad twins. Anhedral quartz and augite crystals are randomly disseminated. Magnetite anhedra are present in small amounts. Infrequent lithic fragments of basalt average 1.5 mm in diameter and attain a length of 10 mm.

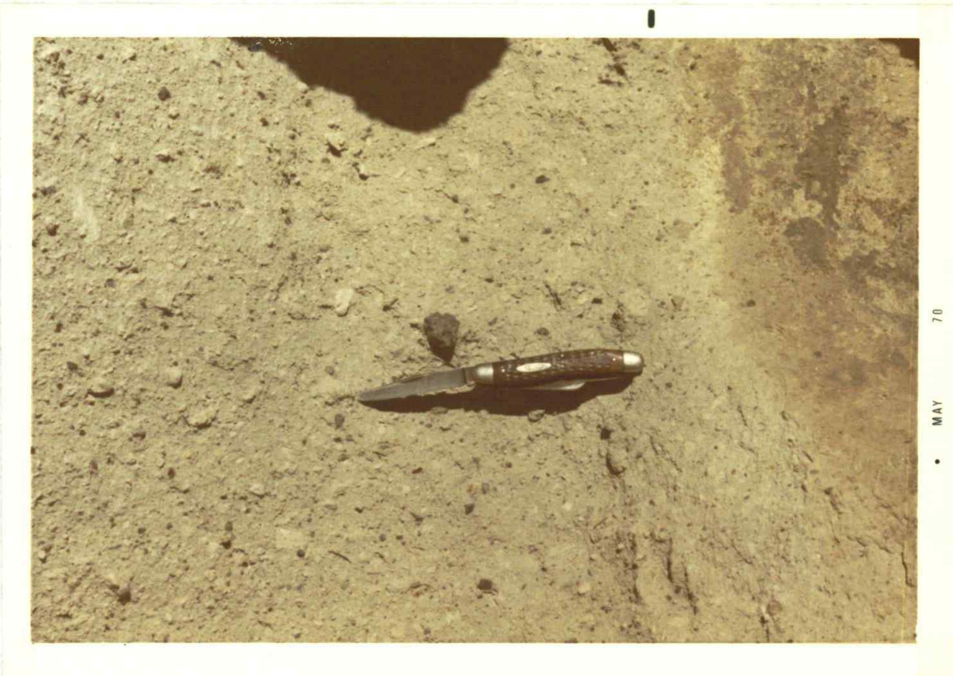

Figure 6. Sillar showing the poorly welded nature of the rock unit. Note the pumice fragments and basalt lithic fragments.

A yellow-brown variety of opal that presumably was derived from the alteration of glass is restricted to vesicle fillings.

Origin and Depositional Environment

The sillar deposits were probably formed by ash flows that spread into flat basins where they consolidated after deposition. The flows were not hot enough to produce extensive welding. However, the presence of abundant lithic inclusions suggests that these deposits were flows and not air fall tuffs.

Correlation and Age

Because of the gradational contact with the underlying tuffaceous sedimentary rocks, the sillar unit is correlated with the same volcanic activity that produced the material for the tuffaceous sedimentary rocks. Thus, the sillar sequence is probably middle to late Miocene in age.

Welded Tuff Sequence

Distribution and Topographic Expression

The ignimbrites strike north-south through the thesis area and crop out over a surface area of 1.6 square miles. Although the unit is thinner than the underlying sillar sequence, the welded tuffs cover a larger surface area because of the long dip slopes exposed. Fairly prominent cuestas of welded tuff dip 16 to 19° to the west. Inface slopes of these cuestas are commonly formed by outcrops of the sillar unit.

Stratigraphic Relationships and Thickness

The welded tuffs conformably overlie the sillar sequence. The ignimbrites extend to the western border of the thesis area where they are covered by alluvium.

The sequence is 139 feet thick and consists of four distinct crystal bearing welded tuff members. Contacts between individual members are poorly exposed and can only be seen in valleys of the northwestern part of the area. In this vicinity, the contacts exhibit erosion between flows as the unconsolidated upper portion of each ignimbrite has been removed. Burnam (1970) has described sedimentary rocks between each of the four members in an area south of the thesis area. These sedimentary rocks are missing in the northern part of the thesis area, but may be present in the southern part where exposures are poor.

Lithology and Petrography

All four members are composed predominantly of glass shards and flattened pumice fragments that form eutaxitic porphyritic textures. The tuffs have abundant quartz and alkali feldspar and are deficient in plagioclase feldspar. All members are named welded rhyolite tuffs.

Quartz generally occurs as double terminated stubby crystals indicating alpha-quartz pseudomorphs after beta-quartz. The second member contains sanidine whereas the others contain anorthoclase as the alkali feldspar. Infrequent grains of phlogophite (or yellow-gold variety of biotite) are randomly disseminated throughout each member. The phlogophite forms eight-sided crystals with opaque borders that indicate pseudomorphs after pyroxene. Ilmenite and magnetite anhedra are found in small quantities in all members.

Chalcedony and yellow-brown opal occur as vesicle fillings in the pumice fragments. Cristobalite and potassium feldspar occur as devitrification products of glass and produce an axiolitic structure. Rising hot gases produced during cooling have caused extensive vapor phase mineralization in the two upper members. It is characterized by the presence of riebeckite, quartz, and potassium feldspar filling vesicles.

All four members exhibit normal vertical welding zonations that define an ignimbrite. Welding grades from poor at the base to well-developed in the lower and middle part of each tuff member. From the densely welded zone, the welding diminishes towards the top.

The distinguishing characteristics of each member are discussed as follows in stratigraphic order of deposition.

Member One. The first member is medium light-gray (N6) and weathers to light brownish-gray (5YR 6/1). It contains seven percent phenocrysts consisting of anorthoclase (four percent) and quartz (three percent). The phenocrysts average 4 mm in length and are euhedral to subhedral in form. The glass contains finely disseminated opaque minerals giving it a medium brown color. Incipient devitrification of glass is present.

Member Two. The second member is characteristically a pale yellowish-brown (10YR 6/2) and weathers to moderate yellowish-brown (LOYR 5/4). It contains 12 percent phenocrysts of sanidine (eight percent), quartz (two percent), and phlogophite (one percent). Phenocrysts average 3 mm in length and are subhedral in form. The glass is light tan and shows incipient devitrification.

Member Three. The third member is light gray (N7), weathers to a pale brown (5YR 5/2), and is porphyritic. Phenocrysts comprise five percent of the host and include anorthoclase (four percent) and quartz (one percent). They average 3.8 mm in length and are euhedral. The glass is dark brown and exhibits moderate devitrification. Extensive vapor phase mineralization is expressed as quartz, potassium feldspar, and riebeckite as vesicle fillings.

Member Four. The upper member is yellowish-gray (5Y 7/2) and weathers to pale brown (5YR 5/2). It contains eight percent phenocrysts consisting of anorthoclase (five percent), quartz (two percent), and phlogophite (one percent). Phenocrusts average 4.5 mm in length and are subhedral in form. The glass is light brown and shows extensive devitrification. Vesicles filled by quartz, potassium feldspar, and riebeckite indicate vapor phase mineralization.

Origin and Depositional Environment

The welded tuffs were produced by solidification of hot nuée ardente flows. As the flows came to rest, internal fusion formed the welded zones. Extensive welding and vapor phase mineralization indicates the flows were originally fairly thick. The depositional basin was flat as is indicated by the straight contacts between flows.

Correlation and Age

The entire sequence of tuffaceous material (tuffaceous sedimentary rocks, sillars, and welded tuffs) have similar mineralogical characteristics. No angular unconformities separate these units. Volcanism that produced this sequence was probably inter-related. As a consequence, the entire sequence of tuffaceous rocks is probably middle to late Miocene in age.

Burnam (1970) correlates this tuffaceous sequence with the Virgin Valley Formation that is middle Miocene in age according to Merriam (1911). The Pueblo Mountain tuffs, however, have a greater number of welded units than are described in the Virgin Valley beds. Even so, the writer does not consider such a correlation improbable.

QUATERNARY DEPOSITS

Quaternary alluvium consists of undifferentiated fluviatile and lacustrine deposits. The fluvial deposits consist of alluvial fans at the mouths of canyons and they contain unconsolidated boulders, cobbles, pebbles, sands, and silts. Alluvial fans are especially prominent along the eastern front of the Pueblo Mountains. Lacustrine deposits of unconsolidated sand, silt, and clay are found in Pueblo Valley. This fine-grained detritus is light in color and suggests that a playa lake was once present in Pueblo Valley. Moreover, the fine-grained nature of sediments over the flat valley floor is strongly indicative of a former lacustrine environment.

GEOMORPHOLOGY

The principal topographic features of the area include Denio Canyon, Van Horn Canyon, and Cowden Canyon. Stream erosion along these and other canyons exumed the pre-Tertiary rocks exposed in this area.

The thesis area can be divided into two distinct geologic units. The eastern one-half to one-third is made up of pre-Tertiary intrusive and metamorphic crystalline rocks. They form prominent northeast trending topographic highs. Steep walled canyons and valleys indicate a youthful stage of stream erosion. Dendritic drainage patterns prevail.

Tertiary volcanics in the western portion of the thesis area constitute the second geologic unit. Numerous cuestas and valleys form the major topographic expression of this unit. The drainage off the western flank of the tilted fault block produces a dendritic drainage pattern in the north-south striking volcanic flows. Cuestas in the basalt sequence form topographic highs that are somewhat lower than ridges of crystalline rock to the east. The less resistant tuffaceous sedimentary rocks and welded tuffs form subdued valleys or cuestas.

Consequent streams, a product of natural drainages off the flanks of a rising fault block, flow in an easterly direction across the pre-Tertiary crystalline rocks. Because Denio, Van Horn, and Cowden Creeks cross the resistant crystalline rocks, the stream valleys were

Figure 7. Looking west along Denio Creek. The prominent cuestas are produced in the Steens Basalt.

probably down-cutting throughout the block faulting episode. Moreover, these consequent streams show evidence of changes of gradient during fault block uplift. For example, Alberson Basin has a thick sequence of alluvium that was deposited when the base level was lower and the stream gradient was less. Dissection of the fault scarp itself is minimal. The valleys along the scarp are shallow and seldom cross the crest of the ridges. Streams in these valleys have high gradients that range from 1, 400 to 2, 000 feet per mile. The high gradient streams are invariably intermittent in discharge.

Thunder showers, springs, and melting snow are sufficient to make running water the most powerful erosional agent in this semi-arid region of sparse ground cover. Stream valleys dissect the entire area. Prominent coalescing alluvial fans are developed along the east and west fronts of the Pueblo Mountains.

Mass wasting is the second most powerful erosional agent. Small rock glaciers are commonly present along steep mountain fronts and cliffs. A few land slides and slump blocks were recognised in the thesis area.

STRUCTURE

The Pueblo Mountains are in the northern part of the Basin and Range Province. This province is typified by north-south trending faults that have produced graben valleys and tilt block mountain ranges.

The Pueblo Mountain area exhibits a physiographic expression that is typical of the Basin and Range type of structure. Pueblo Valley to the east is a graben and the Pueblo Mountains are a tilted fault block. The eastern front of the Pueblo Range shows prominent linear fault scarps (note Plate 1). The entire range has been tilted 20 to 26° to the west, as defined by attitudes of the originally horizontal lava flows. Displacement along the prominent fault is variable from north to south. Along the southern border of the thesis area, the fault exhibits a minimum displacement of 5, 700 feet; whereas along the northern border, it is minimally 7, 800 feet as calculated by extending the eroded lava flows to the fault plane.

Nolan (1943) postulated that the normal faulting of the Basin and Range Province began in Oligecene time and may still be active. The slight angular unconformity between the tuffaceous sedimentary rocks and the Steens Basalt is evidence for active tilting in the Pueblo Mountains during Moicene time. Evidence for recent displacement is provided by the steep, relatively undissected fault scarps along the eastern front of the Pueblo Mountains. More importantly, the fault scarp near the mouth of Denio Creek, cuts both the alluvial fans and basement rocks.

A second prominent north-northeast trending normal fault extends from the southern part of the thesis area to the northern border. The fault cuts the pre-Tertiary crystalline rocks and parallels the basalt contact. The west side is up-thrown relative to the down-thrown eastern block. Erosion has obscured the fault and has rendered quantitative calculations of the movement impossible. The presence of this fault in the northern part of the area may impart errors to calculations of the range front fault. Thus, the estimated 7,800 feet of displacement may represent the combined effects of two faults rather than one.

Other nearly vertical normal faults within the thesis area show two generalized trends. A prominent faulting trend is N 25 to 35° W with a minor conjugate fault system trending N 45° E. All of the basaltic dikes in the area trend N 35 to 40° W. The strong northwest fault and dike trend with conjugate faults trending northeast is readily apparent on the reconnaissance geologic map of the Adel Quadrangle (Walker and Repenning, 1965). Donath (1962) believes that the north-west and northeast faulting trends were originally conjugate strike-slip shears caused by maximum and minimum principal stresses oriented north-south and east-west, respectively. He believes that after these fracture systems were developed, later block faulting occurred along these fractures with dip-slip components producing the present normal faults. Although the thesis area is 140 miles south of the area studied by Donath, the proposed stress fields and movements could be tentatively extrapolated into the Pueblo Mountains as well.

Folding within the thesis area is restricted to pre-Tertiary metamorphic rocks. Although no major folds were recognised, numerous parasitic minor folds were observed. The parasitic folds are isoclinal with prominent northeast trending fold axes. Because the amplitudes of the folds are measured in inches or several feet, they are not recorded on the map.

BRECCIAS

Several breccia zones are present along faults within the metamorphic rocks and along faulted contacts adjacent to the intrusives. Tourmaline embedded in massive quartz as fan-shaped fibers ("sub-bursts") was recognised in these breccia zones. Biotite is also present as green fine-grained, scaley masses and veinlets. Geologic and petrographic evidence suggest both the biotite and the tourmaline are of hydrothermal origin.

A tectonic breccia localized along a fault zone crops out 1,200 feet north of Cowden Canyon, along the contact between metamorphics and a quartz diorite intrusive. The outcrop pattern is circular and presumably represents a breccia pipe. It contains fragments of both intrusive and metamorphic rock, quartz, tourmaline, epidote, and fragments of aplite dikes. The groundmass consists of quartz, tourmaline, and hydrothermal biotite.

ECONOMIC GEOLOGY

Hydrothermal Alteration and Mineralization

Hydrothermal alteration occurs in and near the three granitic intrusives. The intensity of alteration within the intrusives is variable and without an apparent control.

Hydrothermal biotite, sericite, and secondary orthoclase are the dominant alteration minerals. The biotite characteristically occurs in fine-grained felted masses as a replacement of primary mafic minerals and as a whole rock replacement along fractures. Sericite occurs as an alteration product of plagioclase feldspar of the host rock. Secondary orthoclase occurs as a replacement of plagioclase feldspar along grain boundaries and twin planes. Where replacement is advanced, a replacement perthite is developed in the plagioclase grains.

Incipient retrogressive hydrothermal alteration is suggested by the presence of epidote, clinozoisite, and chlorite. Epidote and clinozoisite are developed as an alteration product of biotite. Grains of epidote embay the grain boundaries of biotite. Epidote infrequently occurs as an alteration product with sericite. Chlorite is restricted to the fine-grained felted masses of biotite where it grows at the expense of biotite.

Potassic alteration has formed biotite, sericite, and orthoclase as the dominant assemblage of hydrothermal alteration. As the intrusive cooled, incipient retrogressive alteration of the propylitic alteration type produced epidote, clinozoisite, and chlorite.

Sulfides found within the thesis area include pyrite, chalcopyrite (minor), and cinnabar. The pyrite and chalcopyrite were found near the Denio Canyon area (Farnham property), and the cinnabar was found at the mercury prospect. Small veinlets of crysocola and azurite were found in a breccia zone along the northern tip of the biotite granodiorite intrusion.

Mineral Deposits

Gold Prospects

Numerous small prospect pits are found along the eastern front of the Pueblo Mountains. They were excavated in efforts to find gold-bearing veins. Numerous quartz veins are present, but judging from the limited development, they apparently lack gold. Alluvial fan material in the range front between Cowden Canyon and Denio Canyon has been staked for placer gold. These placer claims have never been in production.

Mercury Prospect

Mr. V. Tiller owns several claims on a mercury prospect located in Oregon (SW1/4, SW1/4, sec. 12, T. 41 S., R. 34 E.). The

Figure 8. Locally altered Steens Basalt found in the fault zone near the mercury prospect.

prospect is along a fault zone in the Steens Basalt. Extensive alteration in the breccia zone has completely obliterated the original basalt. Hydrothermal silica (quartz and chalcedony) and clay alteration minerals have changed the basalt from a dark black color to a grayish orangeish-pink (5YR 7/2). Alteration and mineralization are restricted to the narrow fault zone. Relict textures of the basalt are noted in thin sections with quartz, chalcedony, and clay minerals completely replacing the plagioclase laths.

Extensive percussion drilling and a 30 foot vertical exploration shaft has shown that mineralization is present but not widely enough distributed to warrant exploitation.

The ore mineral is cinnabar and it occurs finely disseminated throughout the latered breccia zone. Hydrothermal fluids that produced the lateration and mineralization probably originated at depth. Perhaps they were derived from a small intrusive at depth that has not yet been exposed by erosion.

Farnham Property

Mr. Ellis Farnham owns and maintains a group of claims on a gold prospect located in the NE1/4, sec. 13, T. 41 S., R. 34 E., and NW1/4, sec. 18, T. 41 S., R 35 E. of Oregon. He has dug two 50 foot vertical chafts from which minor amounts of ore have been produced. Problems with milling the ore have purportedly prevented

Figure 9. Looking east at the gossan along western end of Denio Canyon. The white color is derived from the quartz sericite hydrothermal alteration and the red stains are produced by iron oxide residues left from leaching of sulfides.

full exploitation of the prospect.

The Farnham property has greater geologic potential as a copper deposit. The gold mine shaft is on the northern end of a large gossan. This zone of oxidation is approximately 6,000 feet long in a north-northeast direction and 3,000 feet wide in an east-west direction. Colors of the gossan range from a moderate yellowish-brown (10YR 5/4) to a dark reddish-brown (10R 3/4). Sulfides are present only in Denio Canyon where rapid erosion has cut through the oxidized zone. Denio Canyon is 4,000 feet from the quartz monzonite that is inferred to be the source of mineralization. The sulfides are chiefly pyrite with infrequent grains of chalcopyrite. Most of the gossan was derived from the oxidation of pyrite as suggested by the numerous cellular cavities in the host. Elsewhere, the gossan contains numerous lenses of goethite and hematite that suggest the former presence of copper sulfides. Locally gypsum is present. Much of the gypsum displays euhedral crystal outlines, variety selenite, that suggests it was formed by groundwater activity after the sulfide mineralization.

The mineralization is probably related to the hydrothermal activity associated with the emplacement and solidification of the porphyritic quartz monzonite intrusive to the north. The gossan is generally restricted to the metamorphic rocks; however, minor mineralization is seen along the southern border of the quartz monzonite.

Alteration associated with the hydrothermal activity has affected the metamorphic host rock. Near the porphyritic quartz monzonite, mineral assemblages are indicative of potassic alteration. The significant minerals include secondary biotite, sericite, and orthoclase of hydrothermal origin. In the Denio Canyon area, alteration is characteristically of the quartz sericite assemblage. Extensive introduction of quartz has made the metamorphic host more resistant to weathering and outcrops here are more prominent than anywhere else in the area.

The major fault trending north-northeast through the gossan area may have provided a structural conduit for the hydrothermal fluids. The largest movement along the fault probably took place after hydrothermal mineralization because the gossan terminates against the fault in many areas.

The large size of this gossan clearly justifies more detailed studies of this mineralized zone by a major mining company.

GEOLOGIC HISTORY

The history of the rocks within the thesis area began with deposition of eugeosynclinal sedimentary rocks in Late Paleozoic to Early Mesozoic time. These include impure and quartz-rich sandstones, mudstones, and shales that were accompanied by and interstratified with numerous mafic flows and pyroclastics.

The eugeosynclinal assemblage of sedimentary and volcanic rocks was buried and underwent regional metamorphism to ranks of the middle to upper greenschist facies. Folding accompanied the metamorphism. During Late Mesozoic time, a sequence of granitic intrusions was forcefully emplaced into the regionally metamorphosed assemblage. Hydrothermal activity accompanied the cooling and solidification of one of these plutons and produced the hydrothermal alteration and mineralization present in the Denio Canyon area.

A long period of erosion followed the episodes of regional metamorphism and plutonism. During Eocene and Oligocene time, the area was strongly uplifted to form a welt between a eugeosyncline and miogeosyncline (Nolan, 1943). This period of uplift and erosion produced an angular unconformity between the pre-Tertiary crystalline rocks and the Middle Miocene basalt flows.

The Steens Basalt flows form a thick sequence of lavas produced by Middle Miocene volcanic activity of rapid eruptions from possibly nearby fissures. Extrusion of basalt flows was periodically interrupted by pyroclastic volcanic activity to form minor interbeds of ash flow tuffs. Postdating the basalt flows, a thick sequence of pyroclastic debris was deposited.

The Basin and Range type of normal faulting along the eastern front of the Pueblo Mountains began during Miocene time as suggested by a slight angular unconformity separating the Miocene basalts from the Miocene tuffaceous sedimentary rocks, sillar flows, and welded tuffs. Fault scarps in recent alluvium suggest that tectonic movements continue to the present. The northwest and northeast trending fault systems were developed after Miocene tuff deposition. The most recent movement along these faults is dip-slip.

Thick accumulations of Quaternary alluvium are presently being deposited in the lower regions such as Pueblo Valley. Alluvial fans are prominent features at the mouth of every stream. Recent lacustrine deposits occur as flat lying accumulations of alkali-rich sands, silts, and clays. The lacustrine deposits are probably remnants of earlier playa lake deposition.

BIBLIOGRAPHY

Avent, Jon Carlton. 1965. Cenozoic stratigraphy and structure of Pueblo Mountain region, Oregon-Nevada. Ph. D. thesis. Seattle, University of Washington. 119 numb. leaves.

Baldwin, Ewart M. 1964. Geology of Oregon. Eugene, distributed by University of Oregon Cooperative Book Store. 165 p.

Blake, James. 1873. On the Pueblo Range of mountains. California Academy of Science, Proceedings 5:210-214.

Bryant, George T. 1969. The general geology of the northernmost part of the Pine Forest Mountains, Humbolt County, Nevada. Master's thesis. Corvallis, Oregon State University. 75 numb. leaves.

Burnam, Rollins. 1970. Master's student. Corvallis, Oregon State University. Personal communication. March, April.

Carlton, Richard W. 1968. The structure and stratigraphy of a portion of the Trout Creek Mountains, Harney County, Oregon. Master's thesis. Corvallis, Oregon State University. 116 numb. leaves.

Compton, R. R. 1960. Contact metamorphism in Santa Rose Range, Nevada. Geological Survey of America, Bulletin 71:1383-1416.

Creasey, S. C. 1959. Some phase relations in the hydrothermally altered rocks of porphyry copper deposits. Economic Geology 54:351-373.

________________ 1966. Hydrothermal alteration; in Titley, S. R. and C. L. Hicks, ed., Geology of the porphyry copper deposits of southwestern North America. Tucson, University of Arizona Press. p. 51-74.

Donath, F. A. 1962. Analysis of Basin and Range structure. Geological Society of America, Bulletin 73:1-16.

Fenner, C. N. 1926. Incandecent tuff flows in Southern Peru. Geological Society of America, Bulletin 59:879-893.

Fryberger, John S. 1959. The geology of Steens Mountain, Oregon. Master's thesis. Eugene, University of Oregon. 65 numb. leaves.

Fuller, R. E. and A. C. Waters. 1929. The nature and origin of horst and graben structures in southeastern Oregon. Journal of Geology 37:204-238.

Fuller, R. E. 1931. The geomorphology and volcanic sequence of Steens Mountain in southeastern Oregon. University of Washington Publications in Geology 3:1-30.

Johnson, George D. 1960. Geology of the northwest quarter Alvard Lake Three Quadrangle, Oregon. Master's thesis. Corvallis, Oregon State University. 75 numb. leaves.

Maloney, Neil J. 1961. Geology of the eastern part of Beaty Butte Four Quadrangle, Oregon State University. Master's thesis. 87 numb. leaves.

Merriam, John C. 1907. The Tertiary mammal beds of Virgin Valley and Thousand Creek in northwestern Nevada. Part I. Geologic history. University of California Publications in Geology 6:21-53.

__________ 1910. The Tertiary mammal beds of Virgin Valley and Thousand Creek in northwestern Nevada. Part II. Vertebrate faunas. University of California Publications in Geology 6:199-305.

Nolan, Thomas B. 1943. The Basin and Range province in Utah, Nevada, and California. Washington, D. C. U. S. Geologic Survey. Professional paper 197-D. p. 141-196.

Osmond, J. C. 1960. Tectonic history of the Basin and Range province in Utah and Nevada. Mining Engineering 12:251-265.

Piper, A. M., T. W. Robinson and C. F. Park, Jr. 1939. Geology and groundwater resources of the Harney Basin, Oregon. Washington, D. C. 189 p. (U. S. Geological Survey. Water Supply Paper 841)

Ross, Clarence S. and Robert L. Smith. 1961. Ash-flow tuffs: their origin geological relations and identification. Washington, D. C. 81 p. (U. S. Geological Survey. Professional paper 336)

Ross, C. P. 1941. Quicksilver deposits in the Steens and Pueblo Mountains, Southern Oregon. U. S. Geological Survey, Bulletin 931-J:227-258.

Russell, I. C. 1884. A geological reconnaissance in Southern Oregon. In: Fourth Annual Report of the U.S. Geological Survey. Washington, D.C. p. 431-464.

Smith, James G. 1969. Geologist, U.S. Geological Survey, Alaskan Branch. Personal communications. Menlo Park, California. May 5, 1969.

Travis, Russell B. 1955. Classification of rocks. Golden, Colorado. Quarterly of the Colorado School of Mines. Vol. 50, No. 1. 98 p.

Turner, F. J. and John Verhoogen. 1960. Igneous and metamorphic petrology. New York, McGraw-Hill. 694 p.

Turner, F. J. and L. E. Weiss. 1963. Structural analysis of metamorphic tectonics. New York, McGraw-Hill. 545 p.

Turner, F. J. 1968. Metamorphic petrology. New York, McGraw-Hill. 403 p.

U.S. Weather Bureau. 1957-1963. Climatological data by sections. Annual summaries. Oregon. Vol. 63-72.

Van Houten, F. B. 1956. Reconnaissance of Cenozoic sedimentary rocks of Nevada. American Association of Petroleum Geologists, Bulletin 40:2801-2826.

Walker, George W. and Charles A. Repenning. 1965. Reconnaissance geologic map of the Adel Quadrangle, Lake, Harney, and Malheur Counties, Oregon. Washington, D.C. (U.S. Geological Survey. Miscellaneous Geologic Investigation Map I-446)

Waring, Gerald A. 1908. Geology and water resources of a portion of south central Oregon. Washington, D.C. 86 p. (U.S. Geological Survey. Water Supply Paper 220)

________________ 1909. Geology and water resources of the Harney Basin region, Oregon. Washington, D.C. 86 p. (U.S. Geological Survey. Water Supply Paper 231)

Waters, A. C. 1962. Basalt magma types and their tectonic associations: Pacific Northwest of the United States. Washington, D.C., National Academy of Science-National Research Council. p. 158-170. (Publication 1035)

Wendell, William C. 1969. The structure and stratigraphy of the Virgin Valley-McGee Mountain area, Humboldt County, Nevada. Master's thesis. Corvallis, Oregon State University. 130 numb. leaves.

Whitten, E. H. T. 1966. Structural geology of folded rocks. Chicago, Rand McNally. 663 p.

Wilkerson, William L. 1958. The geology of Steens Mountain, Oregon. Master's thesis. Eugene, University of Oregon. 65 numb. leaves.

Willden, Ronald. 1961. Preliminary geologic map of Humboldt County, Nevada. Washington, D.C. (U.S. Geological Survey. Field Studies Map M F-236)

______________ 1964. Geology and mineral deposits of Humboldt County, Nevada. Nevada Bureau of Mines, Bulletin 59:53-139.

Williams, Howell and Robert R. Compton. 1953. Quicksilver deposits of Steens Mountain and Pueblo Mountains, southeastern Oregon. U.S. Geological Survey. Bulletin 995-B:19-77.

Williams, Howell, Francis J. Turner and Charles M. Gilbert. 1954. Petrography. San Francisco, W. H. Freeman. 406 p.

APPENDIX

STRATIGRAPHIC SECTION AND DETAILED UNIT DESCRIPTION

Volcanic Sequence

Western Part of Thesis Area

Traverse 2

Initial Point: SW1/4 SW1/4 SW1/4 sec. 5, T. 41 S., R. 34 E. at top contact of welded tuff sequence in this area.

Terminal Point: top of Steens Basalt 5,900 feet along bearing N. 88° E. from initial point.

Traverse crosses welded tuffs, sillar sequence, and tuffaceous sedimentary rocks. Several offsets along the line of traverse were made so that the best exposures could be described.

WELDED TUFFS (T_{wt})

Welded ash flow tuffs: extensive welding with a eutaxitic porphyritic texture; welding zonations are noted with the lower middle and middle portions showing extreme welding grading upward and downward into less welded portions; unconsolidated top of each flow has been removed by erosion.

Contact: top covered by a thick sequence of alluvium.

889' - 858' Welded tuff member four: color light gray (N7); shows welding zonations; most intense welding is in a three foot zone, located two feet above base.

858' - 805' Welded tuff member three: top contact undulatory showing minor erosion between the deposition of member three and four; color light brownish-gray (5YR 6/1); shows welding zonations; most intense welding is in a ten foot zone one foot from top contact.

805' - 767' Welded tuff member two: top of flow has less than one foot of poorly welded tuff, in contact with overlying member three; pale yellowish-brown (10YR 6/2); most intense welding is a two foot zone two feet from the base.

767' - 750' Welded tuff member one: top and bottom contacts not exposed; color medium light-gray (N6); poorly exposed and zonations cannot be located.

Total thickness: Welded tuffs - 139 feet.

Contact: Welded tuff sequence, sillar; contact is covered.

SILLAR SEQUENCE (T_s)

Sillar: Poorly welded ash flow tuffs; contains rounded pumice fragments, rounded basalt fragments, and occasional crystal phenocrysts; outcrops form bold exotic hoodoos.

Contact: top contact of this unit not exposed.

750' - 662'	Top member of sillar: top contact not exposed; color is dark yellowish-brown (10YR 4/2); contains two percent basalt fragments, 30 percent pumice fragments, and five percent phenocrysts of anorthoclase and quartz; groundmass small fragments of broken glass shards.
662' - 534'	Lower member of sillar: top contact is not exposed; color is light gray (N7); contains one percent basalt fragments, 15 percent pumice fragments, and two percent phenocrysts of anorthoclase and quartz; groundmass composed of glass shards.

Total thickness: Sillar sequence - 216 feet.

Contact: Sillar sequence, tuffaceous sedimentary rocks; contact covered.

TUFFACEOUS SEDIMENTARY ROCKS (T_{ts})

Tuffaceous sandstone: well bedded silty sandstone composed of greater than 90 percent glass shards and sub-rounded pumice fragments; infrequent pebbles of basalt and pumice; clay rich matrix comprises five percent of rock; poorly consolidated, weathers rapidly to form subdued outcrops; valley former.

Contact: top contact of this unit covered.

534' - 392'	Covered.
392' - 388'	Well bedded tuffaceous sandstone: bedding averages five inches; lenses one inch thick of dark stained sandstone are present between a few of the beds; contacts are covered.
388' - 20'	Covered.
20' - 16'	Alternating bands of tuffaceous sandstone and basalt pebble rich sandstone: sandstone beds average five inches thick, pebble zones are less than one inch thick; flat basal contact.
16' - 15'	Non-stratified tuffaceous sandstone: lower three inches show multiple scour and fill structures.
15' - 13'	Massive non-stratified tuffaceous sandstone: top contact shows multiple scour and fill.
13' - 10'	Well bedded tuffaceous sandstone: bedding varies from 1/2 to 3/4 inch thick with thin bands (1/32 inch) of dark yellowish-orange (10YR 6/6) of silty sandstone; top contact shows load casting (minor).
10' - 8'	Non-stratified tuffaceous sandstone: top contact is flat.
8' - 0'	Poorly stratified tuffaceous sandstone: occasional bands of dark yellowish-orange (10YR 6/6) sandy siltstone are less than 1/32 inch thick.

Total thickness: Tuffaceous sedimentary rocks - 534 feet.

Contact: Tuffaceous sedimentary rocks, Steens Basalt.

Traverse 1

Initial Point: SE1/4 SW1/4 NW1/4 sec. 4, T. 41 S., R. 34 E. at top contact of Steens Basalt sequence.

Terminal Point: base of Steens Basalt in contact with Permian to Triassic metamorphic rocks; 18,480 feet east along bearing N. 87° W. from initial point.

Traverse crosses glomeroporphyritic basalt flows, non-vesicular basalt flows, welded ash flow tuffs, and arkosic sandstones.

STEENS BASALT (T_b)

Glomeroporphyritic basalt: vesicular amygdaloidal basalt; vesicles average 1/8 inch in diameter; vesicle fillings of zeolites, calcite, and chalcedony; phenocrysts of labradorite ubiquitous and attain a length of 28 mm; phenocrysts sometimes aligned parallel to the base within five feet of the base; fresh surface is grayish-black (N2) and weathered surfaces very dusky red (10YR 2/2); groundmass aphanitic; slope former.

Non-vesicular basalt: non-vesicular porphyritic basalt; phenocrysts of labradorite, olivine, and augite average 5 mm in length and range from 15 to less than one percent of the rock; fresh surface is grayish-black (N2) and weathered surface is dark reddish-brown (10R 3/4); pseudo-columnar and platy jointing are frequent; generally a cliff former.

Welded ash flow tuffs: unconsolidated portions are removed and only vitrophyre remains; eutaxitic texture evident; phenocrysts of plagioclase and potassium feldspar.

Arkosic sandstone: well bedded arkosic sandstone with numerous lenses of magnetite and clay and silt; clay rich matrix gives the rock a low porosity and permeability; sand grains are quartz, microcline, magnetite, and plagioclase; occasional lenses of pebbly sandstone; color moderate red (5R 5/4); bedding structures include graded bedding, scour and fill, cross-bedding, truncated bedding, and normal bedding; beds vary from 1/32 to six inches thick.

Contact: Contact covered.

4832' - 4710' Aa lava non-vesicular basalt: clinkery upper surface grades downward to platy non-vesicular basalt; top contact covered.

4710' - 4586' Aa lava of non-vesicular basalt: clinkery upper surface grades downward to platy non-vesicular basalt in lower 60 feet.

4586' - 4528' Non-vesicular basalt: top contact is sharp with no soil horizon present.

4528' - 4524' Welded ash flow tuff: color moderate reddish-brown (10YR 4/6); contacts covered.

4524' - 4521' Welded ash flow tuff: color moderate red (5R 5/3); contacts covered.

4521' - 4474' Non-vesicular basalt: contacts covered.

4474' - 4398'	Aa lava of non-vesicular basalt: clinkery upper surface grades downward to platy basalt; top contacts covered.
4398' - 4256'	Non-vesicular basalt: contacts covered.
4256' - 4153'	Non-vesicular basalt: contacts covered.
4153' - 4068'	Glomeroporphyritic basalt: contacts covered.
4068' - 4026'	Glomeroporphyritic basalt: contacts covered.
4026' - 3931'	Glomeroporphyritic basalt: top contact covered.
3931' - 3913'	Non-vesicular basalt: platy jointing well developed; top contact undulatory with five percent vesicles in top two feet of flow.
3913' - 3666'	Covered.
3666' - 3498'	Non-vesicular basalt: contacts covered.
3498' - 3398'	Covered.
3398' - 3276'	Glomeroporphyritic basalt: contacts covered.
3276' - 3201'	Non-vesicular basalt: top contact covered.
3201' - 3089'	Non-vesicular basalt: top two feet show subtile flow banding; top contact is sharp with overlying flow.
3089' - 3003'	Non-vesicular basalt: top contact covered.
3003' - 2908'	Non-vesicular basalt: contacts covered.
2908' - 2856'	Non-vesicular basalt: contacts covered.
2856' - 2811'	Non-vesicular basalt: well developed platy jointing; contacts covered.
2811' - 2697'	Glomeroporphyritic basalt: pipe vesicles common; top contact covered.
2697' - 2612'	Non-vesicular basalt: contacts covered.
2612' - 2523'	Glomeroporphyritic basalt: top contact covered.
2523' - 2463'	Glomeroporphyritic basalt: top contacts irregular with apophyses of the overlying flow filling the fractures of the top of this flow.
2463' - 2323'	Covered.
2323' - 2197'	Non-vesicular flow: top contact covered.
2197' - 2062'	Glomeroporphyritic basalt: top contact is sharp; more than 50 percent vesicles in top two feet of flow.

2062' - 1974'	Non-vesicular basalt: top contact is sharp with phenocrysts of overlying flow aligned parallel to base.
1974' - 1949'	Glomeroporphyritic basalt: contacts covered.
1949' - 1850'	Covered.
1850' - 1790'	Glomeroporphyritic basalt: top contact is covered but top three feet show up to 40 percent pipe vesicles.
1790' - 1689'	Non-vesicular basalt: flow banding prominent; top contact is sharp showing no erosion.
1689' - 1635'	Glomeroporphyritic basalt: top contacts not exposed.
1635' - 1598'	Covered.
1598' - 1568'	Glomeroporphyritic basalt: top contact not exposed.
1568' - 1529'	Glomeroporphyritic basalt: top contact is highly irregular with apophyses of above flow in fractures.
1529' - 1395'	Covered.
1395' - 1353'	Glomeroporphyritic basalt: top contact sharp.
1353' - 1225'	Non-vesicular basalt: top contact sharp with no weathering evidence.
1225' - 1178'	Glomeroporphyritic basalt: contacts covered.
1178' - 1083'	Covered.
1083' - 1047'	Aa lava: clinkery upper surface present, but base is not exposed; top contact not exposed.
1047' - 1028'	Covered.
1028' - 1003'	Glomeroporphyritic basalt: top contact not exposed.
1003' - 914'	Glomeroporphyritic basalt: top contact sharp with no evidence of weathering.
914' - 880'	Glomeroporphyritic basalt: top contact is seemingly gradational with overlying flow.
880' - 815'	Non-vesicular basalt: top contact straight and sharp.
815' - 754'	Glomeroporphyritic basalt: banding of amygdules; top contact sharp with no evidence of weathering between flows.
754' - 711'	Glomeroporphyritic basalt: contacts covered.

711' -	20'	Covered.
20' -	0'	Arkosic sandstone: top contact shows extensive baking with poorly exposed overlying basalt. Chunks of sandstone are incorporated in the basalt.

Total thickness: Steens Basalt - 4, 832 feet.

<u>Contact</u>: Steens Basalt, Permian to Triassic metamorphic rocks; contact covered.