GEOLOGY OF THE NORTHWEST QUARTER
ALVORD LAKE THREE QUADRANGLE,
OREGON

by

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A THESIS

submitted to

OREGON STATE COLLEGE

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1960

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Date thesis is presented June 10, 1959

Typed by Patricia Malango

ACKNOWLEDGEMENTS

The writer expresses appreciation to Mr. David O. Cochran, who not only suggested the area to be mapped and gave constructive criticism during the preparation of the manuscript, but lent his personal vehicle for use in the field.

To Dr. Ira S. Allison, Dr. David A. Bostwick, and the other members of the faculty who read the manuscript and offered helpful suggestions, the writer is grateful.

Discussions with Mr. Neil J. Maloney and Mr. Frank H. Blair, who were concurrently mapping adjacent areas, proved helpful.

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INTRODUCTION

Location and Size

The Alvord Lake Three quadrangle is in Harney county of southeastern Oregon and lies between lat 42°00' N. and lat 42°15' N. and between long 118°45' W. and long 119°00' W. Note index map, Plate 1.

The mapped area is approximately 100 miles due south of Burns, Oregon. It is accessible from the north by leaving the Frenchglen-Fields road at the western end of Broad Valley, and following a road along the base of Catlow Rim 8 miles to the southwest. From the south, the area may be reached from Nevada Highway 8A by turning north at the Thousand Creek Ranch and traveling approximately 20 miles. Roads in the area, although numerous, are jeep trails which are difficult to travel.

The area mapped is a rectangle, approximately 9 miles long by 6 miles wide.

Purpose and Method of Study

The objective of this study was to map and describe the areal geology of the northwest quarter of the Alvord Lake Three quadrangle. A special effort was made to

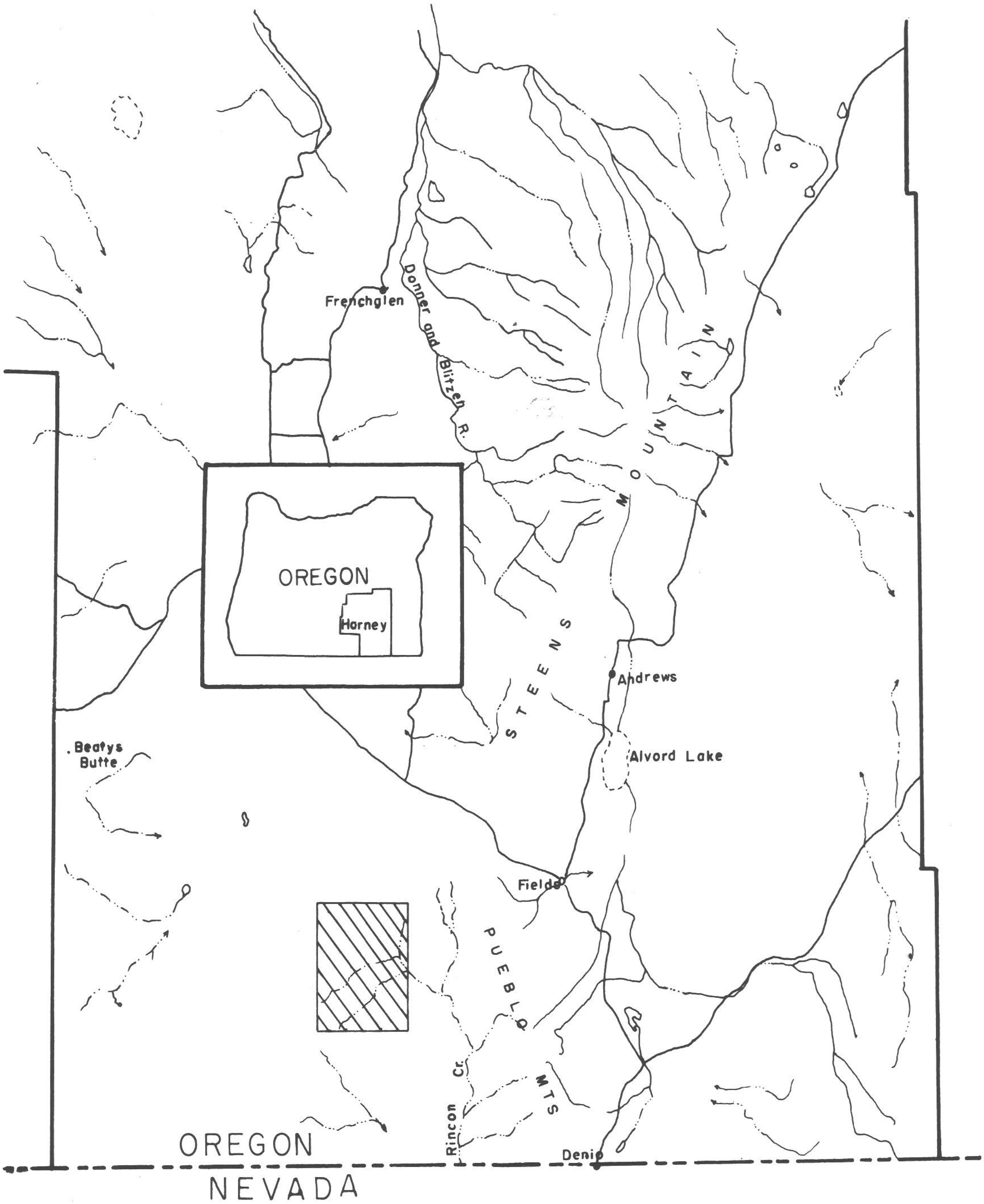


Plate I. Index map showing location of mapped area in Harney county determine the origin of the Canyon "rhyolite" formation. The project was accomplished by field work during 9 weeks of the summer of 1958 and by examining rock samples in the laboratory during the following winter.

The geology was first plotted on aerial photographs prior to being transferred to the base map. A blue-line drainage map supplied by the Oregon State Highway Department was enlarged to 1:31,680 and used as the base.

Previous Investigation

The earliest reports on geological reconnaissances of the general region were made by Blake in 1873 (3), Russell in 1884 (29), and by Waring in 1908 (36).

More detailed studies have been done in adjacent regions. Merriam (24) published papers on the Virgin Valley region in Nevada, which is south of the area described in this paper, in 1910 and 1911. Fuller (8) described Steens Mountain, northeast of the mapped area, in a bulletin published in 1931. Piper, Robinson and Parks (26) were authors, in 1939, of a report on the geology and ground water of the Harney Basin, north of the mapped area.

The most recent publications on the general region are those by Ross (28) in 1941, and by Williams and Compton (39) in 1953, both in connection with a survey of the quicksilver deposits in the Steens-Pueblo area.

Previous work has resulted in conflicting interpretations of the relationships and ages of the formations in the surrounding region.

Merriam (24, p. 16) first described the Canyon "rhyolite" formation in Virgin Valley, where it directly underlies the Virgin Valley formation. The latter formation contains vertebrate fossils of Middle Miocene age. The Steens basalt on the southern part of Pueblo Mountains is overlain by a gray rhyolitic rock which he believed was also Canyon "rhyolite". Merriam concluded therefore that the Canyon "rhyolite" and Steens basalt were nearly the same age.

Fuller, however, thought that the Steens basalt was of Middle or Upper Miocene age, and therefore younger than the Canyon "rhyolite". He collected a fossil flora from the Alvord Creek formation, which underlies the Steens volcanic rocks along the eastern escarpment of Steens Mountain. Chaney (8, p. 114) considered the flora to be similar to that which is found in the Mascall formation of central Oregon, and therefore of Middle Miocene age. Fuller (8, p. 115) consequently believed the Steens basalt, which occurs higher in the column, to be no older than late Miocene. He thought that the Canyon "rhyolite" was much older than the Steens basalt and that therefore the rhyolitic rock which overlies the Steens basalt in the Pueblos was not Canyon "rhyolite". Fuller postulated that the Alvord Creek and Virgin Valley formations were nearly the same age and that the flow of Steens basalt into Virgin Valley had been blocked by the Canyon "rhyolite".

Axelrod dated the Steens basalt as Middle Pliocene. He re-examined the Alvord Creek flora of Chaney together with additional specimens that had been collected later. He acknowledged its similarity to the Mascall flora but believed the Alvord Creek flora to be of early Lower Pliocene age because its leaves were smaller. Axelrod attributed the small size of the leaves to the more arid climate that was thought to have begun in the early Pliocene age . The Thousand Creek formation, which overlies the Steens basalt on the west flank of Pueblo Mountains, has been dated as late Middle Pliocene by using vertebrate fossils. Axelrod considered this formation to be the oldest rock that overlies the Steens basalt. Relying upon this and his dating of the Alvord Creek flora, Axelrod dated the Steens basalt as Middle Pliocene (1, p. 247).

Wallace's work at Beatty Buttes (35, p. 117) suggests an older age for the Steens basalt. The Beatty Buttes area is approximately 30 miles west of the southern Steens

Mountain. The area contains fossil vertebrates which were described by Wallace as comparable to those in the Virgin Valley formation and those in the Mascall formation.

In reference to the supposed correlation of the Alvord Creek with the Mascall, Wallace states: "This would likewise suggest a correlation with the Beatty Buttes horizon, since the fauna from the latter is nearly related to the Mascall assemblage. The Alvord Creek beds, however, lie below the Steens Mountain basalt, whereas the Beatty Buttes' tuffs appear to rest on these basalts."

In the region west of the Pueblo Mountains, recent work has disclosed two formations overlying the Steens basalt that are older than the Thousand Creek formation. This relationship was unknown to Fuller and Axelrod.

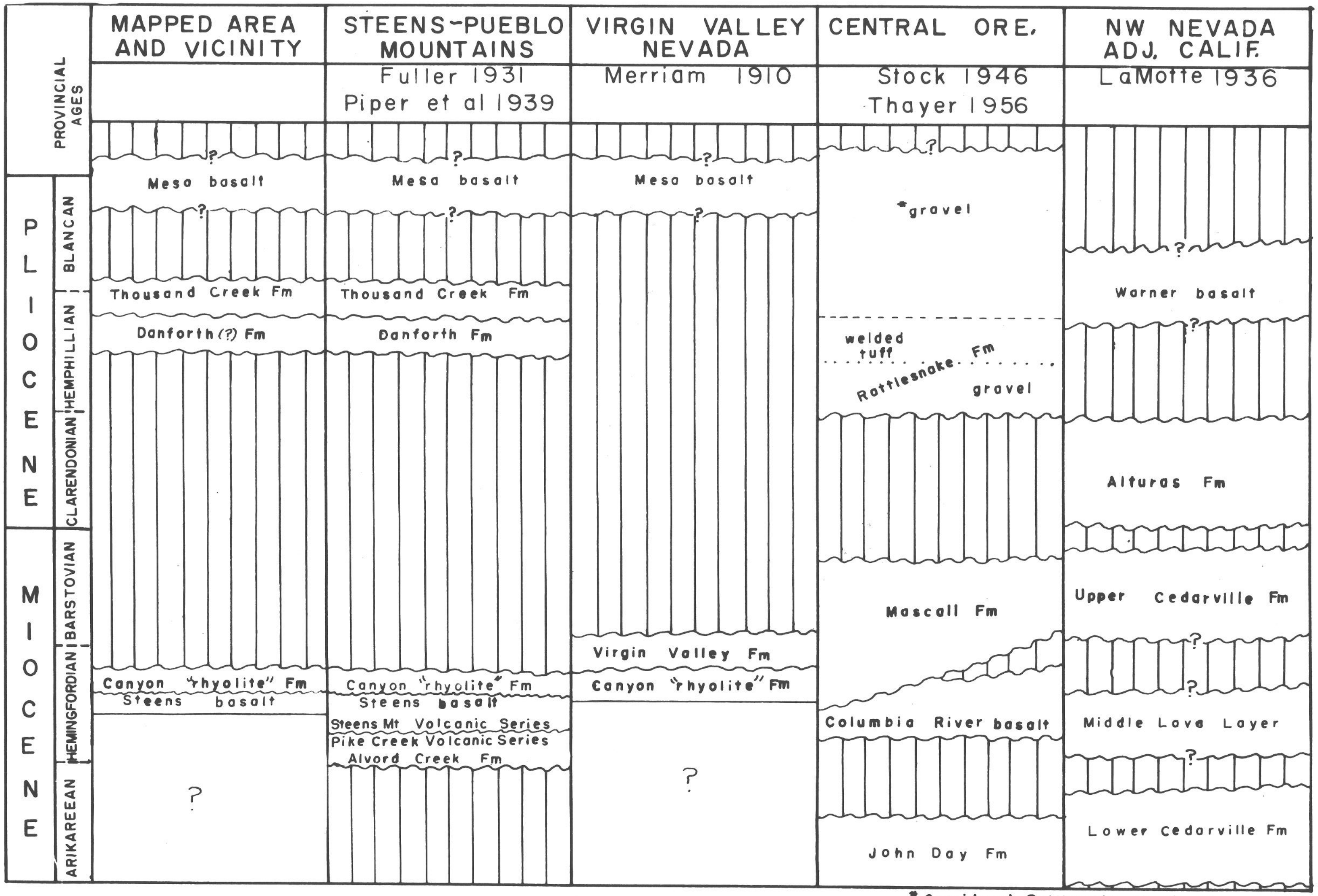
Cochran (6) found a tuff-breccia, which he correlates with the Danforth formation's upper member, overlying the Steens basalt and immediately underlying the Thousand Creek formation on the western flank of Pueblo Mountains. According to Piper (26, p. 44) the upper member of the Danforth formation rests upon the Steens basalt on the western flank of Steens Mountain.

Rhyolitic rocks in the area of Lone Mountain, which rest upon the Steens basalt, have been correlated with the Canyon "rhyolite" formation by Cochran, Blair, Maloney, and the writer, thus confirming the original suggestion of

Merriam.

As there is no evidence for overthrusting of the Canyon "rhyolite", this correlation indicates a Middle Miocene age for the Steens basalt. The Canyon "rhyolite" underlies the vertebrate-dated Virgin Valley formation of Middle Miocene age in Virgin Valley but overlies the Steens basalt in the mapped area and on the west slopes of Pueblo Mountains. See correlation chart, Plate 2.

This dating conflicts with that suggested for the Alvord Creek flora by Axelrod and strongly supports the contention that this flora is as old as Middle Miocene.



* Considered Rattlesnake by Thayer

Plate 2. Correlation Chart

GEOGRAPHY

Topography and Drainage

The topography of the area is controlled by tilted fault-blocks.

Two southeasterly tilted fault-blocks form most of the northern part of the area and are separated by Catlow Rim, an 840 foot high escarpment. Large flat-bottomed playas have formed on the down thrown blocks north of the rim.

The northeast slope of Lone Mountain forms the southern part of the area. Erosion and faulting have there formed the major flat-topped ridges and steep-walled canyons (Fig. 1).

Dissected gravel and tuff deposits lie in the valley formed between the slope of Lone Mountain and the backslope south of Catlow Rim.

The highest point is in the southwest corner of the area on the flank of Lone Mountain, where the elevation is approximately 6,500 feet. The lowest point is in the northeast corner, at the base of Catlow Rim, where the elevation is 4,650 feet. Maximum relief is therefore 1,850 feet.

The principal drainage of the area is to the southeast to Rincon Creek which flows southward. However, the drainage north of Catlow Rim is internal into playas. All streams in the mapped area are intermittent.

Figure 1. View from Lone Mountain to the northeast showing the Pueblo Mountains on the horizon. Catlow Rim is in the left background and Long Hollow is in the middle foreground.

Outcrops are common and well-exposed because of the sparse vegetative cover.

Climate and Vegetation

The climate is semi-arid. Most of the precipitation falls during the winter and spring, although local cloudbursts during the summer occasionally result in as much as one inch of rain within a few hours. The average annual precipitation is about 10 inches. The temperature extremes range from winter lows near 0° to summer highs near 100°, and the average annual temperature is about 43° (34, p. 235-236).

The dominant vegetation is sagebrush and grasses. It supports the raising of sheep and cattle which is the only industry in the area.

STRATIGRAPHY

Rocks exposed in the mapped area are mostly of volcanic origin. Those of Miocene age are the oldest and consist of the extensive flows of the Steens basalt overlain disconformably by an intensely silicified rhyolitic porphyry originally known as the Canyon rhyolite. However, the writer has found evidence suggesting that this formation is a welded tuff, hence refers to it as the "rhyolite". A vitrophyre is interstratified in the formation and is herein considered as part of the Canyon "rhyolite" but is referred to as the vitrophyre as opposed to the silicified rocks which constitute the bulk of the formation.

Welded tuffs consisting of pumice and stony fragments in a tuffaceous matrix are of Middle Pliocene age and overlie the older rocks uncomformably. These tuffs are probably the tuff-breccia and upper member of Piper's Danforth formation and are referred to in this paper as the Danforth (?). In the mapped area, the writer has subdivided this member into a tuff-breccia and a tuff.

Overlying gravel derived from the Canyon "rhyolite" formation and the thin flow of Mesa basalt are known only to be of post-Middle Pliocene age.

The stratigraphic relationships of the exposed rock units is shown in the following table, and the areal geology is shown in Plate 3.

SUMMARY OF EXPOSED FORMATIONS

Age	Formation	Description	Thickness (Ft)
Recent	Alluvium	Gravel, sand and volcanic ash	(?)
Post-Middle Pliocene	Mesa basalt	Thin flow of olivine basalt	0-20
Post-Middle Pliocene	Gravel	Gravel derived from the Canyon "rhyolite"	0-46+
----------	Angular	Unconformity	----------
Middle Pliocene	Danforth(?) Upper Member	Pumice and stony fragments in a welded tuff matrix	0-280(?)
----------	Angular	Unconformity	----------
Middle Miocene	Canyon "rhyolite"	Welded tuff (?) rhyolitic and silicified with interstratified vitrophyre	0-300+
----------		Disconformity	----------
Middle Miocene	Steens basalt	Normal basalt with rare pyroclastic lenses	3,000(?)

Steens Basalt

The basalt exposed in the northern part of the mapped area correlates by continuous outcrops with similar flows exposed on the western flanks of the Pueblo Mountains which Fuller (8, p. 14) identified as Steens Mountain basalt.

The basalt was originally named "Steens Mountain Basalt" by Fuller in 1930, but the name was later shortened to Steens basalt by Piper, Robinson and Park in 1939 (26, p. 50).

The formation's age is Middle Miocene. The Steens basalt is separated by about 3,000 feet of volcanic rocks from the stratigraphically lower Alvord Creek formation, which contains flora which Chaney considered equivalent to that of the Mascall. In the mapped area, the Steens basalt is overlain by the Canyon "rhyolite". In Virgin Valley, Nevada, the Canyon "rhyolite" is overlain unconformably by the Virgin Valley formation of Middle Miocene age.

The base of the Steens basalt is not exposed in the mapped area. At the type section of the Steens basalt, on the east escarpment of Steens Mountain 20 miles east of the head of the Donner and Blitzen Valley, this formation rests upon the Upper Andesite of the Steens Mountain andesite series (8, p. 101).

The basalt is immediately overlain in the mapped area by the Canyon "rhyolite" formation, or by the younger Danforth (?) formation where the Canyon "rhyolite" had been removed by erosion prior to the deposition of the Danforth (?). The stratigraphic position of the Steens basalt is best seen at an inlier of the basalt in a gorge cut in the Canyon "rhyolite" in the SE¼ sec. 29, T. 39 S., R. 32 E.

The structural relationship of the Steens basalt to the overlying Canyon "rhyolite" can not be definitely determined because both formations have been greatly disrupted by faulting. However, knobs of basalt projecting through the overlying formations indicate a disconformity of a few hundred feet relief. The relationship with the Danforth (?) is one of angular unconformity as shown by the gentle dip of the Danforth (?) in sec 15, 22, 23, T. 39 S., R. 32 E. in contrast to the variable and greater dips of the Steens basalt.

Attitudes of the Steens basalt are variable because of faulting. The basalt with platy parting has been locally folded, perhaps by drag caused by faulting. The result is variable strikes, and dips as great as 90°. Regionally the basalt appears to dip about 5° to 20° to the southeast, as suggested by the inclined backslopes of the fault-blocks.

The Steens basalt is the oldest rock exposed in the area; as its base is concealed, its maximum thickness here can not be determined. However, it is known to exceed 840 feet as measured at the escarpment of basalt at Catlow Rim. Piper (26, p. 50) reports that the Steens basalt is more than 3,00 feet thick at the type section.

Distribution and Topographic Expression

Steens basalt is exposed over the northwest part of the area and crops out in secs. 33, 28, T. 39 S., R. 32 E. as inliers where streams have cut through the overlying formations. It is exposed over approximately one-third of the mapped area.

The basalt area generally has gentle slopes except where broken by recent faults. The surface of the region southeast of Catlow Rim dips gently to the southeast because it is the backslope of a tilted fault-block. Consequently erosion is progressively stripping off the overlying formations in the direction of dip and exposing the basalt underneath. Northwest of Catlow Rim the basalt area consists of fault-blocks which have been downthrown relative to the block that forms Catlow Rim. Slumping has modified the rim only slightly. One block almost one-fourth square mile in area has slumped into the basin in sec. 34 T. 38 S., R. 32 E. Its surface, inclined toward the escarpment wall, indicates reverse rotation of the block. Reverse rotation is a feature used by Fuller (8,

p. 17) to distinguish landslides from fault-blocks.

The area of basalt is in the youthful erosional stage owing to recent uplift by faulting. The streams appear to have been rejuvenated as suggested by the steep-walled hanging valleys which join a large graben below Catlow Rim.

Topography is influenced to a minor degree by the differential erosion of the basalt. As seen at Catlow Rim, basalt with platy parting alternates with flows of more massive basalt. The more resistant, massive basalt generally stands out in ridges and crops out over most of the basalt area. However, small valleys are eroded in the less erosion-resistant, platy basalt.

Lithology

Except for one outcrop of pyroclastic fragments, the Steens basalt is composed of interstratified platy and massive basalt. Individual flows of the platy basalt and the massive basalt are as much as 30 feet thick, although their average thickness is approximately 10 feet.

The platy zones are widespread within the formation, so the platy basalt resulted from variations in the rate of cooling of the lava rather than from jointing caused by faulting. The platy basalt is locally somewhat vesicular, and it contains zeolites in some of the more vesicular fragments. The porphyritic texture of the basalt is readily apparent in the hand specimen. The observable phenocrysts are euhedral plagioclase as much as 1 cm long. Fresh surfaces of the rock are light gray but usually weather to a reddish color. The platy basalt has plates from one-half to 2 inches thick, or locally as much as 6 inches thick (Fig. 2).

The massive basalt has more and larger vesicles and zeolites than does the platy variety and presents an uneven, pitted surface and mottled appearance. Dense non-vesicular basalt is common also, but usually occurs near the middle of the thicker flows. The massive basalt is porphyritic, but because of its uneven surface, the phenocrysts are not as evident as they are in the platy basalt. The color of the groundmass is usually a darker gray than that of the platy rock.

One outcrop of pyroclastic fragments was found within the formation, near the top of the Catlow escarpment along the east boundary of the mapped area. The fragments lie between flows of basalt and consist of an 18-inch bed of white lapilli overlying a 15-foot bed of bombs. The bombs are black, vesicular, and 3 to 10 cm in diameter (Fig. 3).

Petrography

The petrography of the Steens basalt is generally uniform throughout the area. However, descriptions of this

Figure 2. Massive Steens basalt overlies 30-foot thickness of platy basalt south of Catlow Rim. Local fractures have displaced part of the rock along slickensided surfaces. The rock in place dips gently to the southeast.

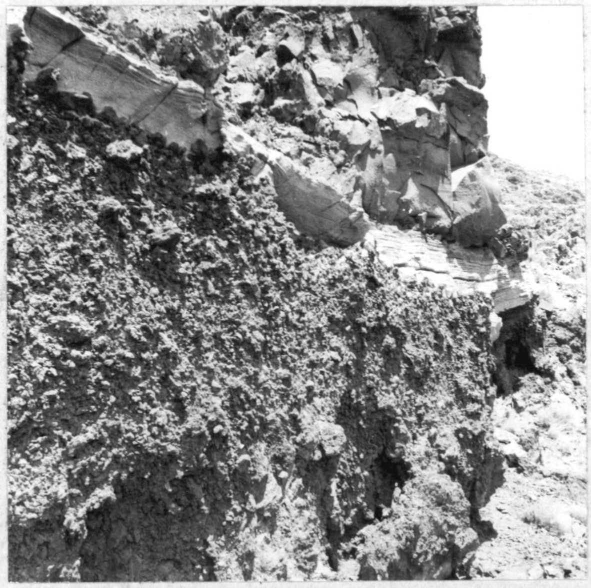


Figure 3. Volcanic bombs overlain by massive Steens basalt and 18-inch thickness of lapilli at Catlow Rim.

basalt from Steens Mountain indicate that the composition is inconsistent for the formation as a whole. Fuller (9, p. 102) states that the basalt generally consists of "thin flows of coarsely holocrystalline olivine basalt of a rather light gray color". The Steens basalt within the mapped area is holocrystalline-porphyritic and contains rare traces of olivine (Fig. 4). It more closely resembles the Steens basalt as described from another area by Ross (28, p. 234), who found it to possess primarily a dense texture with few phenocrysts and a small quantity of olivine in some of the non-porphyritic rocks.

In the mapped area, the phenocrysts are 10 to 25 per cent of the rock. Three-fourths of the phenocrysts are sodic labradorite, one fifth are pyroxene, and the remainder are mostly magnetite. Individual crystals are commonly zoned and embayed (Fig. 5). Some zoning is caused by concentric inclusions, but this type of zoning is uncommon. The plagioclase phenocrysts all have albite twinning and commonly have combined carlsbad twinning as well.

Augite and hypersthene occur in all samples. Augite is usually the more plentiful, but hypersthene forms an equal volume in several samples. The hypersthene, which is pleochroic, is often found partly altered to chlorite and magnetite. The augite is but slightly altered and commonly twinned. Both pyroxenes are euhedral and usually

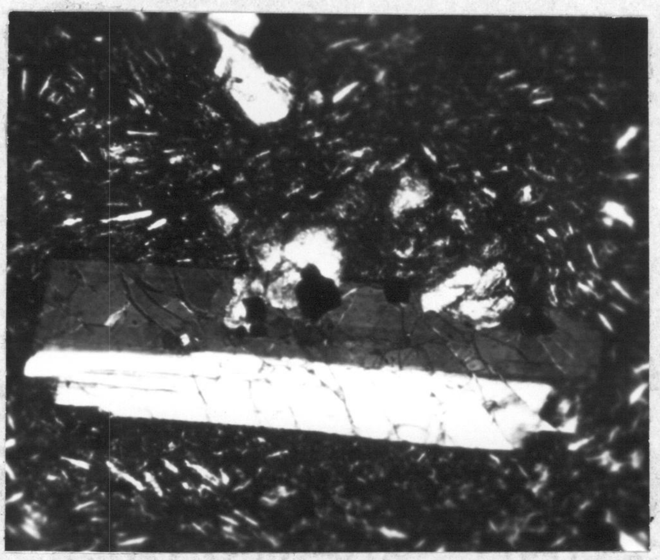


Figure 4. Steens basalt, x50, crossed nicols. Augite, magnetite, and plagioclase in a felty groundmass of plagioclase and pyroxene.

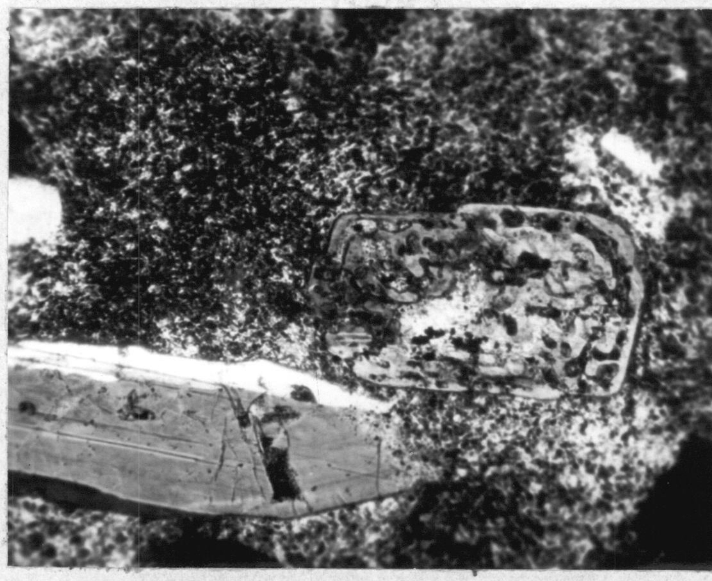


Figure 5. Steens basalt, x50, crossed nicols. Characteristically embayed and zoned plagioclase phenocryst.

form inclusions in the plagioclase phenocrysts.

Magnetite forms inclusions in the phenocrysts and borders on the pyroxenes. Primary, anhedral magnetite occurs clustered with pyroxene in most samples. Hematite or limonite forms reaction rims on the magnetite and also radiates from the magnetite grains to form veinlets throughout the surrounding groundmass.

Apatite and zircons form small, prismatic phenocrysts in the groundmass and inclusions in the pyroxenes and plagioclase. Traces of olivine were found in a few samples.

The texture of the groundmass ranges from felty to pilotaxitic. The groundmass consists of microlites of about equal quantites of anhedral pyroxene and euhedral plagioclase. The plagioclase microlites do not appear to be altered, but the pyroxene is slightly altered to what is probably chlorite. The alteration products appear as minute, green specks on the pyroxene.

Origin and Conditions of Deposition

The Steens basalt consists predominantly of extensive, thin flows that indicate a lava of low viscosity. The formation apparently accumulated during a relatively short period of time as indicated by the lack of weathering on the surfaces of the successive flows. Only one baked soil zone, which crops out on the face of Catlow Rim, was observed.

The source of the Steens basalt could not be determined within the mapped area. Williams and Compton (38, p. 29), however, considered the flows to be "products of fissure eruptions on a grand scale".

Canyon "Rhyolite" Formation

Rocks of rhyolitic composition that crop out in the southern part of the mapped area correlate with the Canyon "rhyolite" formation in the Virgin Valley, Nevada area, 20 miles to the south. Rocks from both areas have similar lithology, topographic expression and the same distinctive petrographic features.

The Canyon "rhyolite" was named by Merriam in 1910 (24, p. 32) who wrote: "From their occurrence in gorges around the borders of Virgin Valley, these lavas may be known as the Cañon Rhyolite. They are presumably only a portion of the extensive series for which the geologic appellation of Pueblo Range series is used."

Most of the formation is a silicified, rhyolitic porphyry similar to the "rhyolitic flows" described by Merriam. The silicified rock, however, occurs with a black rhyolitic vitrophyre that crops out at two or more stratigraphic levels within the formation. The vitrophyre is considered to be part of the Canyon "rhyolite" because its origin is not definitely known, and because it is found associated only with this formation.

The Canyon "rhyolite" is of Middle Miocene age as indicated by its stratigraphic position. In Virgin Valley, it directly underlies the Virgin Valley formation of Middle Miocene age. At Steens Mountain, the Canyon "rhyolite" is separated from the underlying Alvord Creek formation by several thousand feet of Steens basalt and other volcanic rocks. The Alvord Creek formation contains Mascall-equivalent flora.

Wherever the base of the Canyon "rhyolite" is exposed in the mapped area, it rests disconformably upon the Steens basalt formation. This relationship is shown by the hills of basalt which protrude through the Canyon "rhyolite" along the west boundary of the area. The Danforth (?) formation of Middle Pliocene age, as well as younger formations, overlies the Canyon "rhyolite" with angular unconformity.

As indicated by the variable attitudes of the beds, the structure of the Canyon "rhyolite" has been complicated by faulting. Regionally, the tilted fault blocks of Lone Mountain cause the beds to dip at low angles to the southeast. However, strikes are variable, and local dips are as much as 90°.

The Canyon "rhyolite" is estimated to be 300 feet thick where it rests upon the Steens basalt in Long Hollow. The rock may be thicker at higher elevations on Lone Mountain, but the attitudes are not considered consistent enough to calculate reliably the thickness there.

Distribution and Topographic Expression

Within the area mapped, the Canyon "rhyolite" formation is exposed over approximately 18 square miles, most of which is on the northeastern flank of Lone Mountain and along the eastern border of the mapped area. A well-exposed section crops out in Long Hollow, where the vitrophyre and silicified strata of the formation are exposed above the Steens basalt.

The formation was undoubtedly more widespread in the past than it is at present. An isolated, erosional remnant near the northern border of the area in sec. 33, T. 38 S., R. 32 E. suggests that the formation once covered the entire mapped area. Other erosional remnants occur north of Lone Mountain where they support ridges of gravel and the Danforth (?) tuff-breccia in which they are partly buried.

The Canyon "rhyolite" forms the most uneven topography in the area consisting of rounded hills and ridges which are dissected by steep-walled canyons.

Silicified Canyon "Rhyolite"

Most of the silicified rock outcrops are massive, although occasionally platy parting and flow structure can be recognized. The flows appear to have been very viscous (Fig. 6).

Weathered outcrops are well rounded in profile (Fig. 7). but differential weathering has sculptured pinnacles, caves, and pits from the rock. Jointing is widespread in the formation and forms small, vertical, joint-blocks. The jointing is most evident on the faces of cliffs where the joints aid in the formation of hoodoos.

Numerous fault zones criss-cross the area and fracture the rock, although in many situations the trends of these zones can not be established. Slickensided boulders are common and generally weather in a distinctive manner. The smooth slickensided surfaces of the boulders are more resistant to weathering than are the rough surfaces. This results in undercutting of the polished surfaces which then project several inches beyond the main parts of the boulders to form ledges.

Fresh surfaces range from glassy to dull and are gray or brown. The exposed surfaces are usually oxidized red although many of the fragments become progressively lighter in color as they alter to clay minerals. Iron oxide alteration has created small, brown spots on the surfaces of the well-altered, cream-colored fragments.

Phenocrysts of euhedral, glassy potash feldspar, which

Figure 6. Flow structure of the silicified Canyon "rhyolite" on north side of Lone Mt., NW¼ sec. 35, T. 39 S., R. 32 E.

Figure 7. Rounded outcrops of silicified Canyon "rhyolite" showing crude columnar jointing near Long Hollow. Beds dip southeastward.

are as much as 1 cm long, produce a porphyritic texture which can be seen easily in the hand specimen. The feldspars weather away and leave a pitted surface on the rock. Biotite can also be recognized in the hand specimen.

The silicified rock lies upon the Steens basalt along the east boundary of the mapped area, at the Canyon "rhyolite" outliers north of Catlow Rim, and at the outliers along the Steens-Danforth (?) contact. At these places the lowermost few feet of the Canyon "rhyolite" is made up of an unsilicified gray glassy rock with vitreous phenocrysts. Thin sections of this glassy rock reveal it to be composed of greatly compacted and welded glass shards and pumice fragments that bend around stony fragments and phenocrysts of potash feldspar and quartz. The compaction of the shards is greater in some samples than in others. The shards of a few samples are only slightly compacted, but the shards in several samples are compacted to the extent that they easily could be mistaken for the flow structure of a lava except for the few undeformed shards which were protected beside the phenocrysts (Fig. 9).

The glassy rock grades upward into a more porous and partly silicified rock. As seen in thin section, the composition of phenocrysts change very little in the gradation from glassy to porous rock. However, if glass shards are present in the porous rock, they are obscured by silicification or greater melting and compaction. The porous rock is made up of indistinct bands of glass which bend around the phenocrysts. Tridymite fills many of the smaller vesicles in the porous rock. A few of the larger vesicles are incrusted with this mineral.

Higher in the section, the rock forming Lone Mountain is a third variation of the silicified Canyon "rhyolite". This rock has the general appearance of the lower, porous rock, but greater silicification has made the rock denser. The composition of phenocrysts in all rocks in the section are nearly the same. However, rocks near the base of the section contain embayed quartz phenocrysts whereas the quartz in the rock higher in the section appears to be mostly cavity fillings.

There is, therefore, a gradation upward from a rather dense rock with compacted shards, through a more porous, banded rock without shards, to a dense, banded rock that is no longer porous because it is silicified.

More detailed descriptions and possible causes for the lithologic variations follow.

Petrography

Rocks of the crystalline Canyon "rhyolite" are generally uniform in composition of phenocrysts, but differ from one locality to another in texture and degree of silicification.

The glassy rock at the base of the formation is composed of phenocrysts, flattened pumice fragments, and stony fragments in a groundmass of welded glass shards. The phenocrysts, which are about 10 per cent of the rock, consist of approximately equal quantities of embayed potash feldspar and quartz and traces of magnetite, ilmenite, epidote, and zircon. The stony fragments are rare; those sectioned consist of microlites of plagioclase and greatly altered interstitial material. They are probably fragments of the underlying Steens basalt.

The more porous part of the Canyon "rhyolite", which overlies the glassy rock, contains approximately the same kinds and percentages of minerals. Biotite, however, which is commonly partly altered to magnetite, is also present. As seen under crossed nicols, isotropic bands of glass alternate with anisotropic bands of silica. The glass bands diverge to form voids in the glassy groundmass. The larger voids are unsilicified. There is definite lineation of the smaller phenocrysts parallel to the glass bands.

The dense, highly silicified rock, which forms the uppermost part of the formation, is the most widespread type of Canyon "rhyolite". It is composed of 10 to 20 per cent potash feldspar phenocrysts and traces of plagioclase and partly altered accessories. However, phenocrysts compose as much as 50 per cent of the rock in a few samples. The potash feldspars commonly show carlsbad twinning and are usually embayed.

The unusual occurrence of potash feldspars, found also in the other types of Canyon "rhyolite", is one of the most distinctive mineralogic features of this formation. The presence of sanidine is indicated by the low optical angles of many of the potash feldspar phenocrysts. However, the 2V of some of the potash feldspars is about 55°, and rarely these phenocrysts show grid twinning. These characteristics are those of sodic-orthoclase or anorthoclase. Winchell (41, p. 312) states that "anorthoclase is found only in volcanic rocks rich in soda; it is often intergrown with sanidine". The 2V of sanidine may be about as large as that of anorthoclase (42° to 54°), but grid twinning is characteristic of anorthoclase, not sanidine. Sodic-orthoclase with a 2V as great as 52° has been described from the rhyolites of Yellowstone Park (8, p. 244).

Biotite is the major mafic constituent, although it forms only a small percentage of the rock. It is usually partly altered to secondary magnetite, to the degree that some laths are nearly opaque. The alteration begins as coronas on the borders of the biotite, and later develops skeleton crystals of magnetite. Biotite that is not altered has the characteristic "bird's-eye" appearance.

Hypersthene is the most common pyroxene, although traces of augite were found in a few samples. The hypersthene is usually partly altered to green chlorite or yellow-green epidote; in several samples there are many pseudomorphs of epidote after hypersthene. The hypersthene originally formed in the groundmass and as inclusions in the feldspar phenocrysts. In one sample phenocrysts of garnet, partly altered to chlorite, were found.

Primary magnetite and ilmenite are scattered throughout the groundmass and form inclusions in the feldspars and biotite. Some magnetite is partly altered to hematite and limonite, which form veinlets in the groundmass.

Minor constituents are hornblende, zircon, and apatite. Zircon and apatite occur in the groundmass and also form inclusions in the biotite and feldspar phenocrysts.

Isotropic glass forms the groundmass and is mottled and interbanded with anisotropic silica. Whether the silicification was partly paracontemporaneous with the glass or entirely secondary is not known. However, much of the silica fills original voids in the glass. The bands spread around the voids so as to suggest that either fragments or gas once filled these areas. However, other areas of the glassy groundmass have been replaced or devitrified. The glass bands become indistinct as they pass into these anisotropic areas.

Although the smallest minerals in the groundmass can not be identified, most of the anisotropic minerals appear to be tridymite. Tridymite is recognized by the triangular, twinned crystals that have formed in the larger cavities. The groundmass has a distinctive, net-like appearance under crossed nicols because of the extinction crosses of this mineral. In some samples tridymite appears to form more than one-third of the rock's volume.

Anhedral quartz, which is distinguishable in some thin sections by its yellowish interference color, has formed in the largest voids. It is not embayed as are the phenocrysts and is surrounded by tridymite. This indicates that the quartz formed after the glass and may be secondary, perhaps an inversion of tridymite.

Tridymite is generally considered to be a late-forming mineral which is deposited from hot gases (18, p. 681-694). However, Fenner describes metasomatic replacement forming tridymite, quartz, and sodic-orthoclase from the groundmass of a rhyolite (8, p. 225-315).

Canyon "rhyolite" samples from the type section at Virgin Valley were compared in thin section to those from the mapped area. They resemble most closely the "rhyolite" near the top of the section. Rock from the type section is silicified and contains approximately the same kinds and percentages of minerals as does rock within the mapped area.

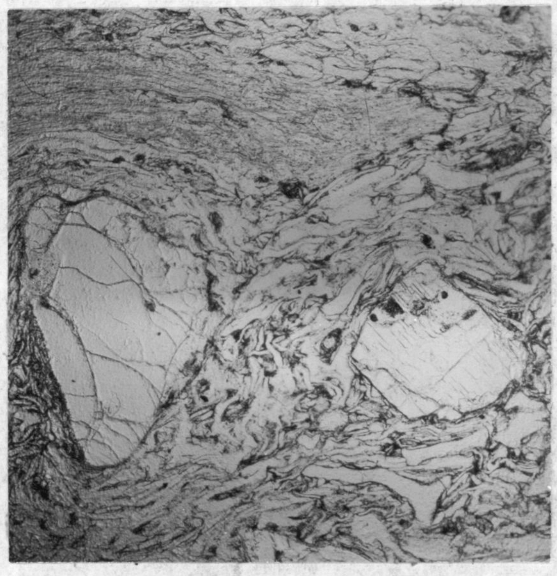


Figure 8. Canyon "rhyolite". Glassy rock at base of section showing welded glass shards and pumice fragment contorted around phenocrysts of potash feldspar. Plain light x30.

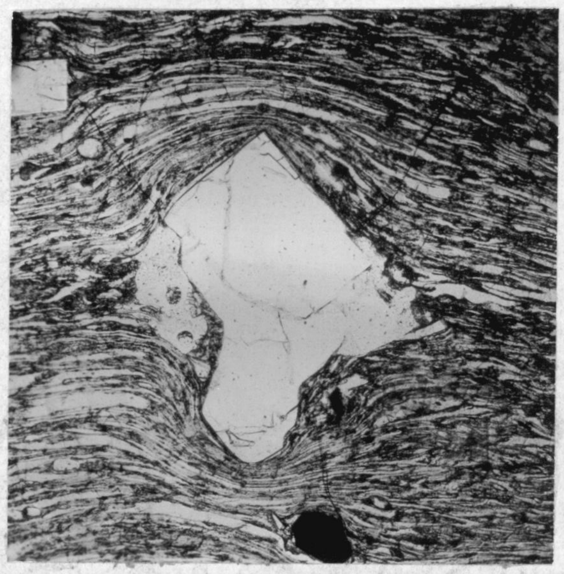


Figure 9. Canyon "rhyolite". Glassy rock at base of section showing compaction or flow (?) of glass shards. Less deformed shards can be seen beside the phenocryst. Plain light x30.

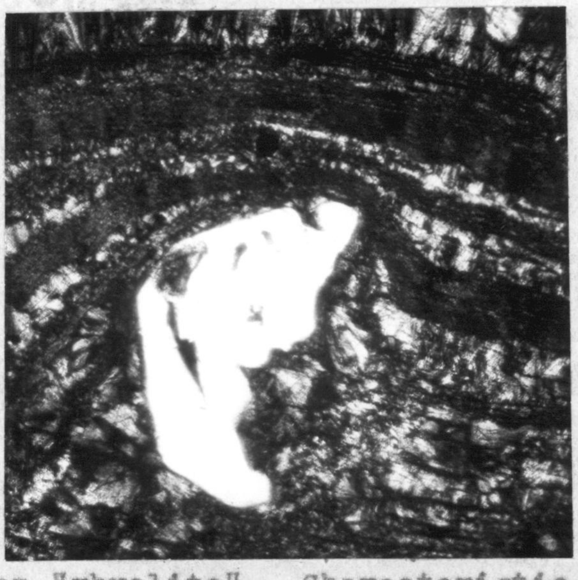


Figure 10. Canyon "rhyolite". Characteristic silicified rock, near top of section. Bands of glass bend around embayed phenocryst of potash feldspar. Voids have been filled with tridymite. Compare with Figure 9. Crossed nicols x30.

However, angular glass fragments and anisotropic fragments of what appear to be silicified pumice occur in rock from the type section; no glass shards were recognized. The distinctive sodic-orthoclase with 2V near 50° is common, although grid twinning was not seen.

Vitrophyre of the Canyon "Rhyolite"

The vitrophyre is restricted to the Lone Mountain area where it crops out over only small areas. It was not found with the silicified rock along the eastern border of the mapped area or at the outliers.

In SE¼ sec. 10, T. 39 S., R. 32 E., at Long Hollow and in the adjacent canyon to the west, the vitrophyre is the basal unit of the formation and forms a 25-foot thick stratum overlying the Steens basalt. All other vitrophyre exposures are isolated and eroded outcrops which are interstratified with the silicified rock higher in the section.

The vitrophyre is concordant with the silicified rock within the mapped area, although Blair (2) and Maloney (21) believe the two types are in some places discordant in areas adjacent on the south and west.

Outcrops of the vitrophyre resemble those of the silicified rock in that they are rounded in outline, and the beds are usually differentially weathered. The methods of weathering differ, however. The vitrophyre is composed of fractured glass and small, brittle lithophysae that easily disintegrate. It erodes rapidly because of this feature except where cliffs are capped by the more erosion-resistant, silicified rock. The vitrophyre is only slightly decomposed, because it is quickly removed by erosion, particle by particle, after it is exposed.

The vitrophyre contains large phenocrysts of potash feldspar, as does the silicified rock. The color of the vitrophyre is usually vitreous black or gray, although a brown phase is occasionally found. Brown and black layers of vitrophyre are laminated in several outcrops (Fig. 11). The brown layers are similar to the black vitrophyre in texture, and both types contain lithophysae. They differ only in color. This difference is attributed to variations in the degree of crystallization as shown by examination of thin sections in which the lighter colored bands contain more anistropic crystallites than do the dark bands (Fig. 12). Iddings (14, p. 424) states that the banding in glasses at Obsidian Cliff in Yellowstone Park was caused by variations in crystallization resulting from a heterogeneous mixing of water vapor.

Petrography

As seen under the microscope, the vitrophyre consists of phenocrysts surrounded by a groundmass of glass. The phenocrysts compose about 10 per cent of the rock and

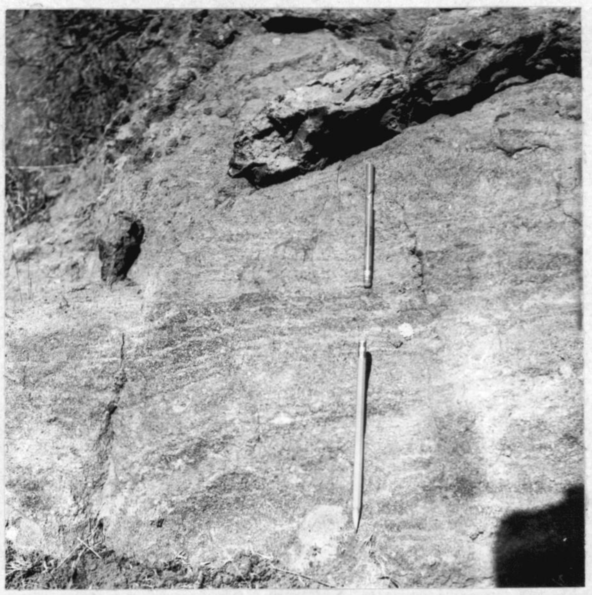


Figure 11. Interlayering of brown and black vitrophyre of Canyon "rhyolite". Pencils outline black layers.

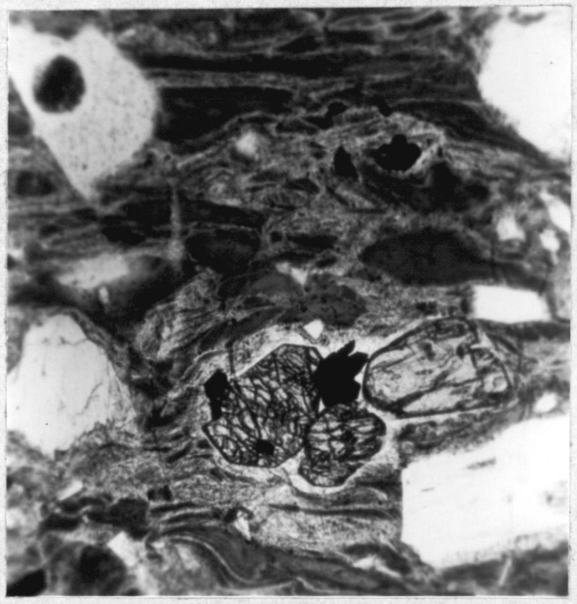


Figure 12. Vitrophyre of Canyon "rhyolite", x50. Plain light. Shows pyroxenes with magnetite in a ground mass of banded, brown glass.

consist of potash feldspar with traces of magnetite, biotite, hypersthene, augite, and zircon. The feldspars consist of both sanidine and sodic-orthoclase. They are embayed and usually show carlsbad twinning. Quartz is rare. The accessory minerals are altered in much the same way as are those of the silicified rock.

The groundmass has flow structure around the phenocrysts. Some layers contain more crystallites than do others, resulting in banding of the rock. The crystallites are anisotropic, curved, hair-like, and aligned with the flow.

Perlitic texture is common to most samples. Crystallites passing through the perlitic whorls indicate that the whorls were formed last. Several samples contain a few pisolites.

The 1.509 refractive index of the glass suggests rhyolitic composition.

Origin and Conditions of Deposition

Although the Canyon "rhyolite" previously has been considered a lava, the writer believes that this formation originated as an ignimbrite or welded tuff whose original pyroclastic texture has been mostly destroyed by intense welding and silicification.

Merriam described the formation as a rhyolitic lava.

However, he identified the rock before the widespread extent of welded tuffs was appreciated. Several welded tuff deposits have been described as rhyolite flows in the past. For example, the shard texture in some of the welded tuffs of Yellowstone Park was attributed mistakenly to the crushing of pumice fragments by the weight of overlying lava (15, p. 66). The ignimbrite on the North Island of New Zealand was thought to be a rhyolite flow until its true origin was recognized (23, p. 198-202 and 12, p. 57-67).

The criteria for differentiating ignimbrites from lavas are controversial and are based principally upon examination of rocks from the small number of nuée ardente eruptions which have occurred within historical time. The eruption of Mt. Pelée is the best known of these. The problem is complex because recent eruptions do not necessarily duplicate those of the past, nor can the results of the alteration of the rocks with time be taken fully into account.

Compaction and what appears to be flow structure occur in the Canyon "rhyolite", but as shown by figures 9 and 10, the two structures are difficult to distinguish. Cook (7, p. 1544) lists compaction without flow structure as a criterion of ignimbrites. Flow structure, however, has been recognized in welded tuffs of southeastern Idaho (22, p. 308-321) and in the Rattlesnake ignimbrite of central

Oregon (16, p. 52 and 20, p. 60). Fuller (8, p. 371-372), while studying volcanic rocks in southeastern Oregon, observed a gradation from tuff to acidic flow. This relationship was emphasized by jointing in the flow which extended downward into the tuff. Fuller believed this indicated that these tuffs originated as flow features and not by eolian accumulation.

A second criterion of ignimbrites is low specific gravity at the base of the stratum and its decrease upward (11, p. 1544). This feature could not be properly investigated in the Canyon "rhyolite" because of the intense silicification. However, this formation appears to be somewhat analogous to the welded Bishop tuff, as described by Gilbert (11, p. 1829-1862). He found the welded tuff to be glassy at the edge and base of the formation. Gilbert believed that rapid cooling created the glassy phase, but the tuff that was higher in the column received hot gases from the tuff that underlay it and consequently cooled more slowly.

Many samples of the Canyon "rhyolite" contain vesicles, although lack of vesicles is a criterion listed by Cook for ignimbrites (7, p. 1544). Mansfield and Ross, however, describe the Idaho tuff as "highly vesicular, strongly resembling rhyolite-flow". Obsidian forms the base of the Idaho tuff and from its description appears to be similar to the glassy, shard-textured rock and the vitrophyre that occur in the mapped area. Thin sections of the obsidian, that they figure, have a shard texture indicating that the obsidian is a cooling phase of the tuff.

Wide areal extent and a horizontal upper surface are other accepted criteria of ignimbrites, but they can not be applied here because this formation was greatly eroded before it was buried by younger rocks.

Welded glass shards, stony fragments and collapsed pumice, which occur in part of the Canyon "rhyolite", are established features of ignimbrites. Admittedly these features occur only at the base of the formation, but as shown by Figures 8, 9 and 10, intense welding and silicification of tuff can produce a rock that differs little from a lava. The ellipsoidal, anisotropic areas about which the glass bands spread in the silicified rock may represent collapsed pumice fragments which have been masked by silicification.

The variable attitudes of the Canyon "rhyolite" may partly be explained by its ignimbrite origin. A deposit of this type will usually assume the initial dip of the surface upon which it is deposited (11, p. 1837 and 22, p. 308-321).

The vitrophyre appears to be a non-silicified phase of the Canyon "rhyolite". Except for silicification, the mineralogy of the vitrophyre is similar to that of the silicified, typical Canyon "rhyolite". Both rocks have a glassy groundmass and similar phenocrysts, including sodic-orthoclase. The vitrophyre contains no apparent shards or fragments, but it is similar in appearance to the non-silicified, shard-textured rocks that form the base of the section at the outliers. Fenner (8, p. 301) describes a silicified rhyolitic rock, similar to the silicified Canyon "rhyolite", which he suggests is a devitrified vitrophyre.

It is difficult to advance a reason why some rocks should be silicified while others are not. However, some rocks may be denser than others and therefore not accessible to mineralizers.

The vitrophyre lacks most of the features of an intrusive. Inclusions of the silicified rock are found in the base of the vitrophyre that is interstratified, but the vitrophyre does not show contact metamorphism and other criteria of intrusion. Glassy flow banding is common to the vitrophyre as it is to the silicified rock, and the contact between the two rocks is gradational in several places.

Similarities of the silicified rock to the vitrophyre make arguments against a lava origin for the silicified rock apply to the vitrophyre too.

In conclusion, it appears that all phases of the Canyon "rhyolite" have a common origin. The differences in lithology that exist are due to variations in welding and silicification.

Danforth (?) Formation

A well-consolidated tuff-breccia and tuff crop out north of Lone Mountain. They are similar in lithology and in stratigraphic position to the top member of the Danforth formation, as described by Piper (26, p. 43). The Danforth's upper member rests upon the Steens basalt on the west slope of Steens Mountain, and part of the tuff-breccia directly overlies the Steens basalt in the mapped area. For these reasons and from comparisons made with the Danforth near Frenchglen, the upper member of the Danforth probably correlates with the tuff-breccia and tuff of the mapped area.

Piper (26, p. 43) named the Danforth formation, in 1939, from its exposure along Cow Creek at the Danforth Ranch in T. 22 S., R. 32½ E. He described its uppermost member as follows: "Tuff-breccia, purplish-gray, massive; vitreous brownish-gray matrix (welded rhyolitic pumice?) enclosing abundant unoriented fragments of white pumice, black obsidian, and massive inflated rhyolite; fragments a fraction of an inch to a foot long."

A complete type section of the Danforth formation is not exposed; however, at the type section on the Silvies River, two miles north of Burns, the tuff-breccia upper member is exposed.

The tuff-breccia and tuff member of the Danforth (?) formation in the mapped area lies immediately upon the Steens basalt or Canyon "rhyolite" formation with angular and erosional unconformity (Fig. 15). The Danforth (?) dips 1°N. 30°E., whereas the dips of the underlying rocks are variable and greater. Where the Danforth (?) crops out at the base of Lone Mountain, it is overlain by gravel derived from the topographically higher Canyon "rhyolite".

Park (26, p. 48) found fresh-water shells in a lower member of the Danforth that were dated as Pliocene or Pleistocene. He inferred that the formation was probably Pliocene in age. Campbell (5) suggested a possible correlation of the upper member of the Danforth with the welded tuff of the Rattlesnake formation of central Oregon, suggesting that the Danforth is of Middle Pliocene age. This dating of Middle Pliocene is substantiated by the fact that Cochran (6) found the Danforth (?) on the west slopes of Pueblo Mountains to underlie the Thousand Creek formation of late Middle Pliocene age.

There are two lithologically distinct units of the upper member of the Danforth (?) in the mapped area (1) a tuff-breccia containing many large pumice fragments and a smaller number of smaller stony fragments in a tuffaceous matrix, and (2) a tuff which contains a few small pumice and stony fragments.

The tuff-breccia crops out as a strip trending northeast across the area from sec. 20, T. 39 S., R. 32 E. The tuff crops out in secs. 15, 22, 23, T. 39 S., R. 32 E.

The stratigraphic relationship between the tuff-breccia and tuff is not definitely understood. Most of the contact between them is hidden by gravel derived from the Canyon "rhyolite". In sec. 15, T. 39 S., R. 32 E. they have a common boundary, but the sequence of deposition could not be determined by reason of talus cover. However, likely the tuff-breccia was deposited first because (1) the tuff-breccia is known to rest on the older formations of Steens basalt or Canyon "rhyolite" wherever its base is exposed, but what rock immediately underlies the tuff is unknown, and (2) where the two units are in contact, the tuff is the highest topographically, although it appears to be no more resistant to erosion.

The tuff-breccia is approximately 150 feet thick where it overlies the Steens basalt near Box Canyon. In sec. 15, T. 39 S., R. 32 E. the tuff forms a 130-foot cliff adjacent to a valley of the tuff-breccia. The height of the cliff represents the thickness of the tuff if, as postulated, the tuff-breccia is older and immediately underlies the cliff. The combined thickness of the tuff-breccia and tuff therefore may be as much as 280 feet. The thickness is variable because the formation was deposited upon an uneven, eroded surface.

Distribution and Topographic Expression

The formation crops out over about seven square miles and forms an irregular, northeast-trending belt across the center of the area. The outcrop is about seven miles long and about one mile wide, except where partly covered by gravel.

The Danforth (?) evidently once covered a much larger area than it does today. Pumice fragments similar to those within the tuff-breccia are found scattered on top of the Canyon "rhyolite" and Steens basalt. Pumice fragments also occur near rodent burrows in soils above these formations. The tuff-breccia projects into canyons cut in the Canyon "rhyolite" along the east boundary and at Lone Mountain. This relationship indicates that the canyons were cut before the deposition of the Danforth (?).

Streams have moved laterally to the southeast on the dipping surface of the underlying basalt and formed homoclinal ridges in the tuff-breccia along the northwest boundary of the Danforth (?). The southeast edge of the formation appears to overlap onto the Canyon "rhyolite". Apparently this contact is covered by gravels at the base of Lone Mountain.

The Danforth (?) in lowland areas, where it is covered by a soil zone, forms low rounded ridges. On the higher ridges the Danforth (?) locally forms hoodoos. However, even surfaces are also produced by the erosion of tabular sheets from the surface of the tuff beds.

Tuff-Breccia

Lithology

The tuff-breccia is composed of coarse pumice and stony fragments in a matrix of tuff. A typical sample contains 40 per cent angular, unoriented, pumice fragments that have a maximum diameter of 15 cm. Most of the fragments are less than 3 cm in diameter. Angular stony fragments embedded in the matrix are about 10 per cent of the rock. The fragments range up to 10 cm in diameter, but most are about 2 cm. The stony fragments are identical petrographically to the silicified rock of the Canyon "rhyolite". The tuffaceous matrix is about 50 per cent of the rock. Small, anhedral, glassy potash feldspar crystals are widely spaced throughout the matrix.

Jointing of the coarse tuff-breccia usually forms large polygonal columns that are as much as six feet in diameter (Fig. 14).

Outcrops weather in two distinctive ways. Surfaces that are directly exposed to weathering form hard crusts on the tuffaceous matrix, apparently by cementing of iron oxides. The pumice fragments contained in the matrix then decompose and fall out to leave pits in the surfaces of the outcrops. Surfaces that are protected in niches are

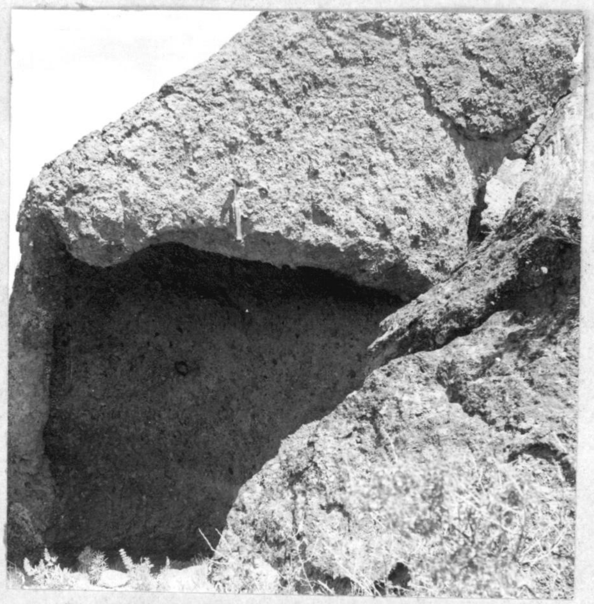


Figure 13. Weathered outcrop of tuff-breccia of the Danforth (?) formation along east border. Note stony and pumice fragments.

Figure 14. Polygonal columnar jointing in tuff-breccia of the Danforth (?) formation. Near Box Canyon.

not hardened; therefore the matrix weathers away first and leaves behind protruding pumice and stony fragments (Fig. 13). Outcrops weather into many bizarre shapes, and tiny caves are formed with the aid of small animals that nest in the rock.

The soil zone of the tuff is cream-colored and easily distinguished from the reddish-brown outcrops. Because many of the fines of the original, tuffaceous matrix of the rock have been removed differentially by erosion, the surface of the soil consists of a residual concentration of pumice and stony fragments. The pumice fragments on the soil surface are porous, hard and cream-colored, but several inches below the surface where there is more moisture the pumice is dense, soft and dark gray.

Petrography

As seen in thin section, the rock is composed of pumice and stony fragments and phenocrysts of potash feldspar, quartz, magnetite, biotite and zircon in a vitroclastic groundmass of glass shards. Several sections exhibit a mottled appearance, apparently because of an alteration to montmorillonite (?). The original glass shards are difficult to recognize in some samples and can be seen only by reducing the light entering the substage. The pumice is partly collapsed.

Most of the phenocrysts are potash feldspar, 4 to 8 per cent of the matrix, and quartz, 1 to 2 per cent of the matrix. The phenocrysts are generally anhedral and are not embayed or altered. The feldspars are mostly sanidine which are neither twinned nor zoned and have poor cleavage. Magnetite and biotite occur in traces. The magnetite occurs as small, anhedral fragments in the groundmass, as dust in the pumice fragments and as reaction rims on the biotite laths.

The groundmass of glass shards is about 90 to 95 per cent of the matrix and is somewhat silicified in several samples. Some of the samples have welded glass shards. The refractive index of the glass is 1.517, which suggests a rhyolitic composition.

Tuff

Lithology

The tuff is somewhat similar to the tuff-breccia but contains smaller and fewer fragments. The fragments are approximately 5 per cent of the rock. Pumice fragments, which are the most plentiful, are as large as 2 cm in diameter although most are less than 2 mm, Stony fragments occur but are less than one per cent of the rock. They are angular, less than 5 mm in diameter and are similar to the silicified Canyon "rhyolite". Rare crystal fragments occur in the tuffaceous matrix.

Outcrops are commonly mottled in appearance. Fresh surfaces are gray but oxidize to reddish-brown upon exposure. A reddish-brown, hard crust forms on the surface and scales away in sheets to expose the underlying gray tuff.

Outcrops of this rock weather into much the same forms as do those of the tuff-breccia (Fig. 16). Polygonal columnar jointing is also common. Soil adjacent to the outcrops is sandy but becomes coarser at a greater distance from the the outcrop because of the concentration of pumice and stony fragments. The color of the soil is the same as that of the weathered outcrops.

Petrography

The tuff has a vitroclastic texture, but in contrast to the tuff-breccia the groundmass of glass shards is about 98 to 99 per cent of the matrix. The glass is rhyolitic, as indicated by its refractive index of 1.499. Small pumice fragments occur but are rare and do not appear collapsed. The tuff also differs from the tuff-breccia in that there is no apparent welding of the shards.

Most of the crystals are potash feldspar, although a trace of quartz, pyroxene, and magnetite are present. Most of the feldspar is neither zoned nor twinned.

Figure 15. Danforth (?) overlying the Canyon "rhyolite" along the east boundary of the area.

Figure 16. Hoodoos and caves weather from tuff of the Danforth (?) formation.

Origin and Conditions of Deposition

Lack of bedding and sorting of the Danforth (?) suggest that this formation did not originate as a normal ash fall or as a water deposit.

Campbell, assuming a Danforth-Rattlesnake correlation, estimates that the upper member covered 5,000 square miles. He and other authors list extensive lateral distribution as a criterion of ignimbrites (5 and 7, p. 1544). That the Danforth (?) is an ignimbrite is also indicated by columnar jointing, collapsed pumice, and welding. Piper (26, p. 43) suggested that the upper member of the Danforth is welded when he referred to the matrix as "(welded rhyolitic pumice?)".

The source vents of the Danforth (?) may have been in the area of Canyon "rhyolite", as indicated by the silicified, Canyon "rhyolite"-like fragments which occur in the tuff and tuff-breccia.

The Danforth (?) was apparently deposited when nuée ardente eruptions ripped fragments from the walls of their vents and (or) swept up fragments from the surface over which the glowing hot avalanches moved before depositing their loads.

The tuff may have traveled a greater distance from its source than did the tuff-breccia, as suggested by the smaller size of the fragments and the apparent lack of welding.

Welding can not be seen in thin sections of the tuff. The lack of welding indicates that the tuff was not intensely hot when deposited. However, the tuff has columnar jointing and other characteristics of ignimbrites not known to apply to ordinary ash falls.

Rhyolitic Gravel

Gravel derived from the Canyon "rhyolite" of Lone Mountain covers the area for several miles north of the mountain's base. What appears to be the original, smooth surface of the deposit can be seen over much of the gravel area. The streams which emerge from the pre-gravel canyons of Lone Mountain have eroded part of the gravel area into long, rolling hills and exposed the underlying older formations at the bottoms of some of the ravines. The streams have left terraces where the gravel once projected into the canyons of Lone Mountain.

Most of the gravel fragments are subangular and of the size of pebbles. The gravel is mixed with ash and is usually unconsolidated and unstratified. However, poorly consolidated gravel in a tuffaceous matrix was occasionally found in depressions of the topography. One such deposit forms a ledge of conglomerate 10 feet thick in the valley north of the prominent ridge of tuff and has the appearance of gravel deposited and reworked in a small lake.

Gravel 46 feet thick rests upon the Danforth (?) formation in sec. 22, T. 39 S., R. 32 E., and may be even thicker near its source at the base of Lone Mountain.

The age of the gravel is post-Middle Pliocene. Gravel partly fills ravines in the Danforth (?), which indicates that the Danforth (?) was eroded before the deposition of the gravel. The age of the gravel is also shown by similar deposits on the south side of Lone Mountain, where Blair (2) has found rhyolitic gravel deposited upon the Thousand Creek formation of late Middle Pliocene age.

Mesa Basalt

A thin, horizontal flow of olivine basalt lies on the lowland at the east side of Lone Mountain within the mapped area. This flow is joined by continuous outcrops with the basalt that forms the prominent mesa at Oregon End Ranch, 6 miles to the southeast.

Merriam (24, p. 43) thought that the basalt at Oregon End Ranch correlated with the Mesa basalt of Virgin Valley. The basalt that is exposed at Oregon End Ranch directly overlies the Thousand Creek formation but extends beyond this formation onto the Canyon "rhyolite" within the mapped area. The Mesa basalt at Virgin Valley, 20 miles to the southwest, has the same topographic expression, lithologic character, and horizontal attitude but rests upon the Virgin Valley formation.

The Mesa basalt was named by Merriam (24, p. 36) from its occurrence at Virgin Valley where it forms the rim-rock of the mesa above the valley.

The basalt's relationship to the rhyolitic gravel was not determined. Gravel lies upon the basalt in several places, but whether this gravel is the same age as that which immediately overlies the Danforth (?) is not known. Gravel from the higher slopes of Lone Mountain may have been redeposited on the lowlying basalt.

The Mesa basalt in the area is dated as post-Middle Pliocene because it overlies the Thousand Creek formation of late Middle Pliocene age, at Oregon End Ranch. The youthfulness of the basalt is evident from its fresh, unweathered appearance and the absence of a soil zone. Stunted sagebrush is almost the only vegetation that grows on its surface.

The surface of the basalt is horizontal, but its thickness is variable in the area because it flowed upon the eroded, uneven surface of the Canyon "rhyolite". The maximum thickness is approximately 20 feet.

Lithology and Petrography

Within the mapped area, the Mesa basalt can be readily distinguished from the Steens basalt by petrographic examination or in the field by examination of the outcrop and the hand specimen. In contrast to the Steens basalt, the Mesa basalt has a fine-grained, uniform texture, and the fresh surface is dark gray to black. Outcrops usually have poorly developed columnar jointing.

Microscopic examination reveals that the rock is holocrystalline and has an ophitic texture of plagioclase, olivine, and magnetite in interstitial augite.

The plagioclase, which makes up approximately 60 per cent of the rock, is labradorite. The plagioclase laths are rarely zoned and usually are not corroded or embayed.

Pale brown, unaltered, anhedral augite is the only pyroxene present. It surrounds all other minerals and makes up approximately 25 per cent of the rock.

The abundance and fresh appearance of the olivine are the most distinctive petrographic features of this rock. Olivine forms in large, usually euhedral phenocrysts that constitute almost 13 per cent of the rock. A few of the phenocrysts are slightly altered to magnetite.

Approximately 2 per cent of the rock is primary magnetite, which is the only accessory constituent. The magnetite forms inclusions in the other minerals and is usually anhedral. It apparently was the first mineral formed, followed in sequence by olivine, plagioclase, and augite (Fig. 17).

Figure 17. Mesa basalt, x100, plain light. Augite enclosing olivine and plagioclase.

Origin and Conditions of Deposition

The uniform thickness of the basalt in the adjacent areas indicates that the basalt was very fluid and spread over an almost level surface. No intrusives or volcanic cones have been found which may have supplied the basalt, so the source of the basalt is not known.

The Mesa basalt is made up of more than one flow. Samples examined from adjacent areas to the southwest differ petrographically from those of the mapped area. The samples from outside the area mapped are finer in texture, and some are porphyritic or glomeroporphyritic. They have approximately the same mineral composition but contain a very fine-grained, colorless clinopyroxene rather than the pale brown augite found in Mesa basalt from the mapped area. In contrast to the fresh olivine in samples from the mapped area, the olivine is altered in basalt from outside the mapped area.

Alluvium

Alluvium has accumulated along the stream beds and in the playas north of Catlow Rim. The largest deposits along the stream beds are those in the areas of tuff and gravel. Where the streams cross basalt areas, temporary base levels form above which the streams widen their channels and deposit alluvium, as in the northeast corner of the area.

The alluvium is composed predominantly of reworked ash and gravels from adjacent formations, but a few lenses of recent ash are interbedded in several places. The eruptions which deposited the ash may explain the presence of angular obsidian fragments, which are scattered over the surface throughout the area. Fuller (9, p. 16) suggested that the obsidian originated with a recent ash fall and remained after the ash had been removed by erosion. This explanation is logical because obsidian is not found in the older rocks in the area.

Although the thickness of alluvium is not known, the large flat-bottomed playas suggest a thickness of several hundred feet.

STRUCTURE

Faulting forms the major structural features in the area. Folds occur but are too small to be plotted at the scale of the map.

Two fault systems can be determined. One system includes Catlow Rim and trends northeasterly; the second is approximately at right angles to the first. These systems are apparent where Catlow Rim, caused by northeast faulting, intersects the northwest fault system along Catlow Valley to the north.

Fault zones extend beyond the areas of apparent fault displacement. The results of these zones are indicated by variable attitudes, by fracturing of the beds, and by many slickensided fragments. However, the trends of many of these zones could not be established.

All faults that were observed are high angle and normal.

Catlow Faults

A mile-wide graben extends to Catlow Valley across the northwest corner of the mapped area and is the major structural feature. Displacement caused by the faults that border the graben has affected the drainage and topography of more than one-half the mapped area.

A series of step faults form an escarpment 140 feet high on an upthrown block on the northwest side of the graben.

The upthrown block is terminated on the north by a fault, which parallels the border of the area and has produced an escarpment at least 100 feet high. North of the base of this fault scarp, a playa has formed on the downthrown block.

A high angle fault borders the graben on the southeast and forms Catlow Rim which is 840 feet high. The large fault-block south of the fault is a tilted fault block as proved by the inclined backslope which dips southeast about 5° to 20° for two miles. Uplift of the block has caused the streams to flow parallel to the strike of the fault and to strip the tuff from the backslope.

Fault at Northeast Corner of Area

This fault passes through sec. 36, T. 38 S., R. 32 E. and parallels Catlow Rim for at least three miles. The fault has produced a 100-foot escarpment and caused a former south-flowing stream to flow southwest in the lowland created by the fault. Overlying the Steens basalt, a thin elongate outcrop of Canyon "rhyolite" is displaced by the fault, showing displacement of the old topographic surface. The southeast block is the downthrown side.

The fault appears to be located along a hinge line for the blocks whose uplift have formed Catlow Rim. Northeast of the fault, in line with it but outside the mapped area, a thin erosional remnant of Canyon "rhyolite" appears to have hinged when its end toward Catlow Rim was uplifted. The surface south of the hinge dips about 7° northwest, but the opposite surface dips about 10° southeast (Fig. 19). However, the variable attitudes of the remnant may have been caused by initial dip.

Transverse Graben at Catlow Rim

A small graben is exposed at the face of Catlow Rim along the northeast corner of the area, although only its southern edge is within the mapped area. The small graben lies transverse to the rim and extends southeast. The movement of the graben was rotational. Displacement at Catlow Rim of the graben is approximately 200 feet, but the displacement diminishes scutheastward until the bounding faults intersect the fault of sec. 36.

The graben is well expressed from the topography (Fig. 18), but the truncation of a pyroclastic bed offers proof of displacement. The bed crops out on the wall of the adjacent block, northeast of the graben, but the bed does not crop out in the graben because there it lies below the present surface. The older faults, that border the graben, have been vertically displaced by the younger Catlow faults. The northwest-trending faults that border the graben continue on the opposite side of the Catlow faults, but the escarpments are not as high there. The variation in

Figure 18. Graben lying transverse to the main faults at Catlow Rim.

Figure 19. Possible hinge line for fault block south of Catlow Rim. The escarpment is just beyond the horizon.

displacement on opposite sides of the Catlow faults suggests that the Catlow fault rejuvenated the transverse faults that border the graben. The transverse faults were planes of weakness along which the graben sagged as the main block forming Catlow Rim was uplifted.

Faults of Lone Mountain

A fault trends northwest along the base of Lone Mountain. The fault has abruptly terminated ridges along the fault line. The southwest side of the fault is the upthrown side.

Southeastward-tilted fault-blocks in Lone Mountain were caused by northeast-trending faults. The attitudes of the strata, although variable, suggest the general dip of the fault-blocks. Asymmetrical canyon profiles are the most apparent result of faulting, and in several places ridges have been truncated. Slickensided boulders occur along the faults but are most evident where two faults converge near the head of Long Hollow. Springs occur along the Long Hollow fault. These faults may terminate at the northwest-trending fault at the base of Lone Mountain but probably continue northeastward under the Danforth (?) formation and the gravels, which are of post-faulting date. In the northeast corner of the area, a continuation of the northeast trending faults is suggested by rectangular drainage and northeast-trending ridges and canyons of the Canyon "rhyolite". No faults were found in the Danforth (?) formation.

Faults of secs. 19, 20, T. 39 S., R. 32 E.

A fault extends from Catlow Rim one mile to the southeast along the west border of the area in sec. 20, T. 39 S., R. 32 E. The fault forms the contact between the downthrown block of Canyon "rhyolite" and the upthrown block of Steens basalt. The contact is evident on the rim wall where the abrupt escarpment of basalt suddenly terminates against the more rounded escarpment of Canyon "rhyolite". Southeast of the rim, the fault has faceted a ridge of Canyon "rhyolite". Relative to the Steens basalt, the Canyon "rhyolite" has moved down at Catlow Rim but up where the ridge of "rhyolite" is faceted; a rotational movement is indicated which probably resulted from the Catlow faulting. The fault line is partly covered by the Danforth (?) formation.

Two other faults extend from the southwest and parallel Catlow Rim before intersecting the southeast-trending fault. They are most easily recognized where ridges are abruptly terminated along their strike east of the mapped area. A graben, which was created by the faults, forms a box canyon at the top of Catlow Rim.

Sequence of Faulting

There was a period of faulting prior to that which formed the youthful Catlow escarpments. Because the Danforth (?) has apparently not been faulted and appears to cover traces of the older faults in the Steens basalt and Canyon "rhyolite", these older faults are dated as probable late Miocene or early Pliocene age. Except where rejuvenated by the Catlow faults, escarpments of the older system are well eroded, as at Lone Mountain.

The northeast-trending Catlow fault system is indicated to be of recent age and younger than the other faults in the area because: (1) The faults vertically displace all other faults that they intersect. One example is shown by the transverse graben at Catlow Rim. (2) Erosion has not yet destroyed the playas which remain at the bases of the escarpments; and (3) The fault scarps are only slightly eroded, and hanging valleys are common on the escarpments.

GEOLOGIC HISTORY

The history of the exposed rocks in the area began in the Middle Miocene when extensive, fluid lava flows buried the area under several thousand feet of Steens basalt. The formation accumulated over a short period of time as indicated by the lack of weathering on the individual flows. Occasionally the lava flows were interrupted by pyroclastic eruptions.

An interval of erosion preceded the deposition of the Canyon "rhyolite" formation. This formation was probably deposited from a nuée ardente eruption. Part of the semi-molten material that was erupted moved down the slopes to form the flow structure that is found occasionally. The rock in general came to rest with initial dips on the irregular surface of the Steens basalt. The absence of soil zones within the formation suggests that the formation accumulated during a short period of time.

The Canyon "rhyolite" surface was eroded to maturity. Next, Lone Mountain was disrupted by faults, interrupting the erosion cycle and causing the streams to cut deep canyons in the mature topography of the Canyon "rhyolite". A topographic discordance can be seen in Fig. 1.

Nuée ardente eruptions at least partly buried the eroded topography of the Canyon "rhyolite" with the Danforth (?) tuff-breccia and tuff. If the Danforth (?) was deposited upon the higher ridges, it was eroded from Lone Mountain together with fragments from the topographically high Canyon "rhyolite". The detritus buried the base of the mountain and overlapped onto the lowlying Danforth (?) formation. This condition remains, although subsequent erosion has removed much of the aggraded material.

The main streams later cut through the gravel and were superimposed upon the underlying structure. One result of superposition is shown where the main stream flows through the ridge to form Box Canyon. There is no displacement of the topography on opposite sides of the canyon or other evidence that might suggest that the canyon originated due to faulting. The tributaries in the northeast corner of the area appear to be subsequent streams that are uncovering the pre-Danforth (?) ridges of Canyon "rhyolite".

In the late Pliocene or early Pleistocene, the highly fluid Mesa basalt spread a thin flow over the even surface of the lowland tuffs. The flow spread westward around the base of Lone Mountain until it wedged out against the eroded surface of the Canyon "rhyolite".

The Catlow faulting occurred subsequent to the deposition of the Mesa basalt and tilted the formations toward the southeast. On the backslopes of the tilted fault blocks, the streams cut through the tuff to the basalt and shifted down dip. The lateral shifting of the streams formed asymmetrical stream bank profiles and the prominent homoclinal ridge of the Danforth (?) tuff. Banks of the northwest sides of the streams are inclined approximately 3°, the banks on the southeast sides about 14°.

Stream piracy occurred in the area. Good examples can be seen in sec. 23, T. 39 S., R. 32 E. where piracy involves three parallel flowing streams. Two streams have each beheaded the stream to its northwest. The middle stream pirated the northern-most stream but was beheaded by the southern-most stream. In the northeast corner of the area, a pirating stream cut through a ridge of Canyon "rhyolite" and diverted the headwaters of a southeasterly flowing stream.

Following faulting alluvium was deposited in local depressions and in lakes formed upon the downthrown blocks. The former levels of one of these lakes is indicated by the terraces in nearby Catlow Valley. Thin beds of ash in the alluvium along the streams indicate that there have been recent, intermittent, pyroclastic eruptions.

Pg. 71 attached separately

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