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Title: GEOLOGY OF THE CENTRAL PUEBLO MOUNTAINS
HARNEY COUNTY, OREGON

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The thesis area consists of 44 square miles in southeast Harney County, Oregon. The Pueblo Mountains are located in the northwest part of the Basin and Range structural province, and are characterized by normal faults of large displacement that produced the tilted fault block mountain range.

The oldest rocks exposed are mafic lava flows, and marine sedimentary rocks, which were subjected to regional metamorphism probably during Jurassic time. A thin sequence of late Oligocene to early Miocene silicic volcanic rocks, arkosic sedimentary rocks and andesite unconformably overlies the metamorphic sequence. These rocks are disconformably overlain by a thick sequence of Miocene basalt flows. Included in the basalt sequence is a unit of silicic volcanic rocks. Overlying the basalt sequence with slight angular unconformity is a sequence of tuffaceous sedimentary rocks, 'sillar',

and welded tuff. A fanglomerate unit crops out in the northeast corner of the area. Quaternary deposits include lacustrine, alluvial fan, and dune deposits.

Major normal faulting, which began in late Miocene time, has continued into the present.

Geology of the Central Pueblo Mountains,
Harney County, Oregon

by

Dennis Brian Tower

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GEOLOGY OF THE CENTRAL PUEBLO MOUNTAINS, HARNEY COUNTY, OREGON

INTRODUCTION

Location and Accessibility

The Pueblo Mountains are in the extreme north-central part of Humboldt County Nevada, and in south-central Harney County, Oregon. The area discussed in this report includes approximately 44 square miles in T. 40 S., R. 34 E., and R. 35 E. of Oregon (Figure 1). The town of Denio, Nevada is 3.5 miles south of the thesis area.

The area may be reached by a graded gravel road paralleling the eastern front of the Pueblo Mountains. The central part is accessible only by off-highway vehicles along an unimproved dirt road leading up Arizona Creek into Van Horn Basin. An unimproved road up Stonehouse Creek from the Oregon End Ranch in Bog Hot Valley, provides the only access to the western part of the area.

Topography and Drainage

The Pueblo Mountains are a southern extension of Steens Mountain to the north. The mountains are abruptly terminated on the east by a steep fault scarp, and to the west long dip slopes formed on

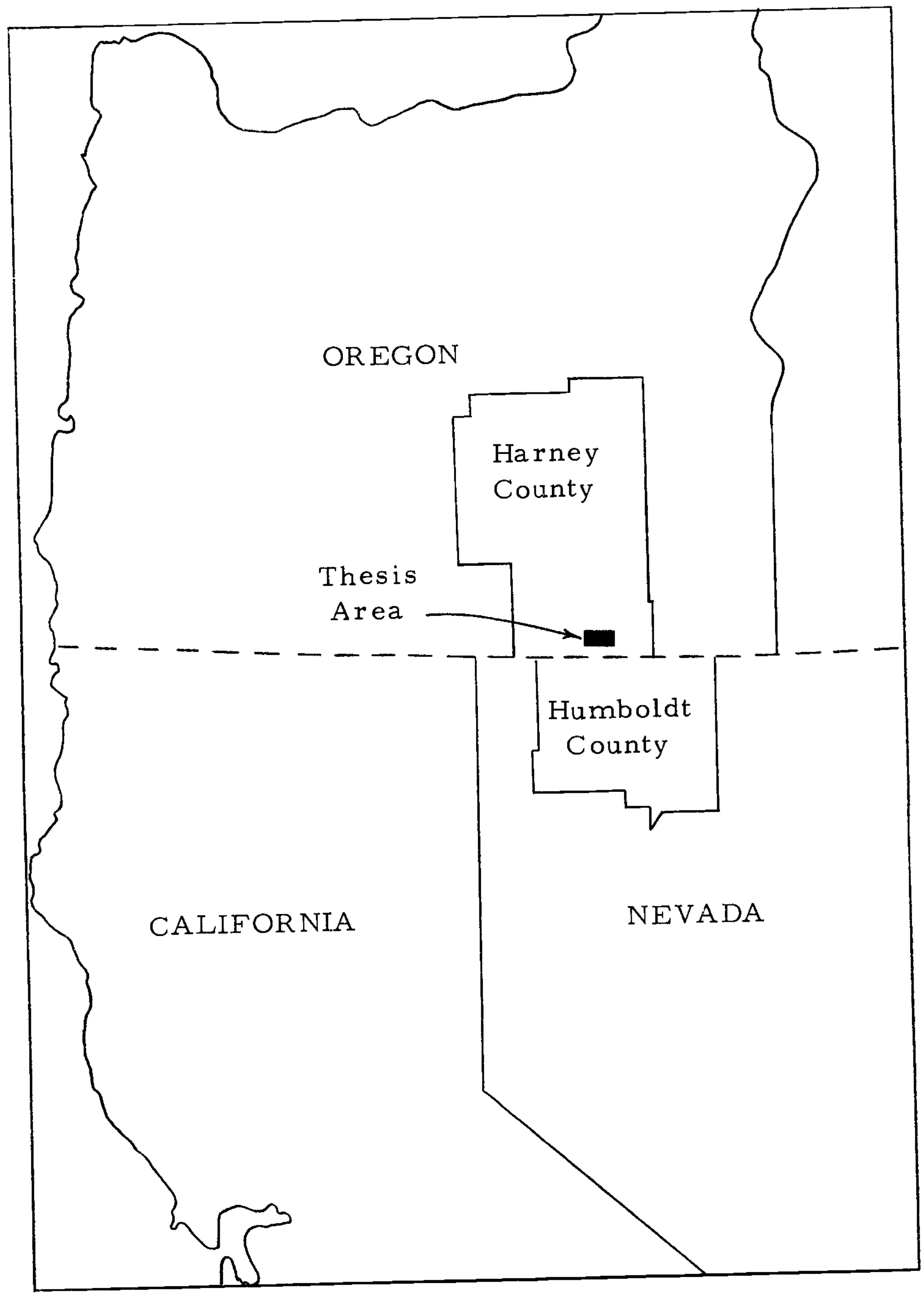


Figure 1. Location of the thesis area.

resistant basalt flows give the mountains an asymmetrical profile. The mountains have a maximum east-west width of nine miles in the thesis area and narrow rapidly south of the area.

The maximum relief is approximately 4, 525 feet. Pueblo Mountain is the highest point with an elevation of 8, 725 feet. Pueblo Valley has an average elevation of about 4, 200 feet.

The Pueblo Mountains consist of two major ridges separated by a high median valley. The west ridge trends north-south and has an average elevation of approximately 8, 000 feet. The highest point on the west ridge is 8, 545 feet. The east ridge also trends north-south but has a much more rugged, variable terrain. It is dominated by the bulky mass of Pueblo Mountain.

The drainage system is characterized by steep, short, intermittent streams that flow only during spring run-off or during summer thundershowers. The drainages terminate in alluvial fans at the foot of the mountains.

The larger intermittent streams of the western Pueblo Mountains are tributaries of Rincon Creek, which drains south into Continental Lake, an alkaline playa at the southern tip of the Pueblo Range. The only perennial stream draining the west ridge is Stonehouse Creek.

The eastern Pueblo Mountains are drained by many steep, short streams which empty into the structural basin occupied by Pueblo

Valley, and ultimately into Alvord Lake, and alkaline playa 20 miles to the north.

Van Horn Creek, which drains Van Horn Basin, is the most prominent perennial stream in the eastern Pueblo Mountains. The creek has eroded a canyon nearly 2,000 feet deep where it cuts through the east ridge. The other perennial stream in the east range is Colony Creek.

Climate and Vegetation

Annual precipitation at Denio, for the years 1951 through 1960, ranged from five to eleven inches. The average was 8.31 inches. Most of the precipitation occurs during the winter months, with a second maximum occurring during May and June. Much of the precipitation during the late spring and early summer comes in thunderstorms. Winter months have moderate snowfalls. Snow is the main source of water for spring run-off in the Pueblo Mountains.

July is usually the hottest month of the year with a mean daily maximum temperature greater than 90°F. January is usually the coldest month with a mean daily minimum of less than 20°F. The mean daily temperature is 71°F., and 30.7°F. for July and January respectively. The highest temperature recorded between 1951 and 1960 was 107°F. and the lowest -16°F.

The climate is a desert climate as the precipitation averages less than ten inches annually and the evaporation potential exceeds the precipitation.

Sagebrush and various grasses are the most abundant plants in the area. Willow and aspen are commonly found along Van Horn Creek, Colony Creek, and Stonehouse Creek. Aspen are also found in fairly large groves above 7, 500 feet on the steep east slope of the west ridge of the mountains. Various other small shrubs and flowers are common.

The grass in Van Horn Basin provides summer grazing for large herds of cattle.

Purpose and Methods of Investigation

The investigation was conducted to produce a detailed geologic map and to describe lithologic units, structures, and stratigraphy.

Field work was conducted during June, July, and September, 1970, for a total of eight weeks. A geologic map was constructed using Oregon State Highway Base Maps Alvord Lake Three and Four, at a scale of 1:62, 500, enlarged to 1: 25, 000 as a base map. Field mapping was done primarily on low altitude aerial photographs (scale approximately 1: 20, 000) and transferred to the base map. High altitude aerial photographs with an approximate scale of 1: 63, 000 were a great aid in tracing contacts, determining structure, and tracing basalt dike trends. Structural attitudes were determined with a

Brunton compass. A Jacob Staff mounted with an Abney level was used for section measurement. Laboratory work involved the microscopic examination of thin sections and samples with petrographic and binocular microscopes. Chemical analyses were done by Dr. E. M. Taylor (Oregon State University Geology Department), using a sample fusion technique for X-ray fluorescence. C.I.P.W. norms were computed from a computer program provided by Dr. E. Julius Dasch (Oregon State University Geology Department) and modified by Michael B. Jones (Oregon State University).

Previous Investigations

James Blake (1873), I. C. Russell (1884), John C. Merriam (1907, 1910), R. E. Fuller, and A. C. Waters (1924), and Richard E. Fuller (1931) briefly discussed the Pueblo Mountains in their investigations. Papers by Ross (1941), and Williams and Compton (1953) discuss the geology and mercury deposits of the Pueblo and Steens Mountains. Ronald Willden (1961, 1964) included the area in his reconnaissance geologic map of Humboldt County, Nevada. In 1965 G. W. Walker and C. A. Repenning published a reconnaissance geologic map of the Adel Quadrangle of Oregon.

Theses which have contributed to knowledge of the Pueblo Mountain area are by Jon C. Avent (Ph.D., 1965, University of Washington), Rollins Burnam (M.S., 1970, Oregon State University), and

Winthrop A. Rowe (M. S., 1971, Oregon State University).

Terminology

The classification of metamorphic rocks used in this paper is from Turner and Verhoogen (1960) and Turner (1968). Igneous rocks are classified according to Williams, Turner and Gilbert (1964).

Geologic Setting

The Pueblo Mountains are in the northwest part of the Basin and Range province. The mountain range is a tilted fault block range, bounded on the east by normal faults and with a gentle dip slope on the west side. Underlying the area are metamorphic rocks of presumed Late Paleozoic and Early Mesozoic age. These rocks are overlain by a thick sequence of late Tertiary volcanic and interbedded volcanic sedimentary rocks.

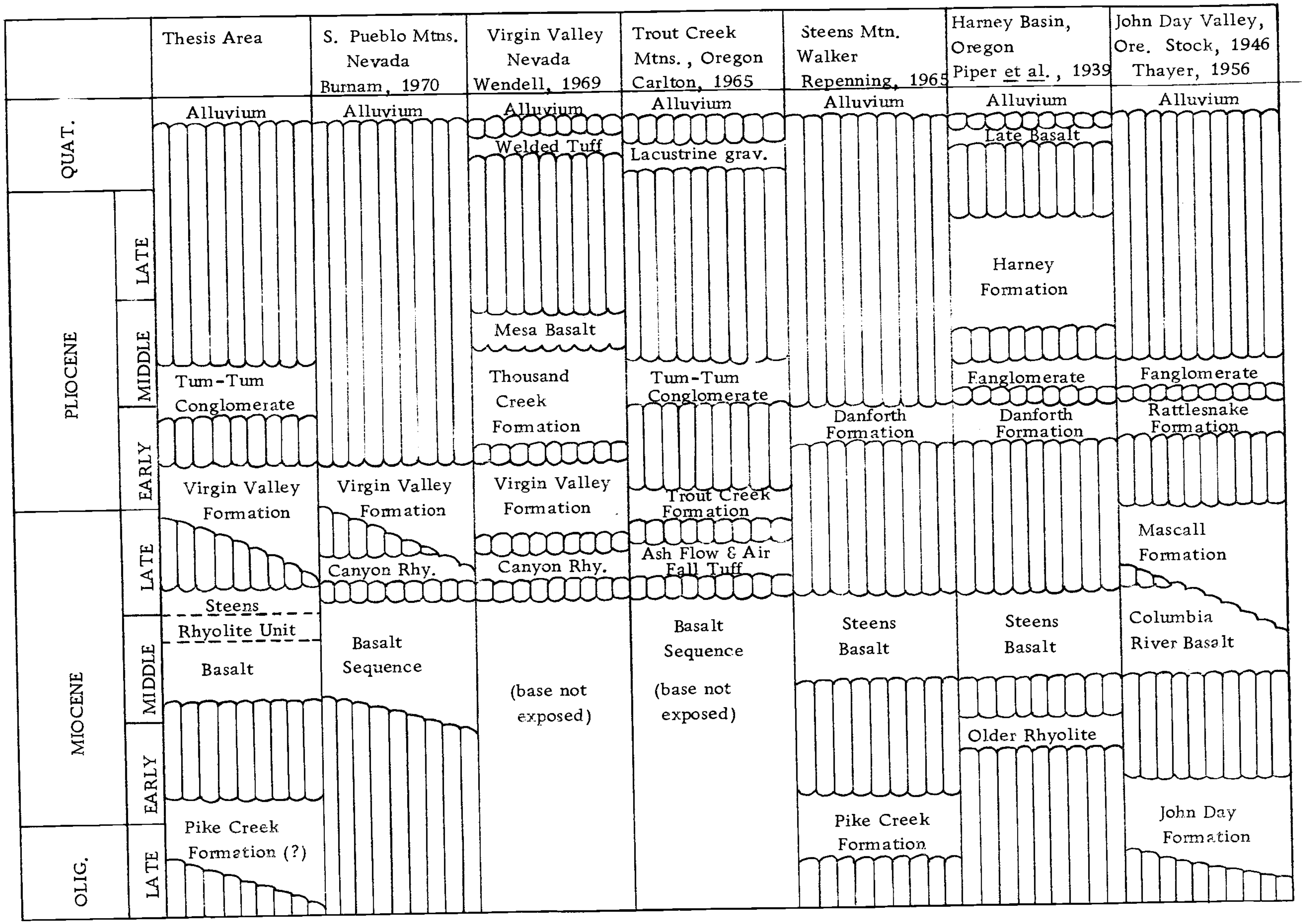
STRATIGRAPHY

The only detailed geologic mapping done previously in the Pueblo Mountains is by Burnam (1970) and Rowe (1971) in the area south of the thesis area. The units described in this study are essentially the same as those defined by Burnam. The primary differences are: there are no Mesozoic intrusive rocks, the metamorphic rocks are subdivided into three units, the lowest unit overlying the pre-Tertiary rocks is tentatively correlated with the Pike Creek Formation of Steens Mountain, a rhyolite unit is included within the basalt unit, a welded tuff unit at Red Point is described, and a sequence of fanglomerates in the northeast section of the thesis area is included. Correlation and age of most rock units are subject to revision for there is little pertinent information on the actual ages of these units.

The stratigraphy of the area is summarized in Table 1. The oldest rocks exposed are schists, phyllites, greenstones, and quartzites of possible Permian-Triassic age. The pre-Tertiary rocks are subdivided into three units. The division is based on differences in color, texture, lithology, and structure. An angular unconformity occurs between the metamorphic rocks and the overlying Pike Creek Formation (?) of probable late Oligocene to early Miocene age. Included in the Pike Creek Formation (?) is a sporadically distributed basal conglomerate composed primarily of boulders of granite,

Table 1. Rock units found in thesis area.

Age	Rock units	Thickness	Description
Quaternary	Alluvium		Playa, terrace, dune, and alluvial fan deposits.
Early to Middle Pliocene	Fanglomerates	1500-2000 (?)	Alluvial fan deposits. Poorly sorted, thick-bedded, cobble to boulder conglomerate.
Middle to Late Miocene	Rhyolite tuff sequence	600 (?)	Air fall tuff and two partly to densely welded crystal rich ash flow tuffs. Excellent eutaxitic texture.
Middle to Late Miocene	Sedimentary-pyroclastic unit	850	Three crystal rich ash flow tuffs, poorly welded 'sillar', and tuffaceous siltstones, sandstones, and conglomerate.
	Slight angular unconformity		
Middle to Late Miocene	Steens Basalt	6, 580	Porphyritic and non-porphyritic vesicular to non-vesicular basalts. Fine-grained silicic volcanic rocks.
	Disconformity		
Late Oligocene (?) Early Miocene	Pike Creek Formation (?)	0-600	Boulder conglomerate, arkosic wacke, welded tuff, tuff breccia, and fine-grained andesite.
	Angular unconformity		
Permian to Triassic	Metamorphic sequence	14, 000 (?)	Greenstone, quartzite, semischist, schist, phyllite, and diorite.



Thesis Area
S. Pueblo Mtns. Nevada Burnam, 1970
Virgin Valley Nevada Wendell, 1969
Trout Creek Mtns., Oregon Carlton, 1965
Steens Mtn. Walker Repenning, 1965
Harney Basin, Oregon Piper et al., 1939
John Day Valley, Ore. Stock, 1946 Thayer, 1956
QUAT.
PLIOCENE
MIOCENE
OLIG.
LATE
MIDDLE
EARLY
LATE
MIDDLE
EARLY
LATE
Alluvium
Tum-Tum Conglomerate
Virgin Valley Formation
Steens Rhyolite Unit
Basalt
Pike Creek Formation (?)
Alluvium
Virgin Valley Formation
Canyon Rhy.
Basalt Sequence
Alluvium
Welded Tuff
Mesa Basalt
Thousand Creek Formation
Virgin Valley Formation
Canyon Rhy.
(base not exposed)
Alluvium
Lacustrine grav.
Tum-Tum Conglomerate
Trout Creek Formation
Ash Flow & Air Fall Tuff
Basalt Sequence
(base not exposed)
Alluvium
Danforth Formation
Steens Basalt
Pike Creek Formation
Alluvium
Late Basalt
Harney Formation
Fanglomerate
Danforth Formation
Steens Basalt
Older Rhyolite
Alluvium
Fanglomerate
Rattlesnake Formation
Mascall Formation
Columbia River Basalt
John Day Formation

granodiorite, and diorite. Also included in the Pike Creek Formation (?) are interbedded tuffs, volcanic sandstone, and andesite. Discordantly overlying the Pike Creek Formation (?) is a thick sequence of middle Miocene basalts. Concordantly included in the basalt unit, but mapped separately is a major unit of rhyolite, tuff, and volcanic sedimentary rocks. Both of these volcanic units are overlain, with slight angular unconformity, by a sedimentary-pyroclastic unit of probable middle to late Miocene age. This unit includes volcanic sandstones, tuffaceous mudstones, and ash flow tuffs. Unconformably overlying the metamorphic rocks in the northeast section of the thesis area is a sequence of fanglomerates of possible early to middle Pliocene age. Recent alluvial fan, stream, and playa deposits are the youngest deposits in the area.

Pre-Tertiary Metamorphic Rocks

Field Relationship

The pre-Tertiary metamorphic rocks form a sequence with a maximum thickness of approximately 14,000 feet in the Pueblo Mountains. Just north of Colony Creek they have a maximum east-west outcrop width of 3.25 miles. The outcrop narrows rapidly to the north and at Pueblo Mountain is only 1.7 miles wide. The outcrop width is 2.3 miles along the south border of the thesis area. The total outcrop area of pre-Tertiary metamorphic rocks is 10.4 square miles.

The pre-Tertiary basement rocks form varied topographic features related to rock type. Greenstones and quartzites form bold, steep, jagged outcrops, whereas phyllites and schists form less steep, regolith covered slopes. The metamorphic rocks are best exposed in the deep, southeast trending canyons, and on ridge crests (Figure 2).

The pre-Tertiary schists and phyllites weather to small, thin slabs. Slopes underlain by the schists and phyllites are covered by a regolith of light bluish-gray to light brown color. Greenstones and quartzites fracture along three major joint sets: one strikes N. 35-50° E., and dips N. W. 80°, the second is nearly horizontal, and N. 60-65° W. and dips 85° S. W. These rocks form large, coarse, blocky talus. The regolith in these areas is a dark yellowish-brown color.

Quartz veins are common throughout the metamorphic terrain. They range from thin stringers less than 1/4 inch thick to larger veins five feet in width. The larger veins parallel the foliation while the smaller veins may be found in any orientation.

The metamorphic unit is abruptly terminated on the east by a normal fault of large displacement. To the west the basement rocks are overlain with angular unconformity by the west dipping Pike Creek Formation (?).

Figure 2. View south along the east ridge from top of Pueblo Mountain, with east dipping pre-Tertiary metamorphic rocks exposed along ridge crest. Note the angular unconformity formed by overlying basalt flows in background.

The foliation strikes N. 20-30° E. and dips 45-65° S. E. throughout most of the area. Along one narrow zone the rocks were observed dipping 55-60° N. W. These reverse dips appear to be related to faulting. Since the foliation parallels lithologic variations it is believed to have developed parallel to the original bedding.

The pre-Tertiary metamorphic rocks were mapped as three informal units, the division of which was based primarily on predominant lithologies.

Lithology and Petrography

Unit One

Unit One consists of approximately 6, 500 feet of greenstone with minor interbedded quartzite, metaconglomerate and breccia, and metagraywacke. Also included in this unit is a metadiorite. Unit One is best exposed on Pueblo Mountain.

The greenstones are dark greenish-gray (5 GY 4/1) to grayish-red (10 R 4/2) in color. Many contain large porphyroblasts of plagioclase up to 2 cm in length. Petrographic examination reveals that albite, epidote, chlorite, quartz, actinolite, and white mica are the major minerals. Minor minerals include biotite, sphene, magnetite, andesine, apatite, carbonates, tourmaline, and clinozoisite.

Porphyroblasts typically are albite (An8). They are heavily altered to white mica, epidote, and chlorite. Alteration minerals are frequently found in alignment with former composition planes and zones in the phenocrysts. Preservation of idiomorphic crystal form and lack of preferred alignment suggests that the porphyroblasts are albite replacements of calcium-rich plagioclase phenocrysts of the parent mafic igneous rocks. Unusually large plagioclase and pyroxene phenocrysts were noted in several rocks (DT-23-70 and DT-80-70). These metacrysts contain unaltered, relic andesine (An45) in the center, surrounded by heavily sericitized and epidotized albite (Figure 3). Pleochroic green actinolite replaces pyroxene phenocrysts and preserves the pyroxene crystal form. The groundmass is composed of albite, chlorite, white mica, epidote, actinolite, quartz, and euhedral magnetite. All former groundmass textures have been obliterated by subsequent metamorphism, but the rock as a whole possesses a blastoporphyritic fabric.

Hard, fine-grained, light gray (N7) to light brown (5 YR 6/4) quartzite forms prominent northeast trending outcrops across the top of Pueblo Mountain (Figure 4). The quartzite consists almost entirely of quartz grains that display sutured contacts and more rarely secondary overgrowths. White mica, iron-free chlorite, and orthoclase are present in amounts up to 10 percent in a few rocks. Other minerals found are biotite, sphene, magnetite, zircon, rutile, apatite, and radiating tourmaline (sample DT-17-70).

Figure 3. Photomicrograph showing original andesine phenocryst containing unaltered andesine surrounded by sericitized and epidotized albite. Note the alteration along distinct composition planes of the albite twins.

Figure 4. Light gray quartzite interbedded with greenstones on the east side of Pueblo Mountain.

Metaconglomerates form subordinate, lenticular interbeds with the quartzite and greenstone. The relic clasts retain their original shape, however they have been metamorphosed to a fine-grained, felty aggregate of quartz, chlorite, and white mica. The relic clasts impart a blastopsephitic fabric to the rock. The clasts appear to have been predominantly derived from porphyritic volcanic rocks. Many clasts contain outlines of euhedral plagioclase phenocrysts. Several samples exhibit crude bedding features. One unit easily traceable in the field has a high content (20-40 percent) of fine hematite.

Metagraywackes are found occasionally in Unit One. They are distinctive in that they retain sedimentary structures such as graded-bedding and cross-bedding. These rocks are non-schistose, very coherent, and dark gray (N3). The major minerals are albite, chlorite, clinozoisite, epidote, and quartz. Microscopic sedimentary textures have been destroyed by metamorphism, however a blastop-sammitic fabric is imparted by the outline of the relict sand-sized clasts. An extrusive igneous source is indicated for the original clasts.

Conspicuously exposed high on the southeast slope of Pueblo Mountain is a metadiorite. Although actual contacts are covered or have been obscured by metamorphism, field mapping revealed that the diorite appears to be concordant with adjacent rock units. Large greenish-gray porphyroblasts are oligoclase. The plagioclase is always heavily altered to white mica, chlorite, and epidote. Large, relic pyroxene phenocrysts with a thick rim of actinolite are distinctive in this rock. Euhedral magnetite porphyroblasts are abundant. The recrystallized groundmass is composed of albite, quartz, epidote, clinozoisite, chlorite, actinolite, and white mica. Accessory minerals present are sphene, rutile, and apatite. The metadiorite is grayish-red (5 R 4/2) on fresh surfaces and weathers to a dark reddish-brown (10 R 3/4).

Unit Two

Unit Two consists of approximately 1,000 feet of blackish-red (5 R 3/2) to dark greenish-gray (5 G 4/1) semischist with minor interbedded greenstone and pelitic schist.

The semischists are derived from the metamorphism of volcanic wacke. Rounded, replaced framework grains occur in a schistose groundmass. A crude fracture cleavage parallels the schistosity and a secondary fracture cleavage diagnostic of this unit has developed at approximately 45-55^{o} from the primary schistosity. Albite, chlorite, white mica and quartz form a typical mineral assemblage. The albite (An7) metacrysts are moderately altered by white mica, chlorite, epidote, and calcite. They are frequently fractured and the fractures are healed with chlorite, white mica, and calcite. Chlorite and white mica form discontinuous wavy bands which impart schistosity to the rock.

The dark color of this unit is due primarily to a large amount (ten percent approximately) of disseminated magnetite. Other minerals commonly found in this unit are sphene and biotite.

Unit Three

Unit Three consists of approximately 6,500 feet of interbedded schists and phyllites. Minor beds of semischist and greenstone are also found. Unit Three is distinguished from Unit Two by its much lighter color, finer grain, and lack of secondary cleavage. The schists and phyllites are both believed to have been derived from fine-grained pelitic sediments.

The schists are grayish-green (5 G 5/2) and composed predominantly of albite, quartz, white mica, chlorite, and epidote. Minerals found in smaller quantities include biotite, sphene, calcite, apatite, and magnetite. Biotite was the dominant green mineral in only one sample (DT-28-70). In this rock biotite is found as a replacement of chlorite. Calcite is found in approximately one-half of the specimens in sufficient quantity to be considered a major mineral. The mineralogical composition is variable and usually only two or three of the major minerals are found in a rock.

The phyllites are fine-grained, a pale red purple (5 RP 5/2) in color, and are typically composed of white mica, albite, and quartz. Other minerals found in small quantities are calcite, sphene and magnetite. Microcrystalline white mica is the only schistose mineral and gives the rock a distinctive sheen on fracture surfaces.

Classification and Origin

The quartz-albite-muscovite-chlorite subfacies of the greenschist facies of low grade regional metamorphism is suggested by nearly all of the mineral assemblages (Turner and Verhoogen, 1960), however, the presence of biotite in several samples suggests the metamorphic rocks may belong to a slightly higher rank subfacies: the quartz-albite-epidote-biotite subfacies.

The metamorphic sequence was derived from interbedded porphyritic mafic lava flows, volcanic wacke sandstones, volcanic breccias and conglomerates, pyroclastics, quartz arenites, and mudstones. Volcanic detritus was undoubtedly derived from local mafic igneous rocks. These rocks, with the exception of the quartz arenite, are lithologically typical of a mobile eugeosynclinal belt.

Age and Correlation

The metamorphic rocks described in this report are similar to a unit described in the Jackson Mountains, 45 miles to the southeast (Willden, 1964). A series of rocks nearly identical to the Pueblo Mountain sequence have been described from the southern Pine Forest Mountains, 30 miles to the south (Smith, 1966). The Jackson Mountain

Figure 5. An outcrop of schist on the ridge crest north of Van Horn Canyon. Schists and phyllites are the predominant rock types of Unit Three.

sequence has been paleontologically dated by Willden as Permian to Triassic. The Pine Forest Mountain sequence has been dated by Smith as "probably Permian and in the upper part possibly Triassic" on the basis that it underlies units containing probable middle Triassic fossils. The Pueblo Mountain sequence is therefore tentatively dated as Permian-Triassic and tentatively correlated with the Permian Happy Creek Group of the Jackson and Pine Forest Mountains.

Late Tertiary Volcanic and Sedimentary Rocks

Pike Creek Formation (?)

The Pike Creek Formation (?) of this report consists of a basal conglomerate, arkosic sandstone, tuff breccia, welded tuff, and andesite. The Pike Creek Formation was named by Walker and Repenning (1965) for exposures on Pike Creek along the eastern base of Steens Mountain. A rock sequence of similar lithology, and stratigraphic position in the Pueblo Mountains is therefore listed as a possible correlative to the Pike Creek Formation.

Field Relationship

The Pike Creek Formation (?) is sporadically distributed in a north-south elongate belt that overlies the pre-Tertiary metamorphic rocks and underlies the middle to late Miocene Steens Basalt. The Pike Creek Formation (?) is best exposed on the ridge just south of Van Horn Creek and in a north-south canyon draining into Van Horn Creek off the west slope of the east ridge. It is also exposed just south of the head of Colony Creek. The best exposures in the Pueblo Mountains are found north of the thesis area along Cottonwood Creek.

An angular unconformity separates the Pike Creek Formation (?) and the underlying pre-Tertiary metamorphic rocks. The formation strikes north-south and dips 20° to 25° to the west, whereas foliations in the metamorphic rocks strike northeast and dip 45° to 55° to the southeast. The Pike Creek Formation (?) was apparently deposited on a surface of considerable relief. The formation thickens and thins rapidly and is commonly absent. The contact with the overlying Steens Basalt is not exposed but the contact appears to be disconformable because basalt flows immediately overlying the formation show considerable variations in thickness and are occasionally abruptly terminated along the strike of the formation. The maximum thickness of the formation is approximately 600 feet.

The Pike Creek Formation (?) is characterized by several interfingering, areally restricted rock types, which change rapidly along strike.

The basal conglomerate is easily recognized in the field. The ground overlying the conglomerate is littered with large light brownish-gray (5 YR 6/1) boulders of plutonic and metamorphic rocks of various lithologies. The rocks range in size from pebbles to boulders over eight feet in diameter. The boulders were not found in place in the thesis area. Their mode of occurrence is inferred from excellent exposures along Cottonwood Creek (Figure 6) three miles to the north. The basal conglomerate is found immediately overlying the pre-Tertiary metamorphic rocks along approximately one-half of the north-south distance of the thesis area. The conglomerate is also found overlying the andesite flow and immediately underlying the Steens Basalt in several places.

A well lithified arkosic wacke is found interbedded with or overlying the conglomerate. The arkosic wacke ranges in color from yellowish-gray (5 Y 8/1) to grayish-red (5 R 4/2). The average grain size is 0.8 to 1.2 mm. Larger grains are present. Graded bedding, cross bedding, and scour and fill are sedimentary structures noted in the field. These structures indicate a fluviatile type deposition.

A tuff breccia is exposed along the south border of the thesis area. It is pale red (5 R 6/2) in color and composed of angular fragments 0.8 to 14 mm in diameter in a tuffaceous matrix. Associated with the tuff breccia is a densely welded dacite tuff. The welded tuff is pale yellowish-brown (10 YR 5/2) and composed of abundant lithic fragments and crystals of biotite, hornblende, and feldspar. A distinct

Figure 6. Basal conglomerate exposed on north side of Cottonwood Creek, north of thesis area. Note angular unconformity between altered pre-Tertiary rocks and overlying conglomerate.

eutaxitic texture is imparted to the rock by flattened pumice fragments. The welded tuff is exposed for approximately 200 feet along the south border of the thesis area.

The most extensive unit included in the Pike Creek Formation (?) is a widespread flow of andesite. The andesite is light brownish-gray (5 YR 6/1) in color. The top of the flow is scoriaceous and dark reddish-brown (10 R 3/4) in color. The unit is distinctly flow banded and is characterized by subparallel joints which bear little relation to flow direction as they change from horizontal to vertical in just a few tens of feet. The only mineral present as a phenocryst is dark brown biotite. The flow varies from 0 to 200 feet in thickness.

Lithology and Petrography

Basal Conglomerate. The basal conglomerate is characterized by clasts of a wide variety of lithologies. Plutonic rock types include granite, quartz monzonite, granodiorite, quartz diorite, diorite, and gabbro. A very distinctive and common plutonic rock is a gneissic quartz monzonite with abundant garnet crystals up to 2 mm in diameter. Metamorphic boulders are mostly quartzite and greenstone, and make up less than ten percent of the conglomerate. The metamorphic rocks are identical to the pre-Tertiary metamorphics described earlier in this paper. A few rounded boulders of fine-grained volcanic rock are found in the conglomerate that overlies the andesite flow.

The plutonic rocks most commonly have a hypidiomorphic granular texture. Quartz is found in amounts greater than ten percent in all rocks examined except the diorite and gabbro. Microcline and/or orthoclase are the most abundant feldspars and compose from 20 to 60 percent of most rocks. Andesine (An 30-40) is the dominant feldspar in the quartz diorite. Oligoclase (An 20-30) is present in amounts ranging from 5 to 25 percent in the more silicic plutonic rocks. Accessory minerals found in small quantities are biotite, augite, hornblende, sphene, magnetite, apatite, zircon, and muscovite. The feldspars are moderately altered to kaolinite and sericite. Biotite is usually partially altered to chlorite. Myrmekitic intergrowths occur where plagioclase and quartz are in contact. The fine-grained volcanic boulders found in the upper conglomerate closely resemble the upper scoriaceous zone of the andesite unit.

Arkosic Wacke. The framework is primarily composed of clasts from granitic rocks and metamorphic rocks. Varying amounts of fine-grained mafic volcanic fragments are also present. Approximately 45 percent of the grains are sodic plagioclase, microcline, and quartz from granitic intrusions. Quartzite grains displaying sutured contacts and highly schistose grains comprise 15 percent of the rock. Sandstones with abundant magnetite weather to a distinctive red color.

Ash Flow Tuff. The ash flow tuff is densely welded and exhibits a distinct eutaxitic porphyritic texture. Phenocrysts of sanidine, plagioclase, and biotite make up 5 to 10 percent of the rock, and basaltic fragments up to 13 mm comprise an additional five percent. The groundmass is dominantly glass with feldspar microlites and finely disseminated magnetite. Devitrification of the glass has produced axiolitic structures.

Phenocrysts of andesine (An 38-45) up to 2 mm long, comprise 60 percent of the total phenocrysts. They are euhedral and extensively altered to sericite and kaolinite. Sanidine and biotite make up the remaining 40 percent of the phenocrysts. Modal analysis indicates that this rock is either a dacitic or andesitic welded tuff.

Tuff Breccia. The tuff breccia is composed of angular to subrounded fragments of tuff in colors of gray, pink, red, and brown. The clasts are in a fine tuffaceous matrix with occasional sand-size grains of plagioclase feldspar and quartz. Subrounded basaltic particles are occasionally found. The glass composing the tuffaceous particles is now largely devitrified to feldspar and cristobalite (?). Minor amounts of biotite and magnetite are also present in the rock.

Andesite. The andesite is composed of plagioclase feldspar, magnetite, biotite, clinopyroxene, apatite, and a trace of hypersthene arranged in a holocrystalline, trachytic texture (Table 4). Dark and light minerals are arranged in parallel layers giving the rock a distinctive banding. Andesine (An 35-40) occurs only as microlites 0.05

to 0.1 mm in length and makes up more than 75 percent of the rock. Light green clinopyroxene (unidentifiable because of its small size) occurs as anhedral crystals that average less than 0.1 mm in diameter. Dark reddish-brown biotite occurs as subhedral phenocrysts up to 2 mm long. The phenocrysts possess opaque zones of magnetite parallel to the biotite cleavage giving the crystals a skeletal appearance. Subhedral magnetite is concentrated in the dark bands of the rock. Apatite in long slender crystals is found associated with the magnetite in the dark bands. Several crystals of hypersthene up to 0.5 mm in length were noted.

Origin

The source of the boulders in the basal conglomerate is uncertain. Only the boulders of non-garnetiferous quartz monzonite, quartzite, greenstone, and fine-grained volcanic rock can be ascribed to rocks presently found in the Pueblo Mountains. Plutonic rocks cropping out in the Pine Forest Range and Trout Creek Mountains are lithologically dissimilar to those found in the conglomerate. The boulders probably were derived from plutonic rocks buried under the basalt sequence to the west or from plutonic rocks downfaulted in the Pueblo Valley graben to the east. Wherever the source, the boulders undoubtedly were derived from an area of high relief and steep gradients. Sedimentary structures found in the interbedded arkosic wacke are indicative of a fluviatile depositional environment. The average size of the boulders is relatively constant throughout the thesis area, however the boulders have not been found south of the thesis area (Rowe, 1971) and are reported to decrease rapidly in size north of Cottonwood Creek north of the thesis area (Avent, 1965). This would indicate that the area of highest relief in the past was located close to the area of highest relief at present. The upper conglomerate unit suggests that this area remained above the level being buried by lava flows for some time and continued to shed coarse detritus from its slopes.

The ash flow tuff is attributed to a nuees ardente type eruption that was hot enough to become welded. The tuff breccia was locally derived and rapidly deposited as is shown by the lack of rounding of soft fragments and absence of sorting.

Thick zones of flow breccia, scoriaceous and rubbley zones on top of the flow, and abrupt thickening and thinning indicate that the andesite was probably viscous. A local source seems highly probable. No dikes or vent areas were observed in the thesis area that could produce such a flow, however, one mile to the north what appears to be a volcanic neck was observed. The rocks found there are identical to the andesite.

Correlation and Age

An arkosic sandstone exposed south of the thesis area along

Figure 7. View across Van Horn Creek showing the Pike Creek Formation (?). Note light colored boulders from conglomerate on the slope to the right, and thick andesite flow with scoriaceous upper surface to the left of the canyon. Pueblo Mountain is in the background.

Denio Creek has been correlated with the Pike Creek Formation of Steens Mountain by Walker and Repenning (1965). The units described in this section are stratigraphically in the same position as lithologically similar units described from Steens Mountain (Fuller, 1931; Baldwin, 1964; Walker and Repenning, 1965). The rocks are distinctly different compositionally from the overlying Steens Basalt. The units are separated from the Steens Basalt by an appreciable time interval during which erosion occurred producing a land surface of moderate relief and a conglomerate unit was locally deposited. A similar disconformable relationship exists between the Pike Creek Formation and Steens Basalt on Steens Mountain (Fuller, 1931; Baldwin, 1964). The Pueblo Mountain units are characterized by a wide variety of lithologies as is the Pike Creek Formation on Steens Mountain (Baldwin, 1964). For the reasons just cited the rocks in this sequence are tentatively correlated with the Pike Creek Formation of Steens Mountain.

An andesite lithologically similar, and in the same stratigraphic position as the andesite in the Pueblo Mountains is found in the northern Pine Forest Range (Bryant, 1970) and in the southern Pine Forest Range (Smith, 1966).

Walker and Repenning (1965) have dated the Pike Creek Formation of Steens Mountain as "late Oligocene (?) and Early Miocene, because the formation is several thousand feet stratigraphically below tuffaceous sedimentary rocks (Tts) containing middle (?) and late Miocene mammalian fossils." The formation in the Pueblo Mountains is tentatively given the same age: late Oligocene (?) and early (?) Miocene.

Steens Basalt

Field Relationship

The Steens Basalt is best exposed on the steep east slope of the west ridge. The more resistant flows form prominent cuestas, whereas less resistant flows form benches giving the east slope a step-like appearance (Figure 8). The cuestas dip 18° to 23° to the west. Exposures are fair on the gentler west dip slope of the ridge, however locally they are excellent as in the cirque shown in Figure 11.

The basalt unit disconformably overlies the Pike Creek Formation (?). The lowest flows in the unit thicken and thin markedly and occasionally pinch out abruptly along strike. Locally the basalt unit is separated from the underlying formation by a conglomerate unit.

Included in the upper two-thirds of the Steens Basalt is a unit of rhyolite, dacite, ash fall and ash flow tuff, and vitrophyre. The lower and upper contacts of this unit are conformable with the basalt. The upper contact changes considerably due to rapid lateral changes

Figure 8. View up Van Horn Basin showing thick sequence of Steens Basalt flows.

in the thickness of individual rhyolite or dacite flows. The Steens Basalt is unconformably overlain by a sedimentary-pyroclastic unit.

An east-west traverse across the north end of the thesis area indicates that the basalt unit is at least 6,580 feet thick. The unit decreases in thickness to approximately 5,000 feet at the south end of the thesis area and appears to remain around 6,500 feet thick for some distance to the north of the thesis area.

Approximately 60 percent of the lower 3,000 feet of basalt flows are vesicular and amygdaloidal. The remaining 40 percent are dense, nonvesicular flows. The values listed here could be somewhat in error as the vesicular basalts typically are the least resistive, hence most poorly exposed, and conceivably could comprise greater than 60 percent of the flows in the lower 3,000 feet. Many of the vesicular basalt flows show a concentration of vesicles in the upper and lower margins of the flow. The vesicles are generally ovoid in shape and range in diameter from 1 to 25 mm. The number of vesicular flows decreases markedly in the upper 3,500 feet of the Steens Basalt. Very few of the vesicular flows in the upper part of the unit are amygdaloidal. Most of the flows appear to have been pahoehoe lava flows as interflow contacts are sharp and flat, but the occasional presence of scoriaceous flow breccias indicate that some of the flows were aa lava flows.

Many of the lower vesicular basalt flows are amygdaloidal. The mineral filling consists of zeolite minerals (stilbite, natrolite, and heulandite), calcite, and chalcedony.

A distinctive feature of many flows is a black-mottled weathered surface consisting of black specks 1 to 2 mm in diameter surrounded by softer brownish material. This surface feature is related to a microscopic ophitic texture and has been called ophimottling. Fuller (1931) considered ophimottling to be the most persistent surficial texture of the type Steens Basalt. Approximately 60 percent of the flows in the basalt sequence are porphyritic to glomeroporphyritic. The plagioclase phenocrysts range up to 6 cm in length. The dense aphanitic flows are generally non-vesicular and platy. Fresh surfaces on aphanitic non-vesicular basalts are grayish-black (N3) and weathered surfaces are dark reddish-brown (10 R 3/4). Fresh surfaces on vesicular porphyritic basalts are grayish-black (N2) and weathered surfaces are grayish-red (10 R 3/2).

Several interbedded ash flow tuffs were noted in the upper part of the basalt sequence. They are compacted and extensively welded. A yellowish-gray (5 Y 8/1) air fall tuff was also noted.

Numerous basalt dikes cross-cut the basalt unit. Two prominent strike trends were noted: N. 15 to 25° E., and N. 30 to 50° W. The dikes are all near vertical, and exhibit well developed horizontal columnar jointing (Figure 9). The dikes are 1 to 20 feet wide and 400 feet to 3.5 miles long. Most dikes stand out in topographic relief,

Figure 9. Prominent basalt dike which trends N. 33° W., for 3.5 miles across the thesis area. Note the horizontal columnar jointing.

however several dikes were noted that form subdued topographic features noted by linear bands of vegetation. The cross-cutting nature of these dikes was observed where they are exposed in creek beds.

Lithology and Petrography

Porphyritic Basalt. Textures in the Steens Basalt vary widely. Phenocrysts of plagioclase typically display a preferred orientation parallel to flow surfaces. A stellate, or glomeroporphyritic, arrangement of plagioclase phenocrysts is also common. Groundmass textures of the porphyritic basalts vary from ophitic to hyaloophitic and intergranular to intersertal.

Plagioclase, augite, and olivine occur as phenocrysts. Plagioclase (An58-72) phenocrysts up to 6 cm in length comprise over 75 percent of the phenocrysts and up to 20 percent of the rock (Figure 10). Inclusions of magnetite, glass, and clay in resorption cavities are common in the plagioclase phenocrysts. Augite and olivine occur as anhedral to subhedral crystals as much as 2 mm in diameter. Olivine is always partially or completely altered to iddingsite.

The groundmass consists of plagioclase, clinopyroxene, olivine, hypersthene, magnetite, ilmenite, glass and chalcedony. Subhedral labradorite (An 54 to 70) microlites have an average size of 0.4 mm. Pinkish-brown clinopyroxene occurs as discrete subhedral crystals with an average grain size 0.5 mm. Larger crystals occur in a

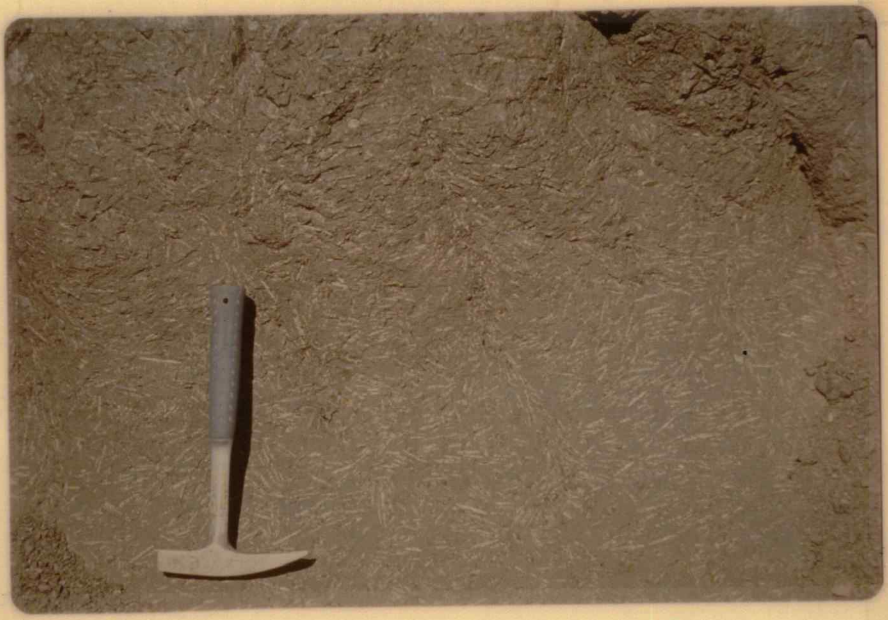


Figure 10. Porphyritic Steens Basalt containing phenocrysts of plagioclase up to 6 cm in length.

Table 2. Chemical analyses of samples from volcanic sequence.

Oxide	DT-42-70	DT-93-70	DT-90-70	DT-50-70
SiO_2	55.6	49.2	51.3	76.7
Al_2O_3	19.8	18.0	18.0	13.9
FeO	8.6	11.6	10.4	1.6
MgO	2.1	6.7	5.4	0.2
CaO	5.1	10.4	8.3	0.6
K_2O	2.6	.4	1.7	4.9
TiO_2	1.3	2.0	1.9	0.2
Na_2O	*	*	*	*
	95.1	98.2	97.0	98.1

*Not determined.

DT-42-70 Fine-grained andesite from Pike Creek Formation (?) just north of Van Horn Creek.

DT-93-70 Fine-grained basalt from prominent arcuate dike in Van Horn Basin.

DT-90-70 Slightly porphyritic medium-grained basalt from Ten Cent Meadow in Van Horn Basin.

DT-50-70 Rhyolite from top of west ridge.

Table 3. C.I.P.W. norms calculated from the chemical analyses in Table 2.*

	DT-42-70	DT-93-70	DT-90-70	DT-50-70
Quartz	9.40	1.77	-	44.50
Orthoclase	15.07	2.48	10.16	28.96
Albite	33.42	14.38	25.39	16.25
Anorthite	18.96	40.24	30.57	2.98
Corundum	3.59	-	-	4.35
Diopside	-	9.32	8.74	-
Wollastonite	-	4.74	4.43	-
Hypersthene	9.93	25.53	14.72	2.02
Olivine	-	-	4.58	-
Magnetite	4.84	2.51	2.25	.61
Ilmenite	2.53	3.76	3.63	.34
Apatite	2.25	-	-	-
	100.00	100.00	100.00	100.00

*Ferrous and ferric iron ratio necessary for the normative analyses was assumed from average andesite, basalt, and rhyolite values published by Nockolds (1954). These values were compared with previously determined values from Steens Mountain to check their validity.

Table 4. Modal analyses of samples from the volcanic sequence.

	DT-42-70	DT-93-70	DT-90-70
Plagioclase	78.2	49.0	55.8
Clinopyroxene	5.6	23.6	18.6
Olivine	-	13.0	4.6
Iron Oxide*	8.2	7.8	7.0
Biotite	4.6	-	-
Apatite	2.3	-	-
Glass and clay	1.2	6.6	14.0

*Includes both magnetite and ilmenite.

subophitic arrangement with labradorite. Subhedral olivine generally is altered to clay (nontronite or saponite) or iddingsite. Hypersthene occurs in small quantities in several specimens. Magnetite and il-menite are disseminated throughout the groundmass in crystals averaging 0.2 mm in diameter. Dark brown glass occurs in quantities up to ten percent in some specimens.

Calcite, zeolites (stilbite, natrolite, and heulandite), and chalcedony are the most abundant vesicle fillings in the more vesicular flows.

Non-porphyritic Basalt. The non-porphyritic basalts are charac-terized by a holocrystalline, intergranular to subophitic pilotaxitic texture. Unaltered labradorite (An53-65) microlites 0.5 to 1.0 mm in length comprise an average of 55 percent of the rock. Pale pinkish-brown clinopyroxene occurs as anhedral to subhedral crystals as much as 1 mm in diameter. The pinkish hue suggests titaniferous augite. Colorless, subhedral olivine crystals up to 1 mm in diameter are generally partially or entirely altered to iddingsite. Magnetite and ilmenite occur as inclusions and also as discrete crystals to 0.3 mm in diameter.

Basalt Dikes. Modal analysis of a typical dike rock (sample DT-93-70) reveals that it is composed of 56 percent labradorite, 19 percent clinpyroxene, five percent olivine, six percent magnetite, and 14 percent glass (Table 4). Labradorite (An 64) is euhedral to subhedral and slightly altered to kaolin. Anhedral pinkish-brown clinopyroxene crystals are intergranular and occasionally subophitic. Subhedral grains of olivine are partially altered to chlorite. Magnetite and ilmenite are finely disseminated throughout the rock. Interstitial glass and clay locally form an intersertal texture.

Ash Flow Tuffs. The interbedded ash flow tuffs are thoroughly welded, display pronounced eutaxitic textures, and contain small amounts of crystals and lithic fragments. The vitric groundmass appears to have been derived from collapsed pumice fragments. A distinctive characteristic of the welded tuffs is the presence of a vitrophyre that represents the densely welded portion of the ash flow.

Phenocrysts of andesine, sanidine, biotite, and augite comprise 8 to 15 percent of the rock. Andesine (An35-40) phenocrysts are 0.5 to 2 mm in length and show moderate alteration to sericite. Andesine makes up approximately 80 percent of the total phenocrysts. Sanidine phenocrysts 0.5 to 1 mm in length make up the bulk of the remaining 20 percent.

The groundmass contains andesine microlites, augite, magnetite, and traces of hypersthene set in a matrix of partly devitrified glass. Glass comprises more than 90 percent of the groundmass. Finely disseminated iron oxide imparts a grayish-black (N2) color to the vitrophyre. Andesine microlites are generally oriented parallel to the direction of flattening of pumice fragments.

Ash Fall Tuff. One tuff was classified as an ash fall tuff because of its poor sorting, unstratified internal structure, and lack of welding.

Rowe (1971) classified these tuffs as rhyolitic quartz latite welded tuffs on the basis of their chemical composition.

Origin

Numerous basalt dikes in the thesis area strongly suggest that the flows of basalt were produced by large fissure eruptions. The structure of most flows indicates that they were fluid, gas charged pahoehoe lavas that spread out in thin flows upon eruption. The presence of occasional zones of flow breccia suggests that a few of the flows were aa lava.

The ash flow tuffs are attributed to nuees ardentes type eruptions. The ash flows were hot and thick enough for most of them to become welded.

Correlation and Age

Fuller (1931) states that the thick basalt sequence can be traced 20 miles north to Steens Mountain. Fuller (1931), Baldwin (1964), and Walker and Repenning (1965) have correlated the Pueblo Mountain basalt sequence with the Steens Mountain sequence. Potassium-argon age dates (Evernden, et al., cited in Baldwin, 1964) for samples collected near the top of the Steens Basalt range from 14.5 to 15 million years (middle to late Miocene). Walker and Repenning have paleontologically dated the Steens Basalt as middle to late Miocene.

Recent work by Watkins and Gunn (1970) has shown that the Steens Basalt sequence was extruded "during a period when the geomagnetic field was changing from reversed to normal polarity. This indicates that the entire 1,000 m section accumulated in no more than 50,000 years and perhaps as little as 2,000 years."

Rhyolite Unit

The south end of the west ridge of the Pueblo Mountains is underlain by rhyolite. This rhyolite was first mentioned by Blake (1875) and later by Merriam (1910). Burnam (1970) described the rhyolite in detail. To the writers knowledge, the rhyolite found in the area of current investigation has not been previously described.

Field Relationship

The rhyolite crops out the full north-south length of the thesis area, along the crest of the west ridge of the Pueblo Mountains. The rhyolite is very resistant to erosion. In the thesis area the ridge is 1,000 to 1,500 feet higher than areas to the north and south where the rhyolite is not present. The east face of the ridge crest is a near vertical cliff ranging from 20 to 500 feet in height depending on the thickness of the rhyolite. The rhyolite is well exposed along the cliff but its steepness makes detailed examination very difficult. The unit is also excellently exposed along the dip slope where erosion has removed overlying rocks and soil cover.

The contact between the base of the rhyolite and underlying basalt is gently undulating, and where observed, unusual in its lack of flow breccia. The underlying basalt flow may be traced with little variation in thickness, nearly the full length of the thesis area. This indicates that very little erosion occurred between the time the basalt flow solidified and the rhyolite was extruded.

The rhyolite unit is disconformably overlain by fine-grained, platy, non-porphyritic basalt. The relief along this contact is considerable due to large, abrupt variations in the thickness of the viscous rhyolite flows (Figure 11). Infrequent bedded lenses of tuffaceous sedimentary rocks overlying the rhyolite indicate that some erosion occurred before the overlying basalt flow was extruded. The upper surface of the sedimentary rocks was baked by the overlying basalt flow. The sedimentary rocks appear to have filled depressions on the upper surface of the rhyolite. A vitrophyre exhibiting a distinct eutaxitic texture is locally found overlying the rhyolite in place of the sedimentary rocks. The vitrophyre probably represents the densely welded portion of a welded tuff associated with the extrusion of the rhyolite.

Figure 11. View toward the north showing cliff forming rhyolite in background, thin basalt flows exposed in cirque, and light colored rhyolite in foreground. Note the thin scoriaceous zones between basalt flows.

The rhyolite unit ranges from 100 to 500 feet in thickness. Five different flows were recognized in the field and additional flows may be present. Flow breccia is common along the margins of flows although apparently not found at the base of the flows where it would be most expected.

Flow banding, mafic lithic fragments, and phenocrysts are found in all flows. Alternating color bands impart flow banding to the rock. The flow banding is typically gently undulating, but highly contorted flow banding is also common. The rhyolite breaks parallel to the flow banding giving it a platy fracture. The flow banding may have almost any orientation. Mafic volcanic fragments, undoubtedly derived from underlying basalt flows, are found in small quantities in most flows. Phenocrysts of sanidine, plagioclase, quartz, and biotite occur in all rocks in quantities ranging from 7 to 20 percent.

Vitrophyres are found at two locations along the ridge. At one location, the vitrophyre is intimately associated with rhyolite and either preceded or was extruded simultaneously with the rhyolite. The vitrophyre is characterized by abundant lithophysae up to 15 cm in diameter (Figure 12). The vitrophyre at the second location is more extensive and possesses a distinct eutaxitic texture. The vitrophyre probably represents the densely welded portion of an ash flow tuff.

Figure 12. Vitrophyre exhibiting lithophysae up to 15 cm in diameter.

Lithology and Petrography

Rhyolite and Vitrophyre. The rhyolite is dense and hard. Flow banding and phenocrysts of sanidine and biotite are megascopically discernible. The color of fresh surfaces varies from pale red (5 R 6/2), to moderate reddish-brown (10 R 4/4), and brownish-black (5 Y 2/1). The vitrophyre is light gray (N7), to dark gray (N3) in color. The vitrophyre is friable, and contains abundant phenocrysts of sanidine. Lithophysae up to 15 cm in diameter are also locally abundant. The rhyolite weathers to dark reddish-brown (10 R 3/4) and the vitrophyre to dark gray (N3).

Modal analyses of three samples of rhyolite show that phenocrysts compose seven to ten percent of the rock (Table 5). Corroded, embayed sanidine phenocrysts comprise over 60 percent of the total phenocrysts except in sample (DT-60-70) in which oligoclase (An28) makes up more than 75 percent of the total phenocrysts. The abundance of plagioclase in this rock suggests the rock is more basic and probably is latitic or dacitic in composition. Quartz phenocrysts are uncommon (less than ten percent of the total phenocrysts) and strongly corroded. Biotite occurs in trace amounts in all samples examined. Euhedral magnetite crystals are also present. Mafic volcanic fragments similar to Steens Basalt are found in small quantities.

The groundmass exhibits flow banding and contains aligned feldspar microlites. The glass is partially to completely devitrified. Radial and aggregate intergrowths of alkali feldspar and cristobalite (?) are the most characteristic devitrification products. Vesicles in sample (DT-53-70) are lined with radial chalcedony and wedge-shaped tridymite twins.

Table 5. Modal analyses of samples from the rhyolite unit.

	DT-50-70	DT-53-70	DT-60-70
Crystals:			
Sanidine	6.0	4.5	-
Quartz	.4	.9	-
Plagioclase	1.9	-	6.0
Biotite	.6	Tr.	Tr.
Hornblende	-	-	Tr.
Magnetite	.8	.2	1.3
Lithic Fragments:			Tr.
Groundmass:			
Glass	-	3.0	18.2
Devitrified	90.3	87.8	74.4

The vitrophyre contains as much as 20 percent phenocrysts of sanidine, quartz and biotite set in a glass groundmass. Sanidine makes up over 75 percent of the phenocrysts and is deeply embayed and corroded. Quartz is common and is also strongly corroded. The groundmass glass is light brown in thin section, unaltered, and displays a perlitic fracture pattern.

Tuffaceous Sedimentary Rocks. The tuffaceous sedimentary rocks are composed of vitrophyre fragments, pumice fragments, sanidine, quartz, and occasional mafic volcanic fragments in a matrix of fine glass dust. They are poorly sorted, slightly lithified, and crudely stratified (Figure 13).

Origin

The contorted flow banding and breccia zones are indicative of a viscous lava. A possible vent area for two of the flows in the north part of the thesis area is located in the canyon between Stonehouse Creek and North Creek approximately two-thirds of a mile west of the ridge crest. What appear to be faint concentric flow ridges, visible only on the aerial photographs, indicate that the rhyolite flowed east from the vent area. Where the rhyolite flows can be observed for a considerable distance they appear to thicken toward the west.

Correlation and Age

The rhyolite exposed at the south end of the Pueblo Mountains has been tentatively correlated with the Canyon Rhyolite of Virgin Valley, Nevada by Merriam (1910) and Burnam (1971). The rhyolite in the south Pueblo Mountains is disconformably overlain by a sedimentary-pyroclastic unit. Burnam states that the tuff member that underlies the rhyolite is unconformably overlain by basalt north of the rhyolite. The rhyolite in the central Pueblo Mountains conformably overlies the

Figure 13. Crudely stratified tuffaceous sedimentary rocks cropping out along the top of the west ridge.

tuff and basalt and is disconformably overlain by 2,000 feet of basalt which is not found overlying the rhyolite elsewhere. By tracing distinctive basalt flows south on aerial photographs it is observed that the rhyolite in the southern Pueblo Mountains is stratigraphically approximately 1,500 feet higher in the basalt sequence than the rhyolite in the central Pueblo Mountains. This makes a positive correlation with the Canyon Rhyolite somewhat tenuous. Descriptions of rhyolites, flow breccias, and vitrophyres from Virgin Valley (Wendell, 1970) are similar to those previously described in this paper. A comparison of chemical and normative analyses of rhyolites from Virgin Valley, the southern Pueblo Mountains, and the central Pueblo Mountains is also quite similar (Table 6). Merriam (1910) and Wendell (1970) described rhyolites and vitrophyres from Virgin Valley. Maloney (1961) described vitrophyres and felsites (a general term in which he included rhyolite, latite, and quartz latite) from Lone Mountain approximately ten miles west of the area of this report. Maloney states that the felsites and vitrophyres of Lone Mountain may be correlated directly with the Canyon Rhyolite, but he elects to name them the Lone Mountain Formation due to slightly differing lithologies. The rocks he describes as felsites are very similar to those described earlier in this section and listed as possible latites. If evidence recently published by Watkins and Gunn (1970) indicating that the Steens Basalt sequence was extruded in perhaps as little as 2,000 to 50,000 years is

Table 6. Comparison of chemical analyses of rhyolites from Virgin Valley, Nevada (Fuller, 1931), the southern Pueblo Mountains (Fuller, 1931), and the central Pueblo Mountains (this paper).

Oxide	Virgin Valley	S. Pueblo Mountains	DT-50-70
SiO_2	78.6	73.8	76.7
Al_2O_3	9.9	12.5	13.9
FeO	0.9	0.9	1.6#
Fe_2O_3	0.7	1.5	
MgO	0.1	0.3	0.2
CaO	0.7	1.0	0.6
Na_2O	3.3	3.8	*
K_2O	4.3	5.4	4.9
H_2O	1.1	0.7	*
TiO_2	0.2	0.1	0.2
	99.8	100.0	98.1

Total iron.
* Not determined.

Table 7. C.I.P.W. norms calculated from chemical analyses in Table 6.

	Virgin Valley	S. Pueblo Mountains	DT-50-70
Quartz	41.8	30.1	44.5
Orthoclase	25.6	31.1	29.0
Albite	26.7	31.4	16.3
Anorthite	-	1.7	3.0
Corundum	-	-	4.4
Acmite	0.9	-	-
Diopside	2.1	2.3	-
Wollastonite	0.5	0.1	-
Hypersthene	-	-	2.0
Magnetite	0.5	2.1	0.6
Ilmenite	0.6	0.2	0.3
H_2O	1.1	0.7	-
	99.8	99.7	100.1

correct, then it is possible that the 2, 000 feet of basalt overlying the rhyolite was extruded in a very short time. Most of the evidence presented here indicates that the rhyolites from the central Pueblo Mountains are probably correlative with the Canyon Rhyolite, however, there is enough uncertainty that a positive correlation can not be made at this time.

As the rhyolite unit is within a unit that is middle Miocene in age; the rhyolite unit is assigned a middle Miocene age.

Sedimentary-Pyroclastic Unit

Field Relationship

The sedimentary-pyroclastic unit, underlying low asymmetrical ridges and valleys, trends N. 5^{o} W. along the west side of the mountains. The valleys are underlain by easily eroded tuffaceous sedimentary and minor pyroclastic rocks. The ridges are underlain by welded rhyolite tuff. The unit is generally poorly exposed due to its lack of resistance to erosion.

The unit overlies the Steens Basalt with an angular unconformable relationship. A divergence in dip of 6 to 8^{o} is apparent. The presence of basalt fragments within the sedimentary rocks suggests an erosional interval prior to deposition.

The unit has a maximum thickness of approximately 850 feet.

This includes 700 feet of tuffaceous conglomerates, sandstones, siltstones, and minor sillars. Graded bedding and scour and fill are the primary sedimentary structures noted. Three distinct members with thicknesses ranging from 25 to 60 feet, and a total thickness of 150 feet, comprise the welded tuff sequence. Burnam (1970), noted the presence of sedimentary rocks between each member of a similar welded tuff sequence. These rocks were not noted between the welded tuffs in the area of the present study. It is possible they are present but are covered by surface debris.

Lithology and Petrography

Tuffaceous Sedimentary Rocks. The tuffaceous sedimentary rocks are very light gray (N8) to medium light gray (N6) in color. Pumice fragments and glass shards compose over 80 percent of the rock. Basaltic lithic fragments, feldspar, quartz, magnetite, biotite, and pyroxenes make up the remainder of the rock.

Most framework grains are subrounded and between 1.0 and 1.8 mm in diameter. Rarely, the clast size is larger, forming tuffaceous conglomerates.

Pumice fragments and glass shards are partially devitrified. Basaltic grains exhibit pilotaxitic and subophitic textures. The feldspar minerals are broken, partially altered plagioclase and anorthoclase. Quartz, biotite, magnetite, and pyroxene comprise less than five percent of the framework, and are randomly distributed through the rock. The framework is loosely bound in a matrix of fine angular glass fragments derived from the pumice fragments and glass shards.

Sillar Sequence. A poorly welded ash flow tuff approximately 150 feet thick, crops out intermittently from the south to the north border of the thesis area. The sillar conformably overlies the tuffaceous sedimentary rocks and conformably underlies the oldest welded tuff member. The term 'sillar' was first proposed by Fenner (1948) to describe poorly welded ash flow tuffs in Peru. Rowe (1971) was the first to use the term to describe poorly welded ash flow tuffs in the Pueblo Mountains. Where exposed, the sillar weathers to hoodoos and pinnacles by differential erosion along irregular joint sets. The weathered surface forms a coherent, pale red (10 R 3/4) crust. The cohesiveness of the sillar is probably due to incipient welding and angularity of the fragments. The most resistant exposures are found where the unit is thickest. Apparently the thicker sections retained their heat longer leading to a greater degree of welding.

Pumice fragments from ash-size to 5 cm in diameter comprise over 80 percent of the rock. The pumice fragments are unflattened and exhibit round vesicles. Anorthoclase and quartz comprise most of the phenocrysts in the rock. Traces of biotite, augite, and magnetite are also present. Subrounded basalt pebbles as much as 10 mm in diameter make up one to five percent of the rock. The basalt fragments are concentrated in the lower part of the section.

Welded Tuff Sequence. The three differentiated members of the welded tuff sequence contain vertical zones of partial and dense welding. Unwelded portions of the tuff are probably present, but they are not exposed. All three members are named welded rhyolite tuffs.

Flattened pumice fragments and elongate glass shards give the welded tuffs a eutaxitic structure. Phenocrysts, predominantly quartz and anorthoclase, up to 4 mm in length, comprise 12 to 25 percent of the rock. Quartz occurs as fresh, rounded, embayed crystals that display distinctive curved fractures. Anorthoclase most commonly occurs as elongate crystals with rounded corners and displays pronounced cleavage in two directions normal to each other. Pleochroic yellow biotite occurs as eight-sided crystals replacing augite. Anhedral magnetite is a common constituent in all members. Sanidine and anorthoclase occur together in the middle and upper welded tuff members. Avent (1965), Johnson (1960), and Maloney (1961) have described the same disequilibrium assemblage from nearby areas. Mafic lithic fragments are widely distributed but rarely comprise more than one percent of the tuffs.

Devitrification of glass producing probable potassium feldspar and cristobalite has resulted in a cryptocrystalline groundmass texture with many axiolites. Relict pumice tube structures are readily noted in hand samples and are identified in thin section by linear aggregates of vapor phase minerals such as riebeckite, cristobalite, and potassium feldspar. Blue, pleochroic riebeckite is found as subhedral crystals and fibrous aggregates (crocidolite). Modal analyses of representative samples from each member are given in Table 8.

Table 8. Modal analyses of samples from welded tuff sequence on the west side of the Pueblo Mountains.

	DT-69-70	DT-70-70	DT-71-70
Crystals:			
Quartz	1.8	1.0	8.6
Anorthoclase	7.8	9.8	10.4
Biotite	Tr.	0.6	Tr.
Magnetite	1.6	2.0	2.4
Aegerine	1.2	-	-
Riebeckite	0.2	-	2.0
Clinopyroxene	-	Tr.	Tr.
Lithic Fragments:	Tr.	Tr.	0.4
Groundmass:			
Glass	55.4	6.8	-
Devitrified	32.0	79.6	76.2

DT-71-70 Lowest member of welded tuff sequence.
DT-70-70 Yellowish colored middle member of welded tuff sequence.
DT-69-70 Reddish colored top member of welded tuff sequence.

The stratigraphically lowest member is grayish-yellow-green (5 GY 7/2) on the fresh surface and weathers to yellowish-gray (5 Y 6/2). It contains 24 percent phenocrysts consisting of anorthoclase, quartz, magnetite, riebeckite, and biotite. The glass is completely devitrified and vapor phase mineralization is extensive.

The middle member is yellowish-gray (5 Y 7/2) and weathers to yellowish-brown (10 YR 6/4). It contains phenocrysts of anorthoclase, quartz, magnetite, biotite, and pyroxene. The glass is light brown in color and partially to completely devitrified.

The upper member is grayish-red (5 R 4/2) and weathers to grayish-red (10 R 4/2). It contains 13 percent phenocrysts consisting of anorthoclase, quartz, magnetite, aegerine, biotite, sanidine, and riebeckite. The glass is partially devitrified.

Origin

Sedimentary structures found in the tuffaceous sedimentary rocks are indicative of a fluviatile environment. The tuffaceous sediments probably were derived from air fall and ash flow tuffs. The sillar sequence and the welded tuff members were produced by nuees ardente type volcanic eruptions. The similar mineralogical characteristics indicate that all the rocks are related to the same volcanic sequence. The writer considers it possible that the three welded tuff members may be compound cooling units of one ash flow tuff.

Correlation and Age

Burnam (1970) tentatively correlates the sedimentary-pyroclastic unit of the Pueblo Mountains with the Virgin Valley Formation of Virgin Valley, Nevada on the basis that both unconformably overlie rhyolite units that are believed to be correlative. The Virgin Valley Formation was assigned an age of middle Miocene by Merriam (1910) on the basis of vertebrate fossil evidence. Willden (1964) suggested that this formation extends into late Miocene time.

Avent (1965) correlates the sedimentary-pyroclastic unit of the Pueblo Mountains with the Danforth Formation of the Harney Basin.

Based on similar stratigraphic positions and somewhat similar lithologies, the writer considers a correlation with the Virgin Valley Formation the most probable, and as such the sedimentary-pyroclastic unit is assigned an age of middle to late Miocene.

Rhyolite Tuff Sequence at Red Point

Field Relationship

A distinctive sequence of rhyolite tuff crops out on Red Point in the northeast corner of the thesis area. The sequence is made up of three distinct members: an air fall tuff, a reddish-brown welded tuff, and a greenish-gray welded tuff. Locally the tuffs form cuestas dipping in a northwesterly direction. Faulting, jointing, and landsliding have largely obscured most relationships in the sequence.

The air fall tuff is very light gray (N8) in color, and is composed of black obsidian fragments, fine-grained mafic fragments, and phenocrysts of quartz and sanidine in a matrix of ash and dust. The tuff is stratified with beds from 2 to 18 inches in thickness. Due to its susceptibility to weathering the tuff is poorly exposed and its thickness can only be estimated to be approximately 150 feet.

The ash flow tuff overlying the air fall tuff is moderate reddish-brown (10 R 4/4) in color and composed of elongate pumice and lithic fragments, and sanidine and quartz phenocrysts in a fine-grained reddish matrix. The tuff is partially welded and compacted. Pumice fragments up to 4 cm in length are flattened and bent imparting a distinct eutaxitic structure to the rock. Many pumice fragments contain cavities lined with drusy vapor phase minerals. Where undisturbed by faulting this member forms the most prominent outcrops in the sequence (Figure 14). The thickness of this member is approximately 150 feet.

The upper member of welded tuff is pale green (10 G 6/2) in color, and composed of elongate pumice fragments, and abundant phenocrysts of quartz and sanidine in a fine-grained greenish matrix. The sanidine phenocrysts in this member possess a distinctive bluish opalescence. Pumice fragments up to 4 cm in length are extremely flattened and elongated imparting a eutaxitic structure to the rock. The tuff is densely welded. The few cavities that are present are lined with vapor phase minerals. The member is very resistant to erosion and topographically forms the highest parts of the sequence. The tuff is found in coherent outcrops only in a few isolated locations.

Figure 14. View toward the northeast showing reddish-brown ash flow tuff at Red Point. Pueblo Valley and Tum-Tum Lake are in background.

More typically, the surface overlying this member is littered with large, angular boulders with relatively constant shapes and sizes determined by joint sets. The thickness of this member is approximately 300 feet.

The reddish-brown welded tuff member grades upwards over a distance of approximately ten feet into the greenish welded tuff. The lack of a sharp contact between members and their mineralogical similarity, indicates they may be a compound cooling unit of a single ash flow tuff. Modal analyses of the two units are given in Table 9.

Lithology and Petrography

Air Fall Tuff. The air fall tuff is composed predominantly of angular glass shards which average 1.5 mm in diameter. Fine-grained lithic fragments up to 2 mm in diameter make up less than one percent of the rock. Broken, embayed, and corroded phenocrysts of sanidine and quartz ranging in size from .25 mm to 1.7 mm comprise ten percent of the rock. The glass shards are light tan and are slightly devitrified.

Ash Flow Tuff (Unit One). The phenocrysts of the lower welded tuff unit are sanidine, quartz, and magnetite (Table 9). The sanidine and quartz phenocrysts are commonly embayed and corroded. Sanidine crystals display excellent cleavages and quartz crystals display a prominent conchoidal fracture. Phenocrysts range from .25 mm to

3 mm in length. Fine-grained mafic volcanic fragments comprise less than two percent of the rock. The groundmass makes up 75 percent of the rock and is composed of devitrified glass shards and pumice fragments. The glass has devitrified to small spherulites, that are probably composed of potassium feldspar and cristobalite, and large numbers of crystallites of hematite. The hematite crystallites are so abundant that in places the rock is nearly opaque. Under reflected light the groundmass appears to be stained red. Elongate cavities in the center of flattened pumice fragments are lined with spherulitic assemblages of vapor phase minerals, probably potassium feldspar and cristobalite. Chalcedony is also present lining cavities. More porous zones of this member have been subjected to silicification in the form of dense reddish-brown opal replacing groundmass and phenocrysts.

Table 9. Modal analyses of welded tuffs from Red Point.

	DT-26-70	DT-32-70
Crystals:		
Quartz	8.4	6.0
Sanidine	5.8	14.2
Magnetite	0.2	0.6
Aegerine	1.8	-
Groundmass:		
Glass	-	0.6
Devitrified	73.8	76.6
Vapor phase Cavity filling	10.0	2.0

DT-26-70 Greenish welded tuff from upper member.
DT-32-70 Reddish welded tuff from lower member.

Macroscopically, the rock exhibits excellent eutaxitic structure, however extensive devitrification has largely obscured the eutaxitic texture in thin section.

Ash Flow Tuff (Unit Two). The phenocrysts found in the upper welded tuff unit include quartz, sanidine and aegerine. Sanidine and quartz phenocrysts average about 1 mm in diameter, and are highly corroded and embayed. Quartz phenocrysts generally exhibit curved fractures, and both sanidine and quartz crystals may be broken. Euhedral aegerine phenocrysts average 0.6 mm in diameter and are pleochroic from dark green to light yellowish-green. Phenocrysts of magnetite are present in minor amounts. The groundmass is composed of devitrified glass and elongate pumice fragments which are commonly bent. Glass shards have devitrified to fine-grained, elongate, spherulitic aggregates of potassium feldspar and possibly cristobalite, and concentrically banded light brown opal (Figure 15). Opal is also found replacing sanidine phenocrysts and groundmass. Chalcedony may occasionally be found lining cavities. Abundant greenish crystallites, identical in form to the hematite crystallites in the lower unit, impart the distinctive greenish-gray color to this rock. The crystallites are a product of devitrification also.

The welded tuff of Unit Two possesses an excellent eutaxitic texture. Devitrification products have replaced the original shards, but have retained the original structure of the shards (Figure 16).

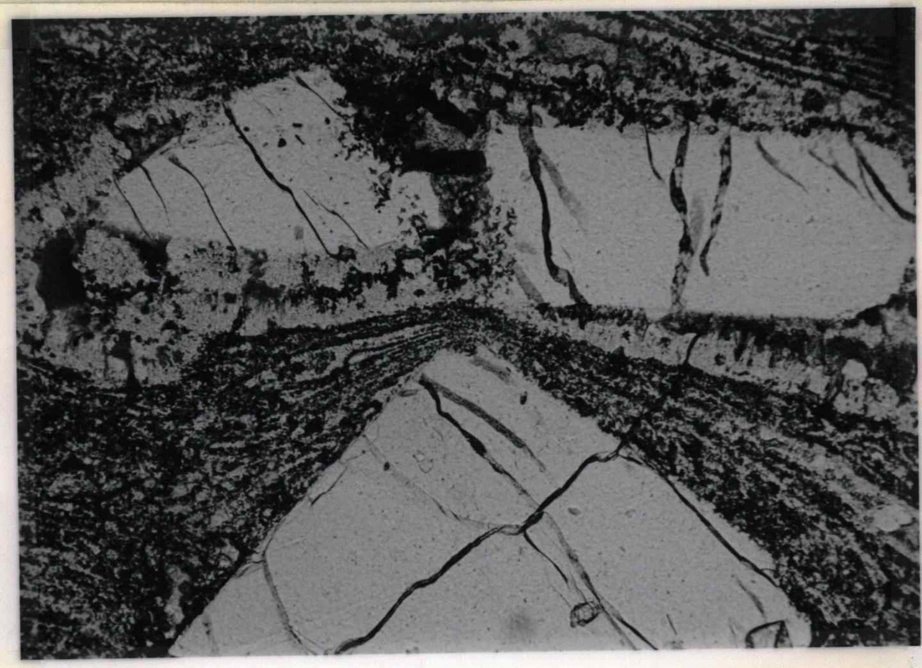


Figure 16. Photomicrograph of upper welded tuff unit. Compaction of pumice fragments and glass shards has resulted in excellent eutaxitic texture. Glass shards have devitrified to fine-grained spherulitic aggregates probably of potassium feldspar and cristobalite. Cavities in pumice fragments are lined with a coarse aggregate of the same vapor phase minerals. Note the sanidine phenocryst which appears to have been broken when compacted over the sharp edge of another sanidine phenocryst.

Origin

The similar mineralogy of the three units indicates they are related to the same sequence of silicic volcanism. The air fall tuff is related to explosive volcanism which preceded the nuees ardente type volcanic activity. As mentioned previously, the welded tuff sequence may possibly be a compound cooling unit of a single ash flow tuff.

Correlation and Age

An identical sequence of air fall and ash flow tuffs has been described by Carlton (1969) eight miles east of Red Point in the Trout Creek Mountains. Carlton states, "Dating of mammalian fossils and potassium-argon dates in the overlying sediments by various workers suggest the ash flow tuffs are middle (?) to late Miocene in age". Walker and Repenning (1965) have correlated the ash flow tuffs with the rhyolitic and dacitic volcanic rocks of Willden (1961) and possibly with the Canyon Rhyolite of Merriam (1910) and Wendell (1970). The author feels the rhyolitic tuffs at Red Point are probably correlative with the same period of silicic volcanism that produced the Canyon Rhyolite of Virgin Valley, and the Pueblo Mountains. This correlation requires that an age of middle (?) to late Miocene be assigned the ash flow tuff sequence.

Tum-Tum Conglomerate

Ross (1940), Williams and Compton (1953), and Walker and Repenning (1964) have briefly described this unit and refer to it as the "older alluvium". Avent (1965) described the same sequence of conglomeratic sedimentary rocks, for which he proposed the name Tum-Tum Conglomerate. Carlton (1969) described a similar sequence of rocks from the west side of the Trout Creek Mountains.

Field Relationship

The Tum-Tum Conglomerate crops out in an elongate belt up to two miles wide that parallels the eastern front of the Pueblo Mountains. The unit underlies low, sparsely vegetated hills that are dissected by numerous east flowing streams draining Pueblo Mountain. The west edge of the conglomerate is believed by the author, to be in fault contact with the underlying pre-Tertiary metamorphic rocks. The contact zone extends along a prominent bench formed along the top of the conglomerate. The metamorphic rocks along this zone are altered, silicified, mineralized, slickensided and brecciated. The actual contact is not exposed. A steep, east dipping normal fault is strongly indicated along this zone. The east edge of the conglomerate is bounded by a northeast trending portion of the range-front fault system south of Red Point, and by a northwest trending portion of the fault system north of Red Point.

The conglomerate is composed of coarse, angular, pebble to boulder-size debris in a matrix of poorly sorted tuffaceous sand and silt. In general, the average fragment size decreases toward the east. North, west, and south of Red Point large boulders of greenish-gray welded tuff are abundant.

The conglomerate strikes approximately N. 15° W. and dips to the west at angles ranging from 10° to 40°. The steeper dips are all found in the extreme south end of the outcrop area where faulting has obscured many of the relationships. The thickness of the unit is difficult to determine. An estimated thickness of 1, 500 to 2, 000 feet is probably close.

Lithology

The conglomerate is poorly sorted and crudely bedded (Figure 17). Thick beds of cobble-boulder conglomerate are interbedded with zones of poorly sorted volcanic sandstone. All clasts are angular to subangular indicating a short distance of transport. The pebble to boulder-sized fragments are set in a matrix of clay, silt, and sand. Rock fragments range from less than one inch to greater than three feet in diameter. The largest boulders are found in the vicinity of Red Point where they are locally derived from the welded tuffs.

The conglomerate includes fragments of dense aphanitic basalt,

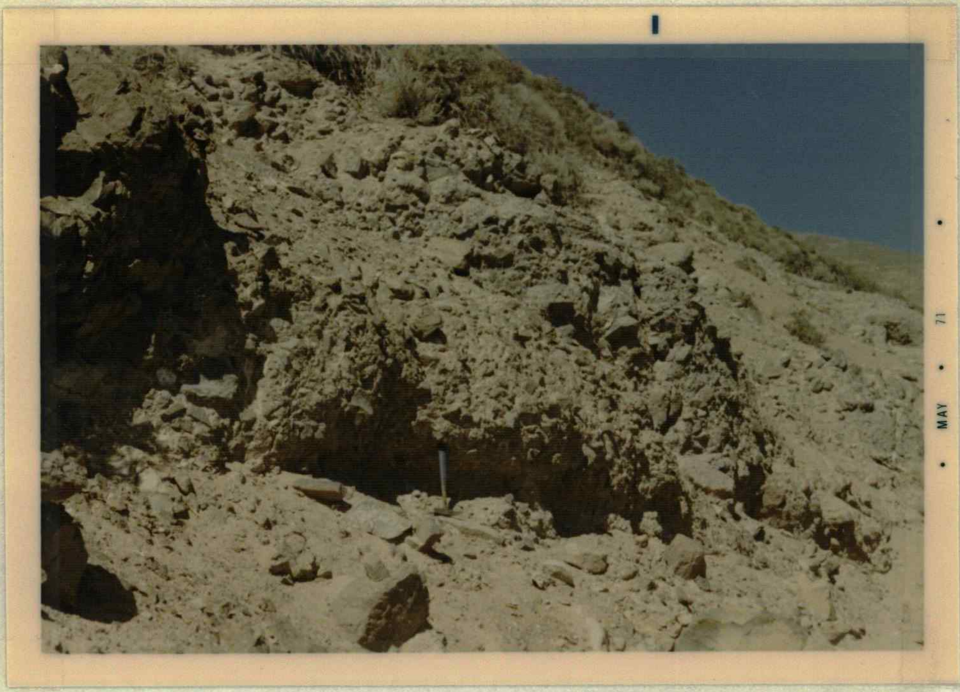


Figure 17. Typical outcrop of Tum-Tum Conglomerate showing its chaotic, unsorted nature. Rock types present in this outcrop include basalt, greenstone, quartzite, schist, granodiorite, and quartz monzonite.

vesicular and amygdaloidal basalt, porphyritic basalt, andesite, greenstone, schist, quartzite, granodiorite, quartz monzonite, welded tuff, and rhyolite. The basalt fragments comprise over 75 percent of the total. Calcite, zeolites and chalcedony are the primary vesicle fillings in the amygdaloidal basalt. Virtually every rock type found in the thesis area can be found in the conglomerate.

Origin

The conglomerate was probably deposited by mud-charged torrential streams as alluvial fans along the mountain front. The large size and angularity of the boulders indicates they are very near their source. The increasing coarseness to the west indicates the conglomerates were derived from highlands in that direction. The fact that every rock type found in the conglomerate can be found in the mountains to the west is also strongly indicative of a source area in that direction.

Correlation and Age

Ross (1940) suggests a Pliocene or possibly early Pleistocene age on the basis of a cameloid bone found in the unit. Walker and Repenning (1965) are reported to have collected early to middle Pliocene fossil mammal bones from this unit near Fields. The author believes an early to middle Pliocene age is probably most nearly correct.

Avent (1965) states, "The Tum-Tum Conglomerate is a locally derived orogenic conglomerate that has no known correlatives in this part of the northern Great Basin". The author would include the conglomerates described by Carlton (1969) from the Trout Creek Mountains as a similar unit.

Quaternary Deposits

Alluvium, terrace, playa, and dune deposits are undifferentiated in the area investigated. Alluvium consists primarily of alluvial fan deposits at the mouths of canyons, especially along the east front of the mountains. Terrace deposits are locally conspicuous near Red Point. Playa deposits and sand dunes are abundant in Pueblo Valley.

STRUCTURE

The Pueblo Mountains are in the north part of the Basin and Range Province. This province is characterized by north-south trending fault block structures. The tilted upthrown fault block of the Pueblo Mountains and the graben of Pueblo Valley to the east are typical of this structure.

The homoclinal structure formed by the volcanic and sedimentary rocks, which dip approximately 20° to the west, is the most dominant feature of the west part of the range. The structure of the metamorphic rocks of the east ridge of the Pueblo Mountains is dominated by foliations which apparently have developed parallel to the original bedding. The metamorphic rocks dip 45° to 65° to the southeast. One linear band of schistosity dipping to the west was observed. It is believed that this band of reversed dips is related to faulting.

Faults in the thesis area occur along two trends. One strikes N. 20° to 35° W., and the other strikes N. 15° to 40° E. All faults observed were steeply dipping normal faults. All basalt dikes also follow the same trends. These two trends are apparent throughout southeast Oregon (Walker and Repenning, 1965). Donath (1962) postulated that this pattern was formed as original conjugate strike-slip shears caused by maximum north-south principal stress and east-west minimum principal stress. Donath believes that, "subsequent to the development of this fracture system, block faulting occurred in which the dominant movement on the shears was dip-slip". Although the area investigated by Donath is approximately 130 miles to the northwest, the author believes that this hypothesis could possibly account for fault and dike trends within the thesis area.

In a paper published in 1943, Nolan postulated that faulting in the Basin and Range Province began in Oligocene time and may still be active. The angular unconformity between the Steens Basalt and overlying sedimentary-pyroclastic unit is evidence that faulting began in the Pueblo Mountains during middle to late Miocene. More recent faulting has further tilted, and uplifted the mountain range. Evidence for recent displacement is provided by the steep fault scarp along the eastern front of the mountains, and a fault scarp which displaces the alluvial fan at the mouth of Colony Creek.

The minimum displacement along the range-front fault, as calculated by extending the lava flows to the fault plane, is approximately 9,000 feet.

GEOMORPHOLOGY

Running water has been the principal geomorphic agent responsible for shaping the Pueblo Mountains. Spring and summer thundershowers and melting snow provide sufficient water for stream flow. The steep gradients of nearly all streams make it possible to transport coarse debris during periods of heavy runoff. Mass wasting and weathering have also contributed to the erosional process. A small cirque at the head of Stonehouse Creek is the only evidence of glaciation (Figure 18).

The structure and lithology of the mountains is reflected in the topography. The eastern range is underlain by massive and schistose northeast trending metamorphic rocks. The metamorphic rocks form a high, steep, northeast trending ridge characterized by numerous short, steep, transverse stream drainages which indicate a youthful stage of erosion. The west-dipping, north-striking homoclinal structure of volcanic and sedimentary rocks underlying the west ridge, controls its topographic form. Resistant basalt, rhyolite, and welded tuff units form prominent cuestas. Dip slopes are formed on the west side of these units giving the west ridge its asymmetrical profile. Less resistant sedimentary rocks and tuffs form valleys.

Numerous transverse consequent streams drain both sides of the mountain range. They are natural drainages produced on the

Figure 18. View toward the east showing small cirque eroded in the Steens Basalt sequence on the dip slope of the west ridge.

flanks of a rising fault block. Van Horn Canyon was formed by the down-cutting action of a stream superposed on the pre-Tertiary metamorphic rocks during the faulting episode. Just west of the contact between the pre-Tertiary metamorphic rocks and the volcanic sequence, Van Horn Creek turns abruptly north and follows a zone of easily eroded basalt flows. Rapid erosion along this subsequent stream has beheaded Colony Creek. Van Horn Canyon is steep and V-shaped, whereas the canyon occupied by Colony Creek has steep walls, but a wide, alluvium covered floor, indicative of an underfit stream.

Prominent coalescing alluvial fans are found along the east and west fronts of the mountain range.

Talus and infrequent land slide and slump blocks are products of mass wasting.

ECONOMIC GEOLOGY

The metasedimentary and metavolcanic rocks which make up the main mass of Pueblo Mountain have been extensively prospected for gold-bearing quartz veins. Only one property, on the east side of Pueblo Mountain in the N.E. 1/4, sec. 17, T. 40 S., R. 35 E., is reported to have had any production (Tom Lawson, personal communication). Minor bornite, chalcopyrite, and chrysocolla are found in several quartz veins, but are economically unimportant because of their small size and minor amounts of copper minerals present.

The author believes that two localities in the thesis area might justify more detailed examination for mineral deposits. The first is along the contact of the metamorphic rocks and the Tum-Tum Conglomerates on the east side of Pueblo Mountain. This is an elongate zone of brecciation, hydrothermal alteration, silicification, and local mineralization. The second area is just north of Van Horn Creek in the N. 1/2, sec. 31, T. 40 S., R. 35 E. In this area the schists and semischists show local hydrothermal alteration, and unaltered dark schists are commonly encrusted with malachite.

GEOLOGIC HISTORY

The earliest recorded geologic events within the thesis area began with the deposition of an eugeosynclinal assemblage of sedimentary and mafic volcanic rocks in late Paleozoic or early Mesozoic time. This assemblage included impure and quartz-rich sandstones, and interbedded mafic lava flows and pyroclastics. Subsequent to deposition, the rocks were buried, deformed, and subjected to regional metamorphism to the rank of lower to middle greenschist facies.

During Eocene and Oligocene time, the region was strongly uplifted and subjected to erosion which exposed the metamorphic rocks. Erosion of granitic plutons in nearby areas produced the basal conglomerate of the Pike Creek Formation (?), during late Oligocene to early Miocene time. The conglomerate was deposited in low areas on the eroded surface of the metamorphic rocks. The sandstones, rhyolite, welded tuff, tuff breccia, and andesite which make up the bulk of the Pike Creek Formation (?) were deposited over the conglomerate. Local beds of conglomerate within the formation indicate that erosion continued in adjacent areas. During middle Miocene, following erosion of the upper surface of the Pike Creek Formation (?), a thick sequence of basalt flows was erupted from nearby fissures. Occasionally interrupting extrusion of the basalt, were periods of pyroclastic volcanic activity which produced interbeds of ash flow tuffs.

A sequence of rhyolite, tuffaceous sedimentary rocks, and welded tuffs were extruded during a hiatus in eruption of the basalt sequence. During middle to late Miocene a sequence of tuffaceous sedimentary rocks and pyroclastic rocks were deposited with slight angular discordance over the basalt sequence. To the east, during this same time interval, a sequence of ash fall and ash flow tuffs was deposited in the vicinity of Red Point.

The slight angular unconformity which separates the basalt and the sedimentary-pyroclastic unit suggests that the Basin and Range type faulting began in the Pueblo Mountain area during middle to late Miocene. As the faulting continued into the Pliocene, a thick sequence of fanglomerates was being deposited in alluvial fans along the base of the fault scarp, forming the Tum-Tum Conglomerate. Renewed faulting during the Pleistocene has tilted and uplifted the Tum-Tum Conglomerate so that it is now undergoing erosion along with the rest of the mountain range.

The graben occupied by Pueblo Valley is now being filled with thick accumulations of Quaternary alluvium, which include alluvial fan deposits, lacustrine deposits, and eolian deposits.

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APPENDIX

Measured Section of the Basalt Unit

The measured section includes one complete stratigraphic section of the basalt unit. Subunits of the measured section are glomeroporphyritic basalt, dense aphanitic basalt, ash flow tuff, air fall tuff, and rhyolite.

Glomeroporphyritic basalt: vesicular, amygdaloidal basalt; medium gray (N4) on fresh surface, weathers to reddish-brown (10 R 5/4) or dusky red (10 YR 2/2); vesicles average 5 mm in diameter; vesicle fillings include zeolites, chalcedony, and calcite; plagioclase phenocrysts average 12 mm in length.

Dense aphanitic basalt: medium gray (N5) basalt that weathers to reddish-brown (10 R 4/6); degree of vesicularity varies between flows and within individual flows; vesicles average 8 mm; vesicles are locally filled with zeolites, calcite, and chalcedony; weathered surface commonly ophimottled.

Ash flow tuff: densely welded vitrophyre portion of welded tuff; eutaxitic structure.

Air fall tuff: light gray (N7) vitric tuff; moderately sorted in zones 2 to 18 inches thick.

Rhyolite: one flow of pale red (5 R 6/2) rhyolite; flow banding contorted; phenocrysts of quartz and sanidine; platy fracture in any orientation.

Section 1

Initial Point: Top of underlying metamorphic unit in the NW 1/4 SW 1/4 NW 1/4 sec. 18, T. 40 S., R. 35 E.

Terminal Point: Base of overlying sedimentary-pyroclastic unit in the NW 1/4 NW 1/4 SW 1/4 sec. 21, T. 40 S., R. 34 E.

6580' - 6502'	Dense aphanitic basalt: upper ten feet vesicular; top contact covered.
6502' - 6478'	Dense aphanitic basalt: top contact covered.

6478' - 6411'	Covered.
6411' - 6350'	Dense aphanitic basalt: platy jointing parallel to flow surface; contacts covered.
6350' - 6313'	Covered.
6313' - 6230'	Ash flow tuff: contacts covered.
6230' - 6218'	Dense aphanitic basalt: platy jointing parallel to flow surface; contacts covered.
6218' - 6159'	Dense aphanitic basalt: contacts covered.
6159' - 6127'	Dense aphanitic basalt: abundant vesicles in top ten feet; scoriaceous upper surface.
6127' - 5987'	Covered.
5987' - 5963'	Dense aphanitic basalt: vesicular; vesicles concentrated in top seven feet; contacts covered.
5963' - 5870'	Covered.
5870' - 5817'	Glomeroporphyritic basalt: vesicles average 12 mm in diameter; plagioclase laths up to 20 mm long; contacts covered.
5817' - 5812'	Glomeroporphyritic basalt: plagioclase laths up to 4 cm in length; upper contact scoriaceous.
5812' - 5785'	Glomeroporphyritic basalt: plagioclase laths up to 6 cm in length; cuesta former; upper contact scoriaceous.
5785' - 5651'	Covered.
5651' - 5630'	Air fall tuff: crudely bedded; coarser concentrated in lower 1/2 of unit; contacts covered.
5630' - 5521'	Dense aphanitic basalt: contacts covered.
5521' - 5466'	Covered.

5466' - 5417'	Glomeroporphyritic basalt: vesicles average 10 mm; plagioclase laths up to 6 cm long; upper contact scoriaceous.
5417' - 5376'	Dense aphanitic basalt: top five feet vesicular; upper contact clinkery.
5376' - 5301'	Dense aphanitic basalt: contacts covered.
5301' - 5283'	Ash flow tuff: reddish-brown; eutaxitic structure; upper contact covered.
5283' - 5256'	Dense aphanitic basalt: platy fracture; upper contact covered.
	Lateral offset 5000' S. 32° W.
5256' - 4935'	Rhyolite: flow banded, reddish-gray rhyolite; platy fracture in any orientation; phenocrysts of quartz and sanidine, lower contact sharp and slightly undulatory, upper surface shows large, abrupt changes in thickness.
4935' - 4716'	Covered.
4716' - 4692'	Glomeroporphyritic basalt: weathered surface is ophimottled; plagioclase laths up to 3 cm long; contacts covered.
4692' - 4611'	Dense aphanitic basalt; contacts covered.
4611' - 4306'	Covered.
4306' - 4293'	Ash flow tuff: eutaxitic structure; contacts covered.
4293' - 4022'	Dense aphanitic basalt: upper 13 feet vesicular; cuesta former; scoriaceous upper surface.
4022' - 3980'	Glomeroporphyritic basalt: amygdules filled with zeolites; plagioclase laths up to 2 cm long; contacts covered.
3980' - 3752'	Covered.
3752' - 3730'	Dense aphanitic basalt; contacts covered.

3730' - 3671'	Covered.
3671' - 3603'	Dense aphanitic basalt; contacts covered.
3603' - 3568'	Glomeroporphyritic basalt: amygdules are filled with chalcedony and zeolites and average 7 mm in diameter; upper surface scoriaceous.
3568' - 3529'	Covered.
3529' - 3473'	Dense aphanitic basalt; platy fracture; contacts covered.
3473' - 3421'	Glomeroporphyritic basalt: amygdules concentrated in upper ten feet of flow, filled with zeolites; contacts covered.
3421' - 3352'	Covered.
3352' - 3304'	Dense aphanitic basalt: ophimottling on weathered surface; contacts covered.
3304' - 3263'	Dense aphanitic basalt: medium gray (N5); platy fracture; contacts covered.
3263' - 3186'	Covered.
3186' - 3151'	Glomeroporphyritic basalt: amygdules filled with zeolites; sharp lower contact.
3151' - 3126'	Covered.
3126' - 3086'	Dense aphanitic basalt: medium gray (N5); platy fracture contacts covered.
3086' - 3001'	Covered.
3001' - 2979'	Dense aphanitic basalt: almond-shaped amygdules filled with zeolites oriented parallel to flow direction; scoriaceous upper surface.
2979' - 2929'	Glomeroporphyritic basalt: plagioclase oriented sub-parallel to flow direction; contacts covered.
2929' - 2909'	Covered.

2909' - 2901'	Dense aphanitic basalt: contacts covered.
2901' - 2851'	Covered.
2851' - 2818'	Glomeroporphyritic basalt: contacts covered.
2818' - 2703'	Glomeroporphyritic basalt: scoriaceous upper and lower surfaces.
2703' - 2690'	Glomeroporphyritic basalt: amygdules concentrated in upper five feet of flow; contacts covered.
2690' - 2641'	Covered.
2641' - 2591'	Dense aphanitic basalt: amygdules filled with zeolites; contacts covered.
2591' - 2549'	Glomeroporphyritic basalt: contacts covered.
2549' - 2531'	Dense aphanitic basalt: contacts covered.
2531' - 2461'	Dense aphanitic basalt: blocky weathering pattern; contacts covered.
2461' - 2156'	Glomeroporphyritic basalt: plagioclase concentrated in lower ten feet and upper 25 feet of flow; amygdules and joints filled with zeolites and chalcedony; scoriaceous upper surface.
2156' - 2138'	Glomeroporphyritic basalt: contacts covered.
2138' - 2099'	Covered.
2099' - 2039'	Glomeroporphyritic basalt: contacts covered.
2039' - 2004'	Glomeroporphyritic basalt: plagioclase laths up to 2 cm in length; contacts covered.
2004' - 1884'	Dense aphanitic basalt: contacts covered.
1884 - 1869'	Glomeroporphyritic basalt; contacts covered.
1869' - 1814'	Glomeroporphyritic basalt: sharp upper contact.
1814' - 1801'	Dense aphanitic basalt: dike trending N. 30° W.

1801' - 1758'	Dense aphanitic basalt: amygdules filled with zeolites, and chalcedony; weathered surface ophimottled; contacts covered.
1758' - 1738'	Glomeroporphyritic basalt: contacts covered.
1738' - 1727'	Dense aphanitic basalt: contacts covered.
1727' - 1592'	Covered.
1592' - 1520'	Dense aphanitic basalt: amygdules filled with zeolites and chalcedony; contacts covered.
1520' - 1490'	Glomeroporphyritic basalt: weathered surface ophimottled; scoriaceous upper surface.
1490' - 1413'	Glomeroporphyritic basalt: contacts covered.
1413' - 1382'	Dense aphanitic basalt: weathered surface ophimottled; sharp upper contact.
1382' - 1338'	Covered.
1338' - 1295'	Dense aphanitic basalt: amygdules concentrated in zones near top and bottom contacts; contacts covered.
1295' - 1230'	Dense aphanitic basalt: scoriaceous upper surface.
1230' - 1203'	Dense aphanitic basalt: contacts covered.
1203' - 1138'	Covered.
1138' - 1113'	Dense aphanitic basalt: abundant amygdules filled with zeolites average 6 mm in diameter; contacts covered.
1113' - 978'	Dense aphanitic basalt: weathered surface shows ophimottling; red, scoriaceous upper surface.
978' - 938'	Covered.
938' - 901'	Dense aphanitic basalt: red, scoriaceous upper surface.

901' - 876'	Dense aphanitic basalt: weathered surface ophi-mottled; contacts covered.
876' - 833'	Dense aphanitic basalt: contacts covered.
833' - 817'	Porphyritic basalt: scoriaceous upper surface.
817' - 762'	Covered.
762' - 749'	Dense aphanitic basalt: weathered surface ophi-mottled; sharp upper contact.
749' - 709'	Glomeroporphyritic basalt: contacts covered.
709' - 629'	Covered.
629' - 616'	Dense aphanitic basalt: contacts covered.
616' - 566'	Covered.
566' - 516'	Dense aphanitic basalt: amygdules filled with zeolites; contacts covered.
516' - 468'	Dense aphanitic basalt: pipe amygdules filled with zeolites; scoriaceous upper surface.
468' - 439'	Dense aphanitic basalt: contacts covered.
439' - 414'	Covered.
414' - 396'	Dense aphanitic basalt: contacts covered.
396' - 356'	Covered.
356' - 331'	Dense aphanitic basalt: amygdules filled with zeolites and chalcedony; sharp upper contact.
331' - 283'	Covered.
283' - 263'	Dense aphanitic basalt: contacts covered.
263' - 173'	Covered.
173' - 153'	Dense aphanitic basalt: scoriaceous upper surface.

153' - 58'	Covered.
58' - 33'	Porphyritic basalt: contacts covered.
33' - 15'	Dense aphanitic basalt: contacts covered.
15' - 0'	Dense aphanitic basalt: contacts covered.