GEOLOGY OF PART OF THE MITCHELL QUADRANGLE, JEFFERSON AND CROOK COUNTIES, OREGON

by

JAMES NICK LUKANUSKI

A THESIS

submitted to

OREGON STATE UNIVERSITY

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1963

APPROVED:

[redacted]

Professor of Geology

In Charge of Major

[redacted]

Chairman of Department of Geology

[redacted]

Chairman of School Graduate Committee

[redacted]

Dean of Graduate School

Date thesis is presented June 8, 1962

Typed by Nancy Kerley

ACKNOWLEDGMENTS

The writer wishes to acknowledge the indispensable assistance given by Dr. W. D. Wilkinson in the fieldwork, laboratory studies, and preparation of the manuscript. Dr. J. V. Byrne contributed much in editing the thesis. Invaluable suggestions concerning preparation of the manuscript were offered by Dr. K. F. Oles. The advice given by Dr. J. C. Cummings and Dr. J. R. Snook is greatly appreciated. The author is grateful to his wife Janna, for her help in typing and for her patience and understanding.

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INTRODUCTION

Location

The mapped area consists of approximately 133 square miles lying within townships 9 through 12 south, range 19 east, in Jefferson and Crook Counties, Oregon (Index Map, Plate 1).

Accessibility

The major access roads are depicted on the geologic map, Plate 2. The lower Cherry Creek area is reached by an unsurfaced, graded county road to Ashwood, and the area south of Stevenson Mountain is reached by relatively good Forest Service roads which branch off State Highway 26. Other roads depicted on the geologic map are traveled best by jeep or truck.

Climate and Drainage

Two distinct climatic zones exist in the area: (1) a semi-arid climate north of Stevenson Mountain, where the summer days and nights are quite warm and the annual precipitation is quite low; and (2) a more temperate climate south of Stevenson Mountain with noticeably lower summer temperatures and a greater annual precipitation.

This region is drained by the John Day River and two tributaries, Cherry Creek and Bear Creek. Several small

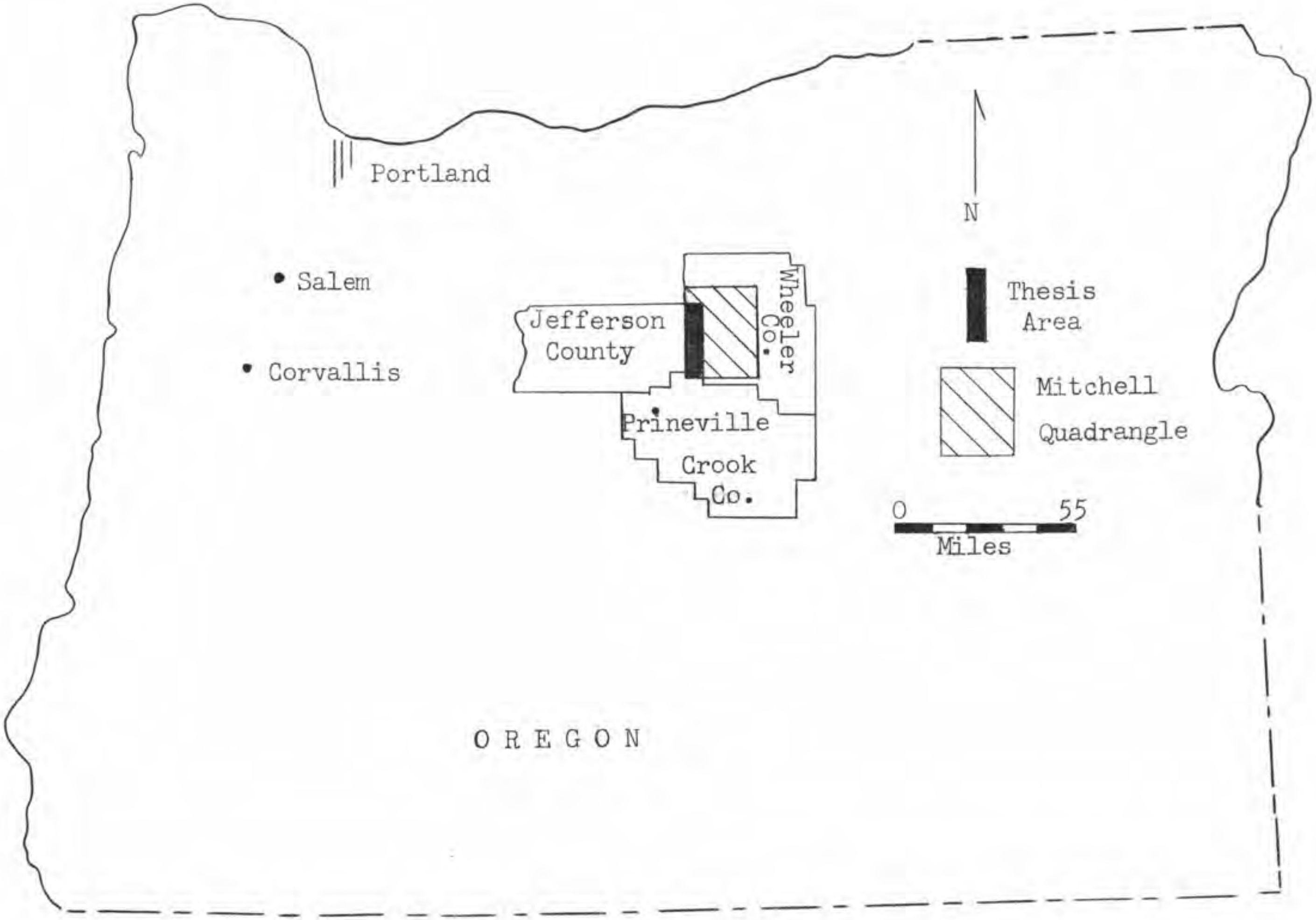

Plate 1. INDEX MAP SHOWING LOCATION OF THESIS AREA.

perennial streams are present in that part of the Ochoco National Forest included in the thesis area. The majority of the streams, however, are ephemeral.

Relief

The elevation on the east side of Stevenson Mountain is 5856 feet, and the elevation near the junction of Cherry Creek and the John Day River is 1454 feet. Thus, the maximum relief is 4402 feet.

Vegetation

Sagebrush and juniper trees are the common plants in the lower, dry areas. The higher country, south of the head of Cherry Creek, is covered predominantly with Ponderosa pine.

Previous Work

The most recent publication dealing with this area is that by Waters (31). Although this paper is concerned primarily with the Horse Heaven Mining district, the geologic map includes sections 31, 32 and 33, T. 9 S., R. 19 E., and sections 4, 5, 6, 7, 8, 17 and 18, T. 10 S., R. 19 E., of the thesis area. Calkins (6) described tuffs and some lava flows along Cherry Creek. The Clarno Formation along Cherry Creek was mentioned by Merriam as a typical exposure (19). Knowlton (16) and Chaney (9) described fossil flora assemblages from a Cherry Creek locality. The geology of the Clarno Basin, which adjoins the thesis area on the north, has been described by Taylor (28). Swarbrick mapped the geology of townships 11 and 12 south, range 20 east (27).

Field and Laboratory Methods

The field study was undertaken between June 14 and August 16, 1961. The geology of the area was plotted on aerial photographs in the field and transferred to enlarged base maps of the 30 minute Mitchell quadrangle (29).

Laboratory work was carried on during the 1961-1962 academic year. Thin sections were made of representative rock types of all formations and their respective members. The Michel-Levy method was used to determine the composition of the plagioclase feldspars.

General Stratigraphy

Rocks exposed in the thesis area are assigned to the Muddy Ranch Phyllite of probable Permian age, and the Clarno and John Day Formations of Tertiary age. The Quaternary deposits consist of fluvial, landslide and terrace sediments. Table 1 is a summary of rock units exposed within the mapped area.

Table 1

SUMMARY OF ROCK UNITS EXPOSED IN PART OF THE MITCHELL QUADRANGLE, JEFFERSON AND CROOK COUNTIES, OREGON

Age	Rock Units	Lithology	Thickness (Feet)
QUATERNARY		Alluvium Landslide deposits	30 variable
-Unconformity-			
TERTIARY			
lower Miocene-upper Oligocene	John Day Formation	Rhyolite flows and lithic tuffs	200-600
-Unconformity-			
post-lower Oligocene	Intrusive rocks	Basalt, andesite, dacite and rhyolite dikes and plugs	
lower Oligocene-Eocene	Clarno Formation		3700
	Upper Member	Basalt and andesite flows, tuffs and flow breccias	(1400)
	Lower Member	Tuff breccias, tuffs, fluvial sedimentary rocks, lava flows, and flow breccias	(2300)
-Angular Unconformity-			
PERMIAN (?)	Muddy Ranch Phyllite	Phyllite and intercalated sandstone beds	3000

MUDDY RANCH PHYLLITE

"Muddy Ranch Phyllite" is the name commonly applied to the metamorphic rocks which crop out at the junction of Muddy Creek and Currant Creek. These rocks, which also extend into the northwest corner of the mapped area, have a total outcrop extent of approximately two- and one-quarter square miles, forty per cent of which is within the mapped area.

Stratigraphic Relationships and Age

In the mapped area, farther north at Muddy Ranch, and along Limekiln Creek east of Tony Butte (5, p. 22) phyllite is overlain unconformably by the Clarno Formation of early Tertiary age.

Elsewhere, comparable meta-sedimentary rocks are overlain by rocks of known Cretaceous age. East of the town of Clarno, wells were drilled by the Clarno Oil Company in 1936, and by the Oregon Petroleum Corporation in 1957. Cores recovered were of marine sandstone, siltstone, and shale, which are considered by Taylor (28, p. 17) to be lithologic correlatives of the known marine Cretaceous sedimentary rocks exposed in the vicinity of Mitchell. This Cretaceous unit unconformably overlies a series of meta-sedimentary rocks exposed on the flanks of Tony Butte and at the head of Meyers Canyon, 24 miles southeast of Muddy Ranch.

The meta-sedimentary rocks in Meyers Canyon and on the flanks of Tony Butte were described by Bowers (5, p. 10) as consisting predominantly of "phyllite, quartzite and chert, with limestone, crystalline limestone, calcareous sandstone, grit and pebble conglomerate."

Dr. D. H. Bostwick* has examined some fusulinids from limestone in the meta-sedimentary rocks in Meyers Canyon, and believes them to be of Upper Wolfcampian to Lower Guadalupian age. He emphasizes that the basis for this age determination is the general appearance of the fauna and therefore is by no means conclusive.

Based on the lithology and stratigraphic sequence, the author believes that the Muddy Ranch Phyllite is probably correlative with the meta-sedimentary rocks at Meyers Canyon and Tony Butte. If so, the Muddy Ranch Phyllite is inferred to be pre-Cretaceous and possibly Upper Wolfcampian or Lower Guadalupian in age.

Field Characteristics

Phyllite and subordinate intercalated beds of sandstone make up the unit in the mapped area. The sandstone beds, however, are not found in the phyllite farther north.

Hills formed in the phyllite are characteristically smoothly rounded, but steep-sided. The rock weathers into thin, splintery fragments and powdery dust which mantle the slopes. Consequently, outcrops generally are low, featureless, poorly exposed, and only in stream valleys are there more prominent exposures.

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* Personal communication, 1961.

The sandstone is more resistant than the phyllite and stands several feet above it. Beds of sandstone range from 2 to 6 feet in thickness and have a maximum exposed length of about 30 feet. Asymmetrical sole markings were found on the base of a sandstone bed in the NW$\frac{1}{4}$, NE$\frac{1}{4}$ section 6, T. 9 S., R. 19 E.

Bedding in the sandstones and schistosity in the phyllites are the dominant structural features, and where both occur together they have concordant attitudes. Although bedding is subordinate to schistosity, enough exposures were found to determine a relatively consistent dip of 50 degrees to the southeast. Based on this dip, the Muddy Ranch Phyllite is approximately 3000 feet thick. Taylor (27, p. 13) reports a thickness of about 5000 feet in the area to the north.

Petrography

Phyllite

Phyllite is by far the most common rock type of this unit. A fresh hand specimen is black and fine-grained, whereas a weathered specimen is light-gray to black, and often has a finely pitted surface. Schistosity and a silky sheen are more evident on a weathered surface than on a fresh surface.

The minerals, as seen in two thin sections, are less than 0.3 mm in diameter. Quartz makes up about 50 per cent of the rock, clay minerals 22 per cent, sericite 20 per cent, iron oxides 2 to 3 per cent, carbonaceous material 3 per cent, with chloritoid and a carbonate in trace amounts. A feldspar peak of 3.20 Angstroms (1) is shown on the X-ray diffraction pattern (Figure 1). This mineral was not recognized in thin section.

A lepidoblastic texture is imparted to the rock by tabular crystals of sericite arranged in streamers interwoven with xenoblastic grains of quartz.

Elongate quartz grains are oriented with their longest dimension and c-axis parallel to the schistosity. Figure 1 shows strong 3.34 and 4.26 Angstrom peaks for quartz (1).

The clay minerals probably are illite as is indicated by 10.0 and 4.48 Angstrom peaks (1) on the X-ray diffraction pattern (Figure 1). The minerals are dark brown in color and so fine-grained that individual particles cannot be resolved even with high magnification.

Iron oxides present are magnetite and hematite. There is a lower percentage of magnetite in weathered rocks than in fresh rocks. This is a result of alteration of magnetite to hematite, as is seen in a weathered specimen in which several grains of magnetite have narrow outer rims of hematite.

Carbonaceous material, probably graphite, is present in individual black flakes and aggregates of flakes elongated parallel to the schistosity of unweathered phyllite. A weighed, crushed sample of the fresh phyllite was treated with hydrogen peroxide to remove any carbon which may have been present. The residue was dried, reweighed and the carbon was calculated as comprising 2.84 per cent of the rock.

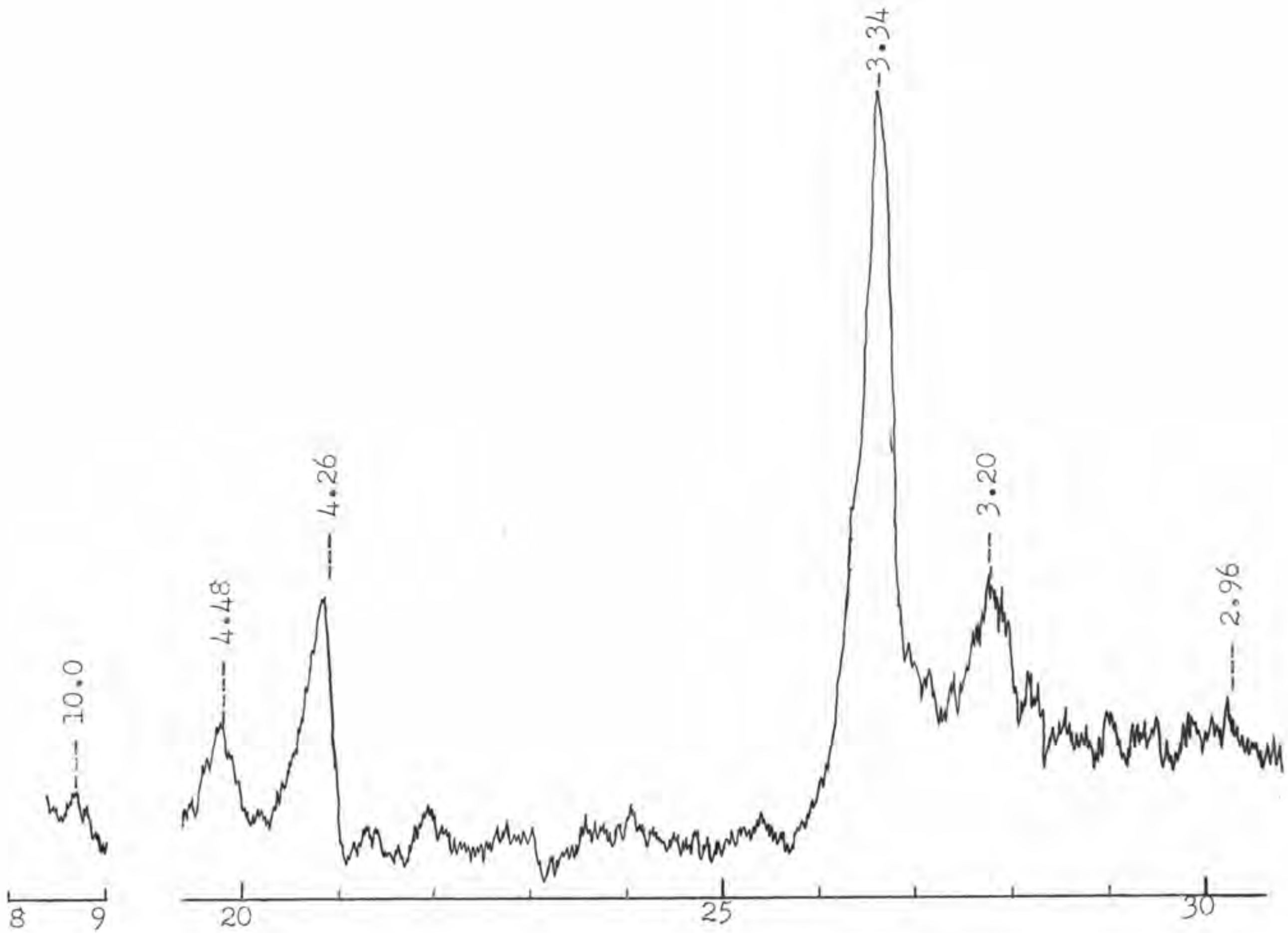

Figure 1. X-RAY DIFFRACTION PATTERN OF PHYLLITE FROM THE MUDDY RANCH PHYLLITE.

Chloritoid occurs as yellow-green flakes associated with sericite streamers. The identification is based on the 2.96 Angstrom spacing (1) shown on the X-ray diffraction pattern of the rock (Figure 1).

Sandstone

Fresh surfaces of the sandstone are finely granular and yellow-brown in color, and weathered surfaces are finely pitted and red-brown to dark-brown in color. Mica flakes with a slight preferred orientation, cloudy quartz grains and an unidentifiable black material are seen with the aid of a hand lens.

Microscopically the rock is composed of about 40 per cent angular quartz, 20 per cent subangular rock fragments, 15 per cent argillaceous material; 10 per cent angular plagioclase, 7 per cent sericite, 5 per cent magnetite and hematite, 1 per cent dark to pale brown biotite altering to chlorite, and trace amounts of rounded epidote, subangular tourmaline, subhedral siderite altering to hematite, and chalcedony. The mineral suite suggests that the sandstone is a feldspathic wacke.

Quartz occurs as irregular shaped grains, 0.05 to 0.10 mm in diameter. Sutured contacts, undulatory extinction and overgrowths were observed in some grains. Irregular and globular inclusions predominate over regular inclusions. Inclusions in quartz were studied by Keller and Littlefield (15, p. 74-84) who defined them as follows: regular inclusions are recognizable minerals such as apatite, zircon and epidote; irregular inclusions are minute opaque "dust" particles and mineral flakes; and globular inclusions are rounded to ellipsoidal, in narrow bands or scattered throughout the crystal. Irregular and globular inclusions, if predominant, are characteristic of igneous rocks, whereas, regular inclusions, if predominant, are characteristic of metamorphic rocks. Angstrom spacings of 3.48 and 4.26 (1) for quartz are shown on the X-ray diffraction pattern (Figure 2).

Rock fragments are a significant part of the feldspathic wacke. They are chiefly fine-grained sericite schist and quartzite fragments. Minor amounts of granitic fragments and very fine-grained rock fragments of indeterminable composition are also present.

The argillaceous material is composed of pale brown and pale green tabular grains about 0.1 mm in length. They occur as irregular aggregates, as narrow masses within sericite streamers, and are commonly associated with hematite. From the optical properties and the association with iron oxides most of the argillaceous material is tentatively identified as an iron-rich montmorillonite. The X-ray diffraction pattern of the rock (Figure 2) shows relatively strong Angstrom peaks of 2.56 and 4.50 for montmorillonite (1). Incipient recrystallization of clay minerals has involved detrital grains, causing them to have irregular and indefinite borders.

Plagioclase composition, as determined from 15 grains, is oligoclase-andesine An_{20}-An_{36}. Minute opaque inclusions

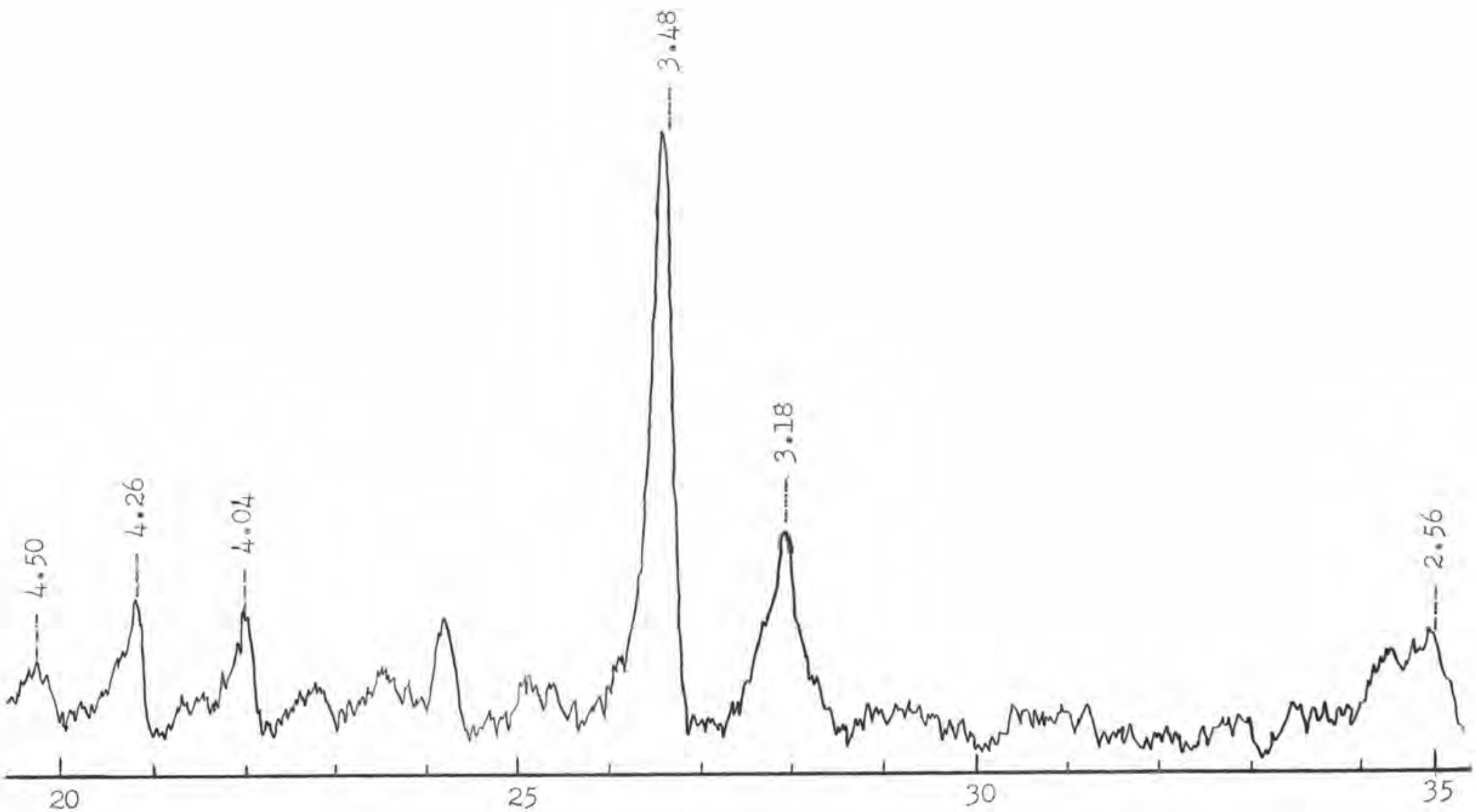

Figure 2. X-RAY DIFFRACTION PATTERN OF THE SANDSTONE FROM THE MUDDY RANCH PHYLLITE.

paralleling the cleavage traces and twin planes are common. Angstrom spacings of 3.18 and 4.04 on the X-ray diffraction pattern (Figure 2) are indicative of a feldspar (1).

Sericite occurs as fibrous, radiating masses 0.10 mm to 0.25 mm in diameter, and as individual minute tabular grains. The smallest particles are arranged with clay minerals in sub-parallel bands that bend around the detrital fragments. Authigenic sericite was observed on the borders of several quartz grains and as thin tabular grains in a haphazard arrangement.

The bonding agents of the rock are primarily the clay minerals and fragments of the framework less than 0.06 mm in diameter. Authigenic silica in the form of quartz overgrowths and chalcedony is a minor cementing agent.

Degree of Metamorphism

Based on the petrography the phyllite belongs to the quartz-albite-muscovite-chlorite subfacies of the greenschist facies. The rock unit is a product of low-grade regional metamorphism that apparently did not affect the unit uniformly. The finer-grained sedimentary rocks yielded most readily to the metamorphic processes, while the sandstone was only slightly altered. This conclusion is drawn from the following facts: in the phyllite most recognizable grains of quartz have wavy extinction, sericite is abundant, and schistosity is distinct; the sandstone, on the other hand, has very few quartz grains with wavy extinction, sericite is not particularly abundant, and definite schistosity planes are lacking. The net effect of metamorphism was recrystallization of quartz and probably clay minerals, development of schistosity, and probably the formation of sericite and chlorite.

Provenance

The relatively unaltered sandstones suggest that the source of clastic particles was a granitic and metamorphic terrane. The significant constitutents characteristic of each rock terrane are listed below:

Granitic terrane	Metamorphic terrane
Quartz	Epidote
Plagioclase	Tourmaline
Granitic rock fragments	Sericite schist and quartzite rock fragments
Biotite (partly altered to chlorite)	

Depositional Environment

The depositional environment of the pre-metamorphic sedimentary shales or mudstones and intercalated sandstone beds is presumed to be marine. This is based on the correlation of the Muddy Ranch Phyllite with marine meta-sedimentary rocks at Meyers Canyon.

CLARNO FORMATION

The Clarno Formation was described by J. C. Merriam (20, p. 496-497) in 1901 as a series of, "ashes, tuffs and lavas, resting upon the Chico near Mitchell, and also showing typical exposures at Clarno's Ferry." This formation is now known to contain many more rock types and to occur over much of central Oregon.

The Clarno Formation within the mapped area consists of andesitic and basaltic lava flows, tuffs, tuff breccias, fluvial sandstones and siltstones, and flow breccias. Welded tuffs or ignimbrites have been reported from other localities, but do not occur in the area investigated.

Stratigraphic Relationships

For the purpose of mapping, the Clarno Formation was divided into two members: (1) a Lower Member consisting primarily of tuff breccias and tuffs, with subordinate fluvial sedimentary rocks, lava flows, and flow breccias; and (2) an Upper Member composed predominantly of lava flows. This subdivision is generally applicable to other exposures of the Clarno Formation (27, p. 44; 18, p. 49; 4, p. 33). The members are generally conformable, but there is an erosional contact between the two members in the SW$\frac{1}{4}$ SE$\frac{1}{4}$ section 32, T. 9 S., R. 19 E. The erosion surface is overlain by fluvial sandstone and conglomerate beds up to 10 feet thick, and apparently is restricted in areal extent.

Angular unconformities delimit the upper and lower boundaries of the Clarno Formation. In the mapped area, an angular discordance ranging from 12 to 24 degrees separates the Lower Member of the Clarno Formation from the underlying Muddy Ranch Phyllite. Beyond the mapped area, in the vicinity of Tony Butte, the Clarno Formation unconformably overlies upper Paleozoic meta-sedimentary rocks (5, p. 21). Near Mitchell, the author has observed an angular unconformity between the Lower Member of the Clarno and Upper Cretaceous sedimentary rocks. In the area investigated an angular unconformity of 5 to 12 degrees divides the Clarno Formation from the overlying John Day Formation of Oligocene and Miocene age (p. 50).

Age

The age of the Clarno Formation, based on stratigraphic relationships is post Upper Cretaceous and pre-Middle Oligocene. Faunal and floral assemblages indicate an Eocene and Oligocene age for the Lower Member.

The author found well-preserved plant remains in tuffaceous siltstones in the NW$\frac{1}{4}$ SE$\frac{1}{4}$ section 17, T. 10 S., R. 19 E. The identified plants include:

Equisetum oregonense Newb.
Juglans bendirei n. sp.
Aralia sp.
Quercus sp.

These flora are listed among those described by Knowlton (16, p. 102) and Merriam (18, p. 289) from a locality along Cherry Creek.

Knowlton says "...it appears the plants of the Cherry Creek locality point to the Lower Eocene age of the beds." An Upper Eocene age has been assigned to the Clarno Formation by Chaney (8) on the basis of fossil leaves. Upper Eocene-Lower Oligocene mammal remains have been found recently in tuffs within the Clarno Basin (28). Stirton (26) describes a Middle Eocene rhinoceros tooth from the tuffs near Clarno. Scott (24) has compared Clarno fruits and seeds to those from the Upper Lower Eocene London clay. The U. S. Geological Survey regards the Clarno formation as Upper Eocene and Lower Oligocene in age (33, p. 454-455).

Lower Member

General Features

The Lower Member, approximately 2300 feet in thickness, consists predominatly of tuff breccias and tuffs, with subordinate fluvial sandstones and siltstones, lava flows, and flow breccias. The member is exposed over approximately 15 square miles of the mapped area, 90 per cent of which is in and around Cherry Creek Valley (Map, Plate 2). There are additional exposures along the John Day River and Muddy Creek.

Tuff breccias. Tuff breccia is the most conspicuous rock type in the member. It forms projecting ledges and stands out from less resistant rocks. Spectacular hoodoos capped by resistant boulders are common (Figure 3). Disintegration of large clastic fragments leaves many holes, forming a "pock-marked"

Figure 3. HOODOOS OF TUFF BRECCIA IN THE $SE\frac{1}{4}$ $SW\frac{1}{4}$ SECTION 9, T. 10 S., R. 19 E.

surface. Outcrop colors vary from a striking bright greenish-white to a dull green-brown.

Tuffs. Two varieties of tuffs are interbedded throughout the member. The most abundant are red, white, green and buff tuffs which are exposed in valleys, saddles, and low, conical hills, Less common are white to brown, lithic and crystal tuffs forming low, narrow benches along stream valleys.

Fluvial sandstones and siltstones. Outcrops of sandstone and siltstone are pale brown to yellow-brown in color. The topographic expression varies from low hills to narrow ledges, dependent on the degree of induration.

Lava flows. The lava flows are gray to black in color, and form the caprock of ridges or, locally, cuestas.

Flow breccias. The flow breccias are intricately dissected, forming steep, irregular slopes with low spires, resembling in general shape those of the tuff breccias. The flow breccias weather generally to shades of gray, but red and red-brown colors also occur.

Structure

The dips of the Lower Member are variable within short distances, but the northeasterly strike is relatively consistent over a large area. Dips range from 12 to 35 degrees northwest, but the majority are between 12 and 18 degrees. The diversity of dips generally is caused by slumping of the rocks, especially where the ash content is high.

Tuff Breccias

Lithology. Tuff breccias occur in beds 5 to 25 feet thick, and have an average thickness of 10 feet. The beds are generally structureless. However, a rude alignment of clastic particles occurs locally (Figure 4). The beds are generally separated by layers of white tuff 0.2 inches to 0.8 inches thick, or by beds of tuffaceous sandstone and siltstone 0.5 feet to 3 feet thick.

The coarse fraction of the tuff breccias consists of subangular to round, aphanitic to porphyritic andesite and basalt rock fragments, 0.2 inches to 3 feet in diameter. Various shades of brown, green and gray are common colors of rock fragments.

The matrix is composed of material less than 4 mm in diameter and constitutes between 25 and 75 per cent of the rock. It consists of rock fragments, clear to cloudy feldspars, dark green amphiboles and pyroxenes, zeolites, and chalcedony, all of which are visible with a hand lens.

In thin section tuff breccias are composed of aphanitic and porphyritic basalt, andesite, and dacite fragments, greater than 4 mm in diameter, set in a matrix which consists of rock fragments less than 4 mm in diameter, various minerals less than 1 mm in diameter, and glass.

Rock fragments greater than 4 mm in diameter contain phenocrysts and microlites of plagioclase, grains of clinopyroxene, lamprobolite, and an iron-rich montmorillonite-type clay mineral, and accessory glass, quartz, calcite, magnetite (partly altered to hematite) and ilmenite (partly altered to leucoxene).

Figure 4. SPIRES OF TUFF BRECCIA IN THE SE$\frac{1}{4}$ SECTION 22, T. 9 S., R. 19 E. NOTE BEDDING.

Plagioclase has a compositional range of sodic andesine to sodic labradorite, and is often partially replaced by calcite. Clinopyroxene occurs as euhedral colorless prisms and basal sections. Lamprobolite occurs in basaltic rock fragments as euhedral, short brown prisms and basal sections, often with an opaque border. The iron-rich montmorillonite is red-brown, fibrous, highly birefringent and has a refractive index greater than 1.54. It is apparently an alteration product of pyroxenes and amphiboles, because it is pseudomorphous after crystal forms characteristic of pyroxene and amphibole (Figure 5). Rock fragments with projecting phenocrysts were observed in most thin sections. These are interpreted as primary pyroclastic material which was subjected to little or no abrasion. The significance of these will be discussed in the concluding section of tuff breccias (p. 25).

The matrix is composed of angular rock fragments with the same composition as the larger fragments, euhedral to subhedral crystals of sodic andesine to sodic labradorite, a montmorillonite-type clay mineral, and subordinate palagonite, glass shards, altered pyroxenes and amphiboles, chalcedony, magnetite altering to hematite and ilmenite altering to leucoxene. Minor accessories include irregular quartz grains, and euhedral zircon and apatite. Plagioclase occurs primarily as microlites, but larger grains are not uncommon. The mineral tentatively identified as montmorillonite occurs as pale pink, microcrystalline aggregates in the shape of shards, with a moderate birefringence, and an index of refraction

Figure 5. IRON-RICH MONTMORILLONITE-TYPE CLAY MINERAL PSEUDOMORPHOUS AFTER CLINOPYROXENE IN TUFF BRECCIA. 35X, PLAIN LIGHT.

less than 1.54. Palagonite (?) is found only in tuff breccias in which basalt rock fragments are the predominant rock type. It occurs as brown to yellow-brown irregular shaped particles with an outer rim of montmorillonite (?) (Figure 6). The pyroxenes and amphiboles are partially altered to an iron-rich montmorillonite and chlorite. This latter mineral also occurs as a rim around irregular shaped, intergrown quartz and feldspar grains.

Origin. Anderson (2, p. 245-258) lists and discusses two classes of volcanic breccias: (1) volcanic breccias not transported by water; and (2) volcanic breccias transported by water. Class I breccias are formed by crumbling of domes, autobrecciation during intrusion, blocky lava flows, and eruptions such as nuees ardentes or dry avalanches. Class II breccias are usually produced from mudflows that accompany and follow volcanic eruptions.

A mudflow origin of the Clarno breccias is indicated by the limited lateral and vertical extent of individual beds, poor sorting, various sizes of rock fragments with varying degrees of roundness, variety of rock types, primary unbroken pyroclastic debris, and euhedral minerals in the matrix.

Mudflows are characterized by a high viscosity which retards various constituents from striking one another and the surface over which the mass flows, so that rounding and extreme fracturing do not occur. The larger fragments evidently float in a slurry of minerals, small rock fragments, ash, and water which glides over the ground surface without the internal turbulence that characterizes

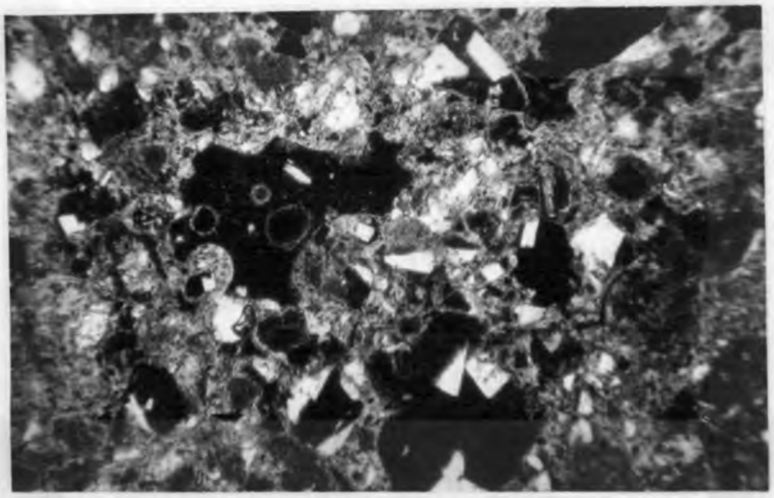

Figure 6. PHOTOMICROGRAPH OF TUFF BRECCIA. IRREGULAR SHAPED PALAGONITE PARTICLE (CENTER), AND DARK ROCK FRAGMENTS. NOTE ANGULAR FELDSPAR GRAINS IN THE MATRIX, AND ROCK FRAGMENT WITH PROJECTING PHENOCRYSTS OF PLAGIOCLASE (UPPER RIGHT CENTER). 25X, PLAIN LIGHT.

a more fluid material. The viscosity and method of transport accounts for the presence of angular rock fragments of various sizes, unbroken glass shards, rock fragments with projecting phenocrysts, and euhedral minerals in Clarno mudflow deposits. Limited lateral and vertical extent of individual mudflow beds is also indicative of a viscous medium.

Poor sorting of the Clarno mudflow deposits is primarily related to the viscous nature of the flow which inhibits separation and settling of constituents with different densities and sizes.

Rounded rock fragments and rocks of different composition were incorporated in the mudflows as they moved down volcanic slopes and stream valleys.

Tuffs

Lithology. A variety of tuffs are found in the mapped area. Most common are poorly indurated red, white, buff, and green tuffs interbedded throughout the Lower Member. They are well-exposed in the SE$\frac{1}{4}$ section 36, T. 9 S., and the NE$\frac{1}{4}$ section 1, T. 10 S., R. 19 E., the W$\frac{1}{2}$ section 14, T. 9 S., R. 19 E., and in many places in the northwest slope of Cherry Creek Valley. These tuffs swell greatly when in contact with water, suggesting a high percentage of expansive clay minerals. It is this property of expansion and an accompanying unctuousness of the tuffs that cause most slumping in the Clarno Formation.

Yellow and buff, thinly bedded tuffaceous shales occur with poorly indurated tuffs in the SW$\frac{1}{4}$ section 2, and the NW$\frac{1}{4}$ section 4,

T. 9 S., R. 19 E. The tuffaceous shales contain poorly preserved leaf impressions and some petrified wood. They weather easily into paper-thin flakes which mantle the surrounding slopes. These shales are common in other exposures of the Clarno Formation (5, p. 77; 32, p. 76), and are regarded as waterlaid tuffaceous deposits.

A white tuff with sparsely scattered rock fragments occurs as a bed six feet thick trending northwest from the SW$\frac{1}{4}$, SE$\frac{1}{4}$ section 32, to the SW$\frac{1}{4}$ section 30, T. 9 S., R. 19 E. Hand specimens are chalky, and contain fragments of pumice, quartzite, lava and phyllite.

In thin section the tuff shows a non-welded vitro-clastic texture. It is composed predominantly of angular glass shards and fragments, spherulitic pumice, and quartzite, with subordinate basalt, phyllite, and clear, fractured andesine and sanidine grains.

Fluvial Sedimentary Rocks

Lithology. This group contains two genetically different sandstones: (1) tuffaceous sandstones, consisting of some primary pyroclastic material as well as epiclastic volcanic material; and (2) volcanic sandstones composed only of epiclastic volcanic material. Sandstones with primary pyroclastic debris contain rock fragments with projecting phenocrysts (Figure 7), mineral grains with attached glass, and glass shards which fell into the depositional site and were subjected to very little or no abrasion. Because

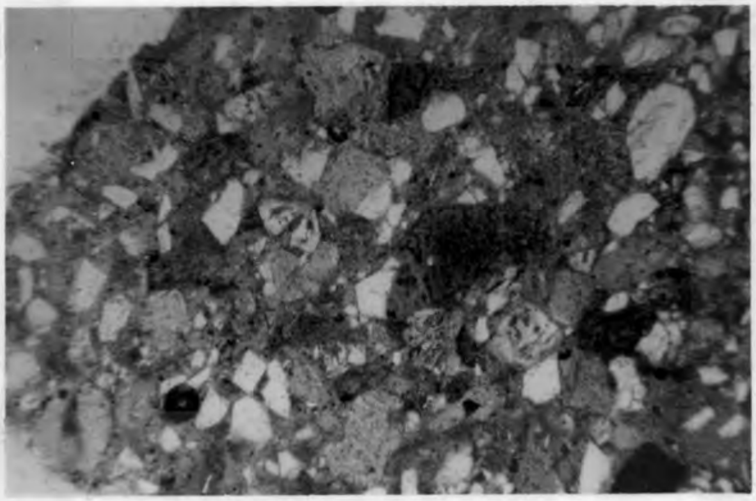

Figure 7. PHOTOMICROGRAPH OF A TUFFACEOUS SANDSTONE SHOWING A ROCK FRAGMENT WITH A PROJECTING PLAGIOCLASE GRAIN (CENTER OF PICTURE). NOTE CLEAR, ANGULAR PLAGIOCLASE GRAINS IN THE MATRIX. 25X, PLAIN LIGHT.

the two sandstone types do not have significantly different outcrop and hand specimen characteristics, and differ microscopically only by the presence or absence of primary pyroclastic debris, they will be discussed together.

The sandstones weather to buff, white or greenish-white colors, are 5 to 20 feet thick, and are 50 to 200 feet wide. Lenticular cross-sections are visible locally (Figure 8), but most outcrops are either extensively covered or dip under associated rocks so that the shape cannot be definitely ascertained. Individual beds range in thickness from 0.5 inches to 3 feet, but are generally less than 18 inches. These are commonly separated by beds of white tuff 0.5 inches to 2 inches thick. Laminae, 0.10 inches to 0.3 inches thick are marked by grain size and color differences. Cross-stratification is confined to beds of volcanic sandstone and is generally of small scale. Gray and white quartzite, black and pale green volcanic rock fragments, and clear to weathered feldspars are the chief constituents visible with a hand lens. Vitreous calcite crystals and limonite are less commonly seen in a hand specimen.

Microscopically the sandstones are composed of 40 to 90 per cent angular to rounded rock fragments, 2 to 45 per cent angular plagioclase grains, up to 3 per cent angular quartz grains, up to 2 per cent glass shards, and minor amounts of ilmenite, magnetite, leucoxene, hematite and limonite. Cement constitutes 2 to 15 per cent and matrix up to 20 per cent of the sandstones.

Figure 8. EXPOSURE OF FLUVIAL SANDSTONE WITH INTERCALATED LAYERS OF WHITE TUFFACEOUS SILTSTONE. PART OF A SANDSTONE LENSE IS SHOWN IN THE LOWER RIGHT HAND CORNER OF THE PICTURE. SE$\frac{1}{4}$ SECTION 22, T. 9 S., R. 19 E.

Rock fragments are between 0.06 mm and 4 mm in diameter. Minerals range in diameter from less than 0.06 mm to 1 mm.

Quartzites, and porphyritic and aphanitic basalts and andesites are the predominant rock fragments. Phyllite, perlitic glass, some of which has devitrified to stilbite but has retained the perlitic structure, spherulitic and some non-devitrified pumice particles, and individual spherulites comprise the remaining portion of the rock fragment fraction. Lath-shaped crystals of plagioclase range in composition from andesine An_{44} to labradorite An_{56}. Most of the glass shards have devitrified to either a zeolite or to montmorillonite.

Cementing agents are calcite and chalcedony. Chalcedony occurs in small amounts in every sandstone. Calcite is a dominant cement in only one rock, in which it has almost completely replaced the original cryptocrystalline cement (Figure 9). Matrix, where present, consists of an iron-rich montmorillonite (?), and minerals and rock fragments less than 0.06 mm in diameter.

Lava Flows

Lithology. Andesite and basalt flows, intercalated with tuff breccias, crop out in the W½ section 26, and S½ section 27, T. 9 S., R. 19 E. The flows cap ridges, or form narrow ledges which stand out from adjacent rocks. Individual flows range in thickness from 12 to 20 feet, and are upto 1500 feet wide.

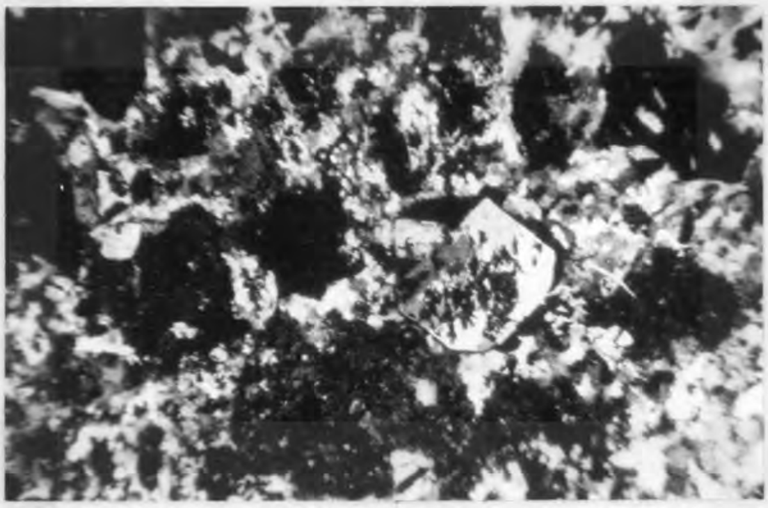

Figure 9. TUFFACEOUS SANDSTONE WITH GLASSY ROCK FRAGMENTS (OPAQUE PARTICLES), AND A SECONDARY CALCITE CEMENT. THE LARGE CRYSTAL IN THE CENTER OF THE PICTURE IS MICROCRYSTALLINE CALCITE PSEUDOMORPHOUS AFTER PLAGIOCLASE. 25X, CROSSED NICOLS.

Andesites weather to brown and gray colors. Fresh fractures are light gray to black in color. Fresh fractures are light gray to black in color. Plagioclase, pyroxene, biotite, and a soft, brownish-green alteration mineral are visible with a hand lens.

Microscopically, the rocks are porphyritic with phenocrysts of middle andesine, an iron-rich montmorillonite, biotite, and subordinate clinopyroxene and pigeonite. Accessory minerals are magnetite partly altered to hematite, chalcedony in veinlets, calcite and zircon. The groundmass is either pilotaxitic, with microlites of andesine, pyroxene and accessories, or cryptocrystalline. Modes of these rocks are given under (1), (2) and (3) in Table 2.

Andesine An_{42} - An_{46} occurs as euhedral to subhedral laths, commonly with normal zoning, and limited replacement by heulandite and calcite. The iron-rich montmorillonite occurs as brown to yellow-brown, highly birefringent, fibrous pseudomorphs after pyroxene (Figure 10). Euhedral crystals of clinopyroxene and pigeonite are large enough to allow determination of the optical properties necessary to differentiate these pyroxenes.

Basalt hand specimens are dark brown on weathered surfaces, and gray to reddish-gray on fresh surfaces. Phenocrysts of feldspar, light and dark green pyroxenes, and hematite are visible to the unaided eye.

In thin section the rock displays a porphyritic and pilotaxitic texture. The phenocrysts are euhedral to subhedral calcic

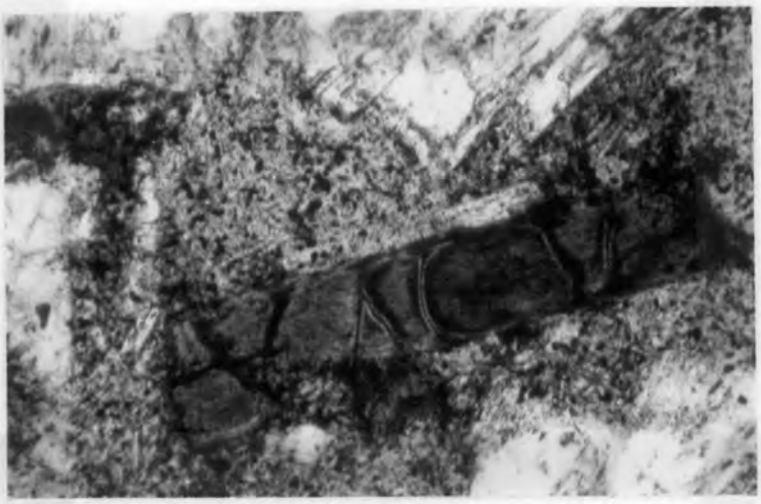

Figure 10. PHOTOMICROGRAPH OF A PORPHYRITIC ANDESITE FROM THE LOWER MEMBER OF THE CLARNO FORMATION. THE LARGE CRYSTAL IN THE CENTER OF THE PICTURE IS AN IRON-RICH MONTMORILLONITE CLAY MINERAL PSEUDOMORPHOUS AFTER CLINOPYROXENE. 35X, PLAIN LIGHT.

Table 2

MODES OF CLARNO FORMATION, LOWER MEMBER LAVAS

Mineral	(1)	(2)	(3)	(4)
Andesine	66	70	69	--
Labradorite	--	--	--	66
Clinopyroxene	6	5	4	8
Biotite	--	--	13	--
Fibrous Alteration Mineral	8	10	--	8
Glass	5	8	4	7
Iron Oxides	9	6	8	10
Zeolites	1	1	--	--
Calcite	--	--	T	1
Apatite	--	T	--	--
Chalcedony	5	--	--	--
Zircon	--	--	T	--

(T: less than 1%)

Explanation:

(1) Pyroxene andesite, SW$\frac{1}{4}$ SE$\frac{1}{4}$ section 27, T. 9 S., R. 19 E.

(2) Same

(3) Biotite andesite, SW$\frac{1}{4}$ section 26, T. 9 S., R. 19 E.

(4) Pyroxene basalt, NW$\frac{1}{4}$ section 26, T. 9 S., R. 19 E.

labradorite An_{64} and colorless prisms of clinopyroxene. Accessory minerals are magnetite altering to hematite, and calcite partly replacing some labradorite crystals. The groundmass is composed of microlites of labradorite, pyroxene, pigeonite, and accessory minerals. The mode of this rock is under (4) in Table 2.

Flow Breccias

Lithology. Flow breccias are exposed along Cherry Creek in the S½ section 34, T. 9 S., in the NW¼ section 3, and the NW¼ NE¼ section 5, T. 10 S., R. 19 E. Differential erosion has produced prominent craggy pinnacles which are weathered to brown and red-brown colors (Figure 11). The rock is pitted where fragments and minerals have weathered out. Fresh surfaces are gray to brown in color.

Fragments, 0.5 inches to 2 feet in diameter, are difficult to distinguish on weathered surfaces, but are slightly more evident on fresh surfaces. This similarity in appearance of fragments and groundmass is presumed to be related to similarity in composition, because the only visible minerals in both fractions are plagioclase laths and hornblende prisms. Megascopic examination suggests an andesitic composition.

Beds of yellow-brown tuff, 12 to 24 inches thick are locally interbedded with flow breccias. Breccia fragments are scarce in a narrow, irregular, ill-defined zone above the tuff bed, but they increase in abundance upwards to form a true flow breccia.

Figure 11. OUTCROP OF FLOW BRECCIA IN THE LOWER MEMBER OF THE CLARNO FORMATION. SECTION 4, T. 10 S., R. 19 E. NOTE SIMILARITY TO SPIRES OF TUFF BRECCIA.

Upper Member

General Features

The Upper Member is the dominant rock unit in the mapped area. It consists mainly of lava flows, with subordinate interbedded tuffs and flow breccias, and approximates 1400 feet in thickness.

Lava flows. Lava flows in Cherry Creek and Muddy Creek Valleys stand in relief as low scarps above less resistant rocks of the Lower Member. Elsewhere in the area investigated, the flows form asymmetric ridges with deeply dissected slopes. Platy jointing, parallel to the upper surfaces of flows, is a characteristic structural feature (Figure 12). Columnar jointing is less common.

Dips of flows range from 8 to 30 degrees on the limbs of northeast trending folds.

Tuffs. Beds of poorly-indurated red tuff, ranging in thickness from 1 to 3 feet, are locally interbedded with lava flows. The tuffs are lithically similar to those in the Lower Member (p. 27).

Flow Breccias. A flow breccia is exposed in sections 21, 22, 23, T. 9 S., R. 19 E. at the base of the Upper Member. This flow breccia, weathered to a greenish-gray color, has been eroded to low spires which rise above the tuff breccia of the Lower Member. At Sandrock Gulch, in sections 34 and 35, T. 10 S., and in the NE$\frac{1}{4}$ section 16, T. 11 S., R. 19 E., a bright red flow breccia, 100 to 150 feet thick, is intercalated with lava flows. The flow breccia is best exposed as buttes in the NE$\frac{1}{4}$ section 16, T. 11 S., R. 19 E.

Figure 12. PLATY JOINTING IN AN ANDESITE FLOW IN THE UPPER MEMBER OF THE CLARNO FORMATION.

Lava Flows

Lithology. Lava flows in the mapped area are divided into andesites, leuco-andesites, basaltic andesites, and basalts. They will be described in this order.

Andesite flows generally form low outcrops with well-developed platy jointing (Figure 12), but prominent cliffs occur locally. The rock is red-brown on weathered surfaces and gray on fresh break. The andesites are megascopically aphanitic.

In thin section the rocks are usually aphanitic, and less commonly microporphyritic. A pilotaxitic texture is characteristic of these rocks. The phenocrysts in microporphyritic andesites are mainly calcic andesine averaging An_{44}, with subordinate clinopyroxene. The groundmass in all andesites examined consists of plagioclase microlites, clinopyroxene, enstatite, hypersthene, and minor amounts of corroded quartz, hematite, magnetite, limonite, and apatite. Chalcedony veinlets were observed in one of the andesites examined. Modes of these andesites are given in Table 3.

Enstatite occurs as colorless narrow prisms, 0.5 mm in length, with weak birefringence and parallel extinction. Hypersthene is the same size as enstatite, but has the typical pleochroism and higher birefringence.

Leuco-andesite is exposed in section 19, T. 9 S., R. 19 E. It forms conspicuous, smooth surfaced spires which are in direct contrast to adjacent low-lying basalts of the Upper Member.

Table 3

MODES OF CLARNO FORMATION
UPPER MEMBER EXTRUSIVE ANDESITES

Mineral	(1)	(2)	(3)	(4)	(5)
Andesine	70	67	71	73	76
Clinopyroxene	3	22	16	6	9
Hypersthene	5	--	5	--	--
Quartz	T	--	--	--	--
Enstatite	4	--	--	--	--
Iron Oxides	10	6	4	7	6
Fibrous Alteration Mineral	8	--	2	--	--
Glass	--	5	2	--	9
Apatite	--	T	T	T	T
Hornblende	--	--	--	14	10

T: less than 1%)

Explanation:

(1) Enstatite-bearing andesite, SE$\frac{1}{4}$ section 24, T. 9 S., R. 19 E.

(2) Pyroxene andesite, NW$\frac{1}{4}$ section 19, T. 10 S., R. 19 E.

(3) Hypersthene-bearing andesite, SW$\frac{1}{4}$ section 13, T. 10 S., R. 19 E.

(4) Hornblende andesite, NE$\frac{1}{4}$ section 15, T. 10 S., R. 19 E.

(5) Leuco-andesite, SE$\frac{1}{4}$ section 19, T. 9 S., R. 19 E.

Weathered surfaces of leuco-andesite are red-brown to buff in color, and fresh fractures are pale red-brown to pale brown. Flow banding, plagioclase and a red, lath-shaped mineral are visible on fresh surfaces.

Microscopic examination reveals a trachytic texture, with phenocrysts of both calcic andesine (An_{46}) containing inclusions of glass, and hornblende, partly altered to hematite. The groundmass consists of andesine microlites with subordinate glass and ilmenite. The mode of this rock is given in Table 3.

Basaltic andesite flows crop out in townships 11 and 12 south, range 19 east. Exposures generally have little relief, but steep cliffs of basaltic andesite occur in the N½ section 2, T. 12 S., R. 19 E. Flows are 50 to 80 feet thick and generally display platy jointing.

Weathered surfaces of the basaltic andesites are gray to red-brown and usually finely pitted, whereas fresh surfaces range from black to gray in color. Where porphyritic the phenocrysts are plagioclase, dark green pyroxenes, and an unidentified green-brown alteration mineral.

Microscopically, intergranular textures are predominant, and intersertal and subophitic textures are subordinate. Phenocrysts of plagioclase are abundant in every specimen; clinopyroxene, hypersthene, and lamprobolite occur in lesser amounts. The groundmass is composed of microlites of plagioclase, clinopyroxene, hypersthene and lamprobolite, with accessory pale brown glass, ilmenite partly altered to leucoxene, magnetite partly altered to hematite, and euhedral apatite. Phenocrysts range in length from 1 to 3 mm and microlites are 0.1 to 0.5 mm long. Modes of basaltic andesites are given in Table 4.

Plagioclase phenocrysts are euhedral to subhedral and have a compositional range of An_{50} to An_{56}. Normally zoned crystals do occur, but are not abundant. Microlites of plagioclase range from middle to calcic andesine. Clinopyroxene occurs as colorless, euhedral to subhedral prisms and basal sections, locally altered to a fibrous, red-brown, highly birefringent iron-rich montmorillonite mineral. Hypersthene is present as euhedral to subhedral crystals, infrequently enclosing clinopyroxene. Lamprobolite, found in only one rock, encloses several clinopyroxenes, and is itself partially altered to an iron-rich montmorillonite-type clay mineral.

Basalt flows are exposed in section 3, T. 9 S., R. 19 E. The flows range in thickness from 20 feet to 50 feet thick, and generally have well-defined columnar jointing. Weathered surfaces are brown and finely pitted where minerals have weathered out. Fresh surfaces are black and dense in texture and have visible grains of plagioclase, and subordinate quartz.

In thin section porphyritic and subophitic textures are displayed. Phenocrysts of labradorite and subordinate quartz xenocrysts are set in a groundmass of labradorite and clinopyroxene microlites, with accessory brown glass and magnetite.

Table 4

MODES OF CLARNO FORMATION UPPER
MEMBER EXTRUSIVE BASALTIC ANDESITES

Mineral	(1)	(2)	(3)	(4)
Andesine	60	57	63	61
Labradorite	11	9	9	6
Clinopyroxene	13	6	16	9
Hypersthene	4	9	2	3
Iron Oxides	8	6	5	12
Fibrous Alteration Mineral	--	5	3	8
Glass	4	7	2	T
Titanium Oxides	--	T	--	--
Apatite	T	--	--	--
Hornblende	--	T	--	--

(T: less than 1%)

Explanation:

(1) Hypersthene-bearing pyroxene basaltic andesite, NW$\frac{1}{4}$ section 35, T. 10 S., R. 19 E.

(2) Hypersthene basaltic andesite, SW$\frac{1}{4}$ section 28, T. 11 S., R. 19 E.

(3) Pyroxene basaltic andesite, SW$\frac{1}{4}$ section 21, T. 12 S., R. 19 E.

(4) Same, NE$\frac{1}{4}$ section 3, T. 12 S., R. 19 E.

Plagioclase is less than 1 mm in length and quartz is less than 1 mm in diameter. Modes of these rocks are given in Table 5.

Labradorite phenocrysts have a composition which approximates An_{58}, and are slightly embayed and corroded. Microlites of labradorite have an approximate composition of An_{52}. Quartz xenocrysts are fractured, embayed and corroded (Figure 13).

Flow breccias

A flow breccia at the base of the Upper Member crops out in sections 21, 22, and 23, T. 9 S., R. 19 E. It is similar to the flow breccia in the Lower Member (p. 26). However, the flow breccia of the Upper Member is characterized by abundant chalcedony veins.

The conspicuous bright red flow breccia exposed in the NE$\frac{1}{4}$ section 16, T. 11 S., R. 19 E., is unique in the mapped area. It consists of angular fragments of black aphanitic basalt and red scoria, 0.5 inches to 1 foot in diameter, set in a groundmass of red scoria. Occasional elongate fragments, 4 to 10 inches long, display a subparallel alignment. Aphanitic basalt fragments and scoria fragments occur in a ratio of 1:5. Cavities in the scoriaceous groundmass and within the fragments are lined with fine, white, globular zeolites.

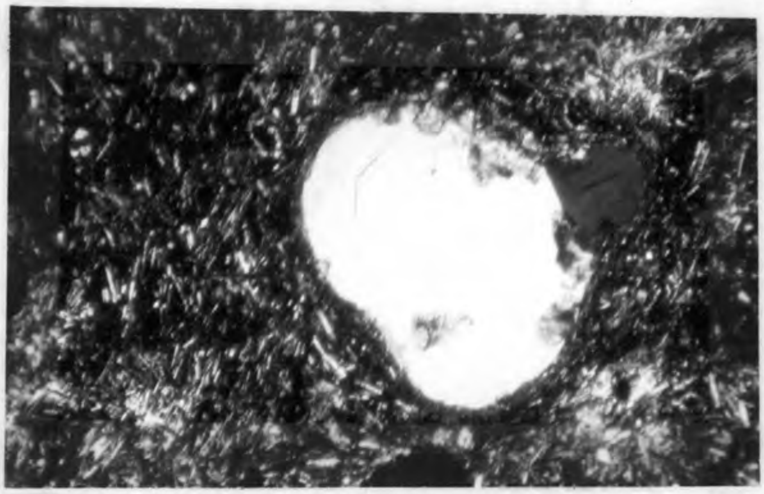

Figure 13. PHOTOMICROGRAPH OF CLARNO, UPPER MEMBER BASALT SHOWING A CORRODED QUARTZ XENOCRYST. 25X, CROSSED NICOLS.

Table 5

MODES OF CLARNO FORMATION
UPPER MEMBER EXTRUSIVE BASLATS

Mineral	(1)	(2)
Labradorite	60	78
Clinopyroxene	25	15
Glass	10	3
Iron Oxides	4	4
Quartz	1	--
Apatite	T	--

(T: less than 1%)

Explanation:

(1) Pyroxene quartz-bearing basalt, NW$\frac{1}{4}$ section 3, T. 9 S., R. 19 E.

(2) Pyroxene basalt, NE$\frac{1}{4}$ section 11, T. 10 S., R. 19 E.

Depositional Environment

The Clarno Formation is a continental deposit formed during the existence of a humid subtropical climate. Plants found in the formation such as fig, cinnamon, persimmon, palms, sycamore and avocado are now confined to regions with subtropical climates (7, 9). Fruits and nuts from the Clarno Formation are comparable to those of living flora found in humid tropical or subtropical climates (24).

Chalcedony veins and cavity fillings, and Equisetum, which incorporate silica in their structure, are relatively common in the Clarno Formation. Deposition of silica was facilitated by acid groundwater which accompanied the humid subtropical climate. This acidic condition inhibited precipitation of carbonate minerals, except in rocks adjacent to basaltic intrusions.

Abundant angular, unstable rock fragments and minerals, and the poor sorting of fluvial and lacustrine sandstones suggest short transportation and rapid deposition of these clastic particles. Rapid deposition is further indicated by buried upright stems of Equisetum and other flora which grew in lakes and ponds, and by the rarity of soil layers in the sedimentary deposits.

JOHN DAY FORMATION

The John Day Formation was described by Merriam in 1901 (20, p. 496-497) as, "...consisting almost entirely of ashy or tuffaceous materials..., with a minor amount of rhyolite flows." These flows have since been redescribed as welded tuffs (4, 5, 11, 13, 25). The formation is generally divided into a Lower Red Member, a Middle Green Member, and an Upper Buff Member, and is typically composed of tuffs. Within the mapped area, however, this three-fold division is not applicable because the lateral correlatives of the John Day Formation are rhyolite flows and lithic tuffs instead of the three tuff members. The formation includes all rocks stratigraphically above the Clarno Formation and below the Columbia River Basalt.

Stratigraphic Relationships

The lithic tuffs exposed on Horse Heaven Mountain in the SW$\frac{1}{4}$ section 7, and the NW$\frac{1}{4}$ section 18, T. 10 S., R. 19 E., are stratigraphically above rhyolite flows exposed along the Ashwood road in the SW$\frac{1}{4}$ section 5, and in the center of section 6, T. 10 S., R. 19 E. The relationship between the lithic tuffs and other rhyolite flows in the mapped area is not certain because they are not in contact.

The John Day Formation rests with angular unconformity on the Clarno Formation. In the vicinity of the Horse Heaven mine, mudflows and associated tuffaceous sandstones of the Clarno Formation dip 10 to 15 degrees northwest. The overlying John Day rhyolite flows dip gently westward. West of the Mitchell quadrangle (29) in section 36, T. 9 S., R. 18 E., nearly horizontal John Day rhyolite flows overlie gently northwest dipping lavas of the Clarno Formation. The surface of unconformity had considerable relief, possibly as much as 600 feet, as evidenced by thick intra-canyon rhyolite flows, and thinner fluvial sandstones and conglomerates.

A red clay layer is present on ridge crests in sections 7, 8 and 18, T. 10 S., R. 19 E., and immediately west of this area in R. 18 E. This layer was mapped as a separate unit by Waters (31) who considered it to be, "a thick coating of residual soil rich in clay," formed by the erosion of the upturned Clarno Formation. The author agrees with this interpretation. However, the use of the red clay layer as a marker bed is limited because in the mapped area it is present only in the vicinity of Horse Heaven Mountain. Furthermore, caution must be exercised because superficially the red clay layer bears a striking resemblance to the red tuffs intercalated within the Clarno Formation. However, a distinction between the two can be made on strati graphic position and the lighter color and sandy nature of the red clay layer.

Age

No fossils have been found in the John Day Formation within the mapped area. In adjacent areas faunal and floral assemblages collected from pyroclastic deposits suggest an Oligocene and Miocene age.

Chaney (10, p. 97) regards the Bridge Creek flora as lower John Day and probably late Oligocene. Vertebrate remains from the John Day Lower Member in Picture Gorge (11, p. 30) further verify this age. The age of the Middle and Upper Members is in some doubt. Merriam and Sinclair (21, p. 193-195) favor the restriction of the John Day Formation to the Oligocene, with a possible extension of the Upper Member into the early Miocene. An early Miocene age for both the Middle and Upper Members is suggested by Schultz and Falkenbach (23, p. 83-92). The U. S. Geological Survey (33, p. 1048) places the John Day Formation in the "Lower Miocene and Upper and Middle Oligocene."

Rhyolite Flows

General Features

The topographic expression of the flows varies from narrow, steep-faced, outcrops on Stevenson Mountain and in the southwest corner of the mapped area, to low, rounded hills along the Ashwood Road in sections 5 and 6, T. 10 S., R. 19 E. The flows are generally white in color on a fresh surface, but are often stained red-brown on weathered surfaces.

Flow structure varies from indistinct, nearly horizontal bands to well-developed, highly contorted, sharply folded bands which typify the rhyolite flows on Stevenson Mountain. The folded bands are generally 1 inch wide, but the crests of the sharp folds attain a width of 3 inches.

Platy jointing which breaks the rock into thin slabs of various sizes is predominant, but vertical joints with a crude columnar pattern do occur.

The rhyolite flows, 200 to 600 feet thick, are intra-canyon to the Clarno Formation. On Sevenson Mountain in the NE$\frac{1}{4}$ NE$\frac{1}{4}$ section 5, T. 12 S., R. 19 E., the contact between andesites of the Clarno Formation and rhyolite flows is gently concave upward. This is interpreted as a valley which was cut in the andesites and filled by later rhyolite flows. Other exposures are less enlightening, but the general "perched" appearance of rhyolite flows on the Clarno Formation implies an intra-canyon relationship between them.

Attitudes of rhyolite flows vary greatly from exposure to exposure. It is not unusual to find a 40 to 60 degree difference in strike and a 9 to 20 degree range in dip within a few miles.

Petrography

Biotite rhyolite. Biotite rhyolite is the most common rock type in the formation.

Weathered surfaces of biotite rhyolite are brown to red-brown in color, whereas fresh surfaces are white to gray. In some rhyolites round to irregular shaped quartz grains and deeply weathered feldspars are visible, but other rocks are too fine-grained to recognize these minerals. Biotite and hematite are seen in every specimen.

Microscopically the biotite rhyolite shows an eutaxitic texture with irregular and round quartz grains, subhedral sanidine crystals, and subordinate albite-oligoclase, biotite partially replaced by hematite, and sericite. Microlites of quartz and potassium feldspar, and interstitial glass comprise the groundmass.

An X-ray diffration pattern (Figure 14) of rhyolite from Stevenson Mountain shows the presence of the following minerals: quartz (3.35 Angstroms), tridymite (4.30 and 4.08 Angstroms) and feldspars (4.09, 3.80, 3.75 and 3.24 Angstroms) (1).

Porphyritic rhyolite. A pale red-brown porphyritic rhyolite crops out in the central part of section 18 and in the NW$\frac{1}{4}$ section 17, T. 11 S., R. 19 E. Round and euhedral quartz crystals, plagioclase laths, potassium feldspars, and accessory biotite and hematite are visible with a hand lens.

Microscopic examination shows a porphyritic texture with quartz constituting 50 per cent, potassium feldspar 30 per cent, and plagioclase 20 per cent of the phenocrysts. Quartz ranges in diameter from 1 to 3 mm, and the feldspars are 1 to 4 mm long. The groundmass consists of microlites of quartz and feldspars, a minor amount of biotite in various stages of replacement by hematite, spherulites, and interstitial glass. Locally the hematite bears no relation to biotite. Fractures in phenocrysts are commonly stained by hematite, which was probably precipitated from circulating waters.

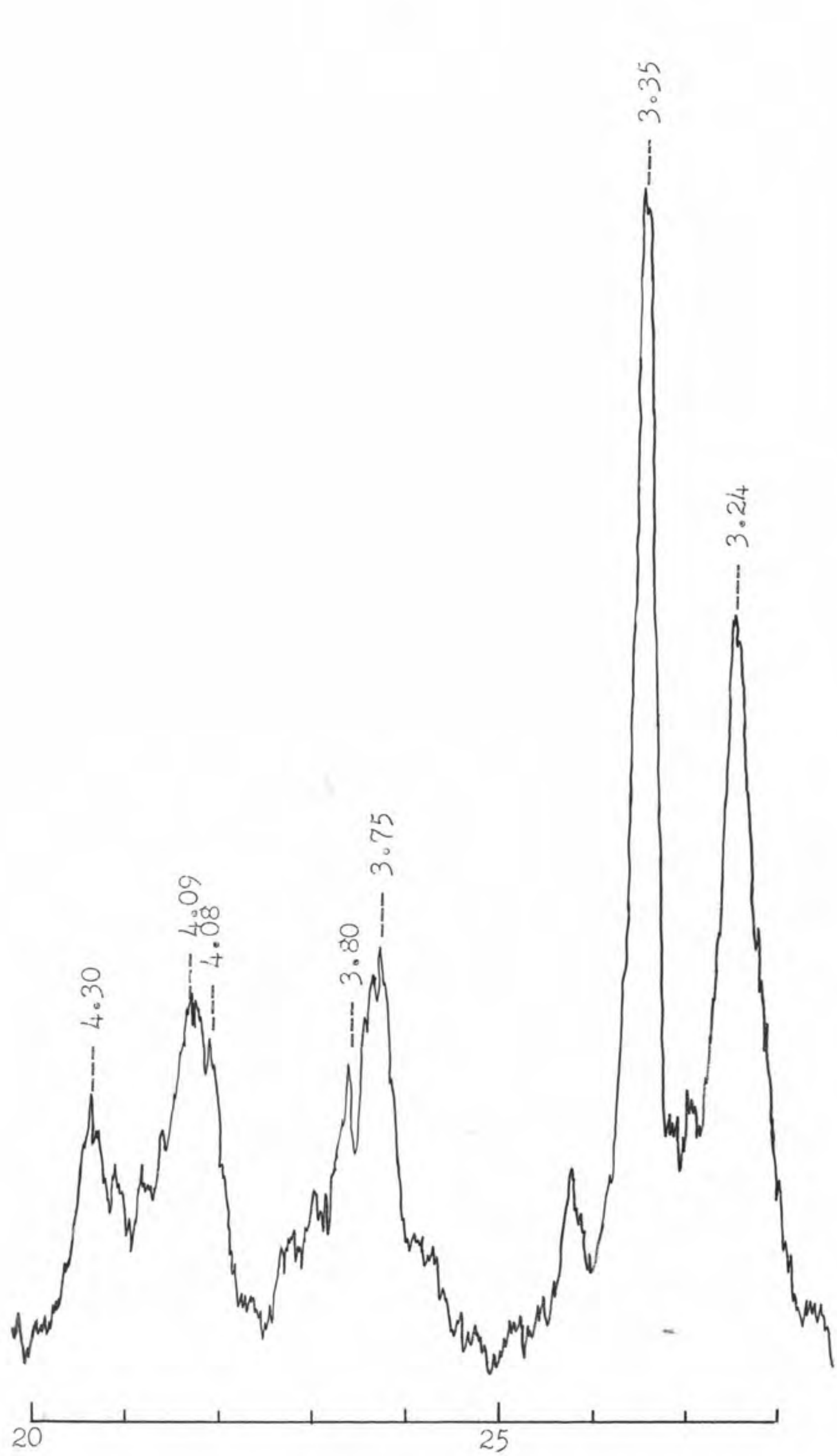

Figure 14. X-RAY DIFFRACTION PATTERN OF RHYOLITE FROM STEVENSON MOUNTAIN.

Quartz occurs as round, ellipsoidal and irregular shaped grains, respectively representing increasing stages of resorption (Figure 15). Subhedral oligoclase-andesine, An_{28} to An_{36}, generally occur in clusters of two or more crystals. Varying degrees of resorption and repair are depicted by several larger grains. Sanidine occurs as subhedral crystals and as narrow rims around plagioclase. Local sericitization of feldspars is confined to areas along cleavage traces and in fractures.

Petrogenesis

The rhyolite flows contain a record of plagioclase-potassium feldspar reactions. The occurrence of small sanidine crystals with larger plagioclase crystals, and rims of sanidine around plagioclase grains are results of early crystallization of plagioclase and its subsequent reaction with the melt to form sanidine. Magmas that are rapidly cooled before the completion of this reaction will produce rocks containing two feldspars.

Rounded, corroded and embayed quartz grains, and some plagioclase grains, are resorption features caused by disruption of the equilibrium between solid and liquid phases. This may result from a change in the chemical composition, a change in depth, or a recovery from undercooling of the magma (14, p. 21). A change in depth and reaction with a magma of changing chemical composition were probably primary causes of resorbed phenocrysts in rhyolite flows.

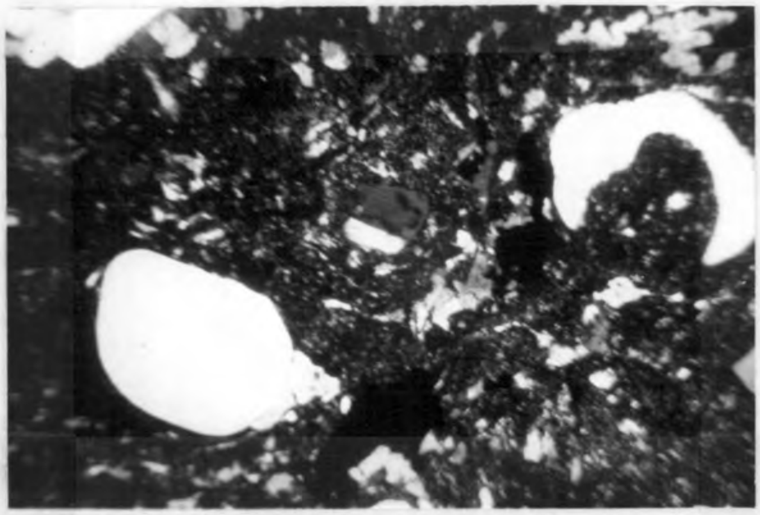

Figure 15. CORRODED AND EMBAYED QUARTZ PHENOCRYSTS IN PORPHYRITIC RHYOLITE. 25X, CROSSED NICOLS.

The resorption of biotite and oxidation of its iron to hematite is a prevalent feature of the rhyolite flows. This process is favored by near surface conditions. Part of this change may have occurred before the magma reached the surface, but a large part occurred after extrusion (17, p. 428). The process is related to the loss of water and other volatiles by the magma. Water may be the oxidizing agent.

Precipitation of sericite in fractures which traverse the porphyritic rhyolite and extend into quartz and plagioclase phenocrysts is a result of hydrothermal activity. The potassium-bearing solutions or gaseous emanations were apparently of small volume because sericite is confined to cleavage traces of feldspars and fractures.

The rhyolite flows exposed along the Ashwood Road in sections 5 and 6, T. 10 S., R. 19 E., are the only flows which may be traced with any certainty to a source vent. This source is Hinkle Butte, located 0.5 miles west of the Mitchell quadrangle (29) in section 1, T. 10 S., R. 18 E.

Lithic Tuffs

General Features

Lithic tuffs are exposed in the SW$\frac{1}{4}$ section 7 and the NW$\frac{1}{4}$ section 18, T. 10 S., R. 19 E. The tuffs form distinctive buff colored spires with a cellular surface caused by disintegration of rock fragments. The deposit is non-stratified and very poorly sorted. There is no apparent lateral or vertical change in size of rock fragments.

A local, thinly-bedded tuff, composed primarily of ash with subordinate pumice fragments, occurs at the base of the lithic tuffs.

Petrography

Weathered surfaces of lithic tuff are buff colored and fresh surfaces are white. The rock consists of 50 per cent groundmass, 40 per cent various rock fragments, and 10 per cent cavities. The rock fragments are phyllite, quartzite, pumice, basalt, and rare sandstone.

A slab of the lithic tuff was stained by the Bailey and Stevens method (3, p. 1020-1025) for distinguishing plagioclase and potassium feldspars. This process showed that the groundmass is rich in potassium feldspars, and that plagioclase is absent.

Under the microscope phyllite, quartzite, pumice, basalt, and sandstone fragments display a sub-parallel arrangement. These fragments are between 3 and 12 mm in length. The groundmass consists predominantly of spherulites, axiolites, broken and devitrified shards, with subordinate euhedral to anhedral quartz grains, and subhedral sanidine crystals.

The minerals of the devitrified shards, spherulites, and axiolites are too small to be determined. But, the staining process suggests that the minerals are potassium feldspar.

Origin

The lithic tuff exposed in the mapped area was derived from a small volcano about 0.5 miles west of the Mitchell quadrangle (29) in section 12, T. 10 S., R. 18 E. (31, p. 121).

The initial eruption of the volcano deposited the thin basal tuffs. This was followed by an extremely violet eruption in which rock fragments were torn from the sub-volcanic basement and the crystals and glass shards were fractured and broken. This mass of rock fragments, crystals and glass shards may have been enveloped in a gaseous cloud which flowed down the slope of the volcano. It did not travel far, only a little over 2 miles, because it either did not possess the energy necessary to cover a great distance, or because it was blocked at its distal end.

This tuff did not become welded. The factors that control welding, as determined by Ross and Smith (21, p. 43), are as follows: (a) the presence of volatiles; (b) pressure within the system; (c) intimate contact of the individual particles; (d) threshold mobility within the system (adequate temperature); (e) inner mobility (yield value viscosity and surface tension); and (f) creeping or flow factor.

The factors listed above are intimately related and if one or several are inoperative during emplacement of an ash-flow tuff, welding will not occur. Such must have been the case in the formation of the tuff in the thesis area.

TERTIARY INTRUSIVE ROCKS

Intrusive rocks of Tertiary age include basalt, andesite, rhyolite and dacite dikes and plugs.

The age of these intrusive bodies is uncertain. The majority were emplaced after accumulation of the Clarno Formation, but before the John Day Formation. But a rhyolite dike in the $S\frac{1}{2}$ section 18, T. 10 S., R. 19 E., intrudes the lithic tuffs of the John Day Formation. Most of the intrusive bodies are tentatively dated as post-Eocene or lower Oligocene.

Basalt Intrusives

General Features

Basalt dikes form linear ridges which stand 10 to 30 feet above the country rocks, range in width from 30 to 70 feet and are about 1000 feet in length. A dike swarm 900 feet wide and 1700 feet long occurs in the $E\frac{1}{2}$, $NE\frac{1}{4}$ section 26, T. 9 S., R. 19 E., (Figure 16). This multiple intrusion may be the source of Clarno basalt flows in this area. Horizontal columnar jointing characterizes basalt dikes (Figures 16 and 17).

Plugs of basalt occur as irregular knobs rising 100 to 300 feet above adjacent rocks and range in diameter from 200 to 800 feet. Platy jointing is predominant but columnar jointing occurs locally. The large basalt intrusion in the $W\frac{1}{2}$ section 4, T. 9 S., R. 19 E., consists of at least four plugs and associated feeder dikes.

Figure 16. BASALT DIKE SWARM IN THE NE$\frac{1}{4}$ SECTION 26, T. 9 S., R. 19 E.

Figure 17. HORIZONTAL COLUMNAR JOINTING IN A BASALT DIKE. NE$\frac{1}{4}$ SECTION 34, T. 9 S., R. 19 E.

Petrography

Outcrop surfaces of basalt dikes and plugs are brown to red-brown in color, and smooth to finely pitted. Fresh surfaces range in color from gray to black. Grains of plagioclase, zeolites, hematite, and occasionally a short, dark green pyroxene are visible with the aid of a hand lens.

Microscopically the basalts are porphyritic with trachytic, hyaloophitic, and felted textures. Phenocrysts of plagioclase, clinopyroxene, some euhedral olivine, and rare hypersthene range in length from 1 to 3 mm. The groundmass consists of labradorite microlites, crystals of clino- and orthopyroxene 0.3 mm to 0.6 mm in length, chlorophaeite and its decomposition products, brown glass with included magnetite, accessory magnetite grains often partially altered to hematite, and apatite. Modes of these basalts are given in Table 6.

Basalts (7) and (8) in Table 6 are lithologically similar to the Picture Gorge basalts of the Columbia River Basalt as described by Waters (30). However, the basalts in the mapped area are not associated with Columbia River basalt flows and cannot be definitely assigned to this formation.

In all the basalts euhedral to subhedral plagioclase phenocrysts range in composition from labradorite An_{60} to labradorite-bytownite An_{70}. Plagioclase is locally replaced by calcite in a dike and by heulandite in a plug. Regularly arranged inclusions of iron-rich glass and clinopyroxenes occur locally

Table 6

MODES OF TERTIARY INTRUSIVE BASALTS

Mineral	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Labradorite	65	59	71	60	36	70	50	48
Clinopyroxene	16	5	6	18	3	3	29	26
Hypersthene	8	12	13	5	T	12	--	--
Glass	9	9	6	12	--	10	2	4
Iron Oxides	1	5	3	5	16	5	6	6
Calcite	--	2	T	--	--	--	--	--
Heulandite	--	--	--	--	45	--	--	--
Leucoxene	--	--	--	--	--	T	--	--
Apatite	T	T	T	T	--	--	T	--
Clay Mineral	--	8	--	--	--	--	--	--
Olivine (incl. saponite)	--	--	--	--	--	--	8	12
Chlorophaeite and decomposition products	--	--	--	--	--	--	5	4

(T: less than 1%)

Explanation:

(1) Pyroxene basalt, NE¼ Section 26, T. 9 S., R. 19 E.

(2) Hypersthene basalt, Same

(3) Same

(4) Pyroxene basalt, NW¼ section 26, T. 9 S., R. 19 E.

(5) "Zeolitized" basalt, NE¼ section 4, T. 9 S., R. 19 E.

(6) Hypersthene basalt, NE¼ NE¼ section 34, T. 9 S., R. 19 E.

(7) Olivine basalt, SW¼ section 2, T. 10 S., R. 19 E.

(8) Same, NE¼ NE¼ section 22, T. 9 S., R. 19 E.

(Figure 18). Where the composition of plagioclase microlites could be determined it ranged from labradorite An_{58} to labradorite An_{66}. Clinopyroxene phenocrysts and small grains occur as colorless prisms with a birefringence of .025, extinction angles of 36 to 45 degrees, and a moderate 2E. A green-brown clay mineral partially replaces clinopyroxene in one of the dikes. A fibrous dark-green mineral, tentatively identified as saponite, is a common pseudomorph after olivine (Figure 19). Hypersthene occurs mainly in the groundmass as subhedral prisms with typical pleochroism and parallel extinction. Chlorophaeite occurs as irregular shaped, green, isotropic particles which grade into a dark brown to black isotropic material. This latter substance is probably an alteration production of chlorophaeite described by Waters (30, p. 595).

Andesite Intrusives

General Features

Andesite dikes form linear outcrops which stand from 5 to 80 feet above the surrounding rocks, range in width from 100 to 500 feet, and are up to 1300 feet in length. Vertical platy jointing is a characteristic feature of these dikes. An andesite dike swarm 2500 feet long and 1700 feet wide, with associated flows, occurs in the E½ section 28, T. 9 S., R. 19 E.

Andesite plugs rise from 300 to 1400 feet above the country rocks and range in width from 1700 to 2500 feet.

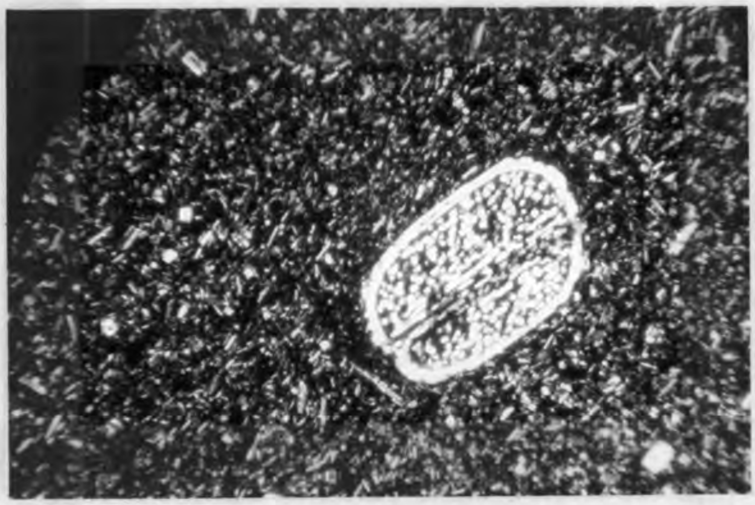

Figure 18. PHOTOMICROGRAPH OF BASALT DIKE SHOWING A CORRODED LABRADORITE GRAIN WITH REGULARLY ARRANGED INCLUSIONS OF IRON-RICH GLASS. 25 X, CROSSED NICOLS.

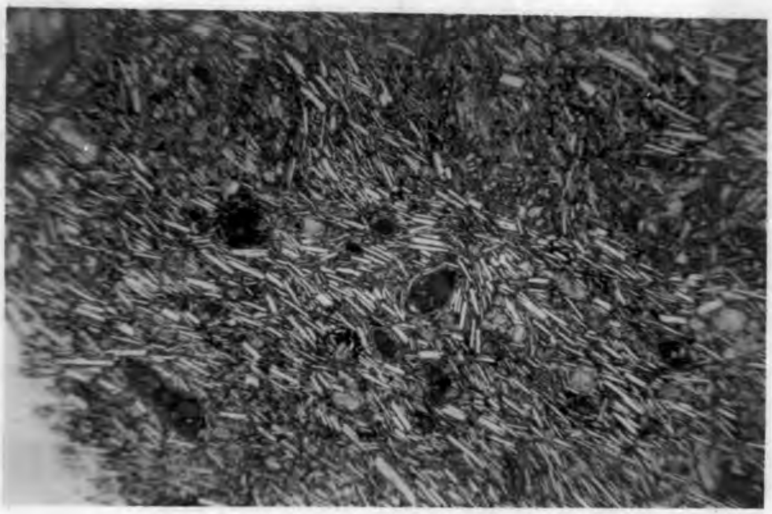

Figure 19. PHOTOMICROGRAPH OF A BASALT DIKE SHOWING SAPONITE PSEUDOMORPHOUS AFTER OLIVINE (CENTER OF PICTURE). NOTE WELL-DEVELOPED TRACHYTIC TEXTURE. 25X, PLAIN LIGHT.

Petrography

Outcrop surfaces of andesite dikes and plugs are colored a dull red-brown, whereas fresh surfaces are gray to greenish-gray in color. Plagioclase laths, a stubby dark green pyroxene, and a green-brown alteration product are generally visible to the unaided eye. Flattened, aligned chalcedony amygdules are a conspicuous feature of a dike in the SW$\frac{1}{4}$ NE$\frac{1}{4}$ section 26, T. 9 S., R. 19 E.

Microscopic examination shows that the andesites are prophyritic with phenocrysts, 2 to 5 mm in length, of andesine, and euhedral to subhedral, colorless prisms of a clinopyroxene. The groundmass consists of aligned andesine microlites, hypersthene grains 0.3 mm to 0.5 mm in length, clear glass, magnetite, a ferruginous clay mineral, and minor amounts of hematite and zircon. Modes of andesite intrusives are given in Table 7.

Phenocrysts of andesine An_{42} to An_{46} have normal zoning and a minor amount of magnetite inclusions. Partial replacement of andesine by calcite and heulandite was noted in one dike rock. Albite twins on plagioclase microlites have the extinction angles of andesine An_{36} to An_{40}. Magnetite occurs as discrete grains in the groundmass, as inclusions, and as a resorption product of hornblende. The ferruginous clay mineral is fibrous, red-brown in color, and has a birefringence of .033. It occurs in fractures and cleavage traces of most clinopyroxene grains, as pseudomorphs after clinopyroxene, in the groundmass as narrow fibers, and as narrow rims around chalcedony amygdules.

Table 7

MODES OF TERTIARY INTRUSIVE ANDESITES

Mineral	(1)	(2)	(3)	(4)
Andesine	64	63	66	66
Clinopyroxene	8	11	4	6
Hypersthene	5	3	--	T
Clay Mineral	10	9	5	8
Hornblende	--	--	19	8
Glass	3	6	2	T
Iron Oxides	9	8	4	11
Apatite	T	T	--	--

(T: less than 1%)

Explanation:

(1) Hypersthene-bearing pyroxene andesite, NW$\frac{1}{4}$ section 36, T. 11 S., R. 19 E.

(2) Same, Section 1, T. 12 S., R. 19 E.

(3) Hornblende pyroxene andesite, NE$\frac{1}{4}$ section 15. T. 9 S., R. 19 E.

(4) Same, center section 18, T. 9 S., R. 19 E.

Rhyolite Intrusives

General Features

Outcrops of rhyolite dikes and plugs are generally steep, craggy and rise up to 15 feet above the country rooks. The dikes range in width from 20 to 100 feet and are 500 to 1700 feet long.

Petrography

Weathered surfaces of rhyolite intrusives are pale brown to pale red in color. Fresh surfaces are usually white, but red-brown colors occur locally. The rocks generally have well-developed sub-parallel flow bands, but massive rhyolite dikes are not uncommon. Quartz grains 1 to 2 mm in diameter, biotite plates 2 mm long, and euhedral sanidine crystals are visible in hand specimen.

A dike occurs in the NE$\frac{1}{4}$ NW$\frac{1}{4}$ section 7, T. 11 S., R. 19 E. The border zone is perlitic, the central zone is porphyritic rhyolite, and the intermediate zone is a rhyolite breccia with irregular shaped areas of porphrytic rhyolite. The zonation is the result of differing rates of cooling and autobrecciation. The intermediate zone was brecciated as it moved slowly past the rapidly cooled border. Before the central zone solidified, portions of it welled into and incorporated fragments of the breccia.

Zoned dikes and plugs of this type are common in the Horse Heaven Mining district (31, p. 124).

Dacite Intrusives

General Features

A dacite plug is exposed in the NE$\frac{1}{4}$ section 31, T. 9 S., R. 19 E. It forms craggy spires which stand 10 to 20 feet above the country rocks, and has a maximum outcrop width of 1200 feet.

Petrography

Weathered surfaces of dacite are colored a pale brown and fresh fractures are white in color. Phenocrysts of quartz, plagioclase, a pale green tabular material, and biotite are visible with a hand lens.

In thin section phenocrysts of andesine 1 to 3 mm in length, plagioclase laths 0.3 mm in length, quartz phenocrysts 2 mm in diameter, and biotite 1 to 2 mm in length rest in a cryptocrystalline groundmass. Magnetite and hematite are accessory minerals. The mode of this rock is given below:

Mineral	Per Cent
Cryptocrystalline groundmass	42
Andesine phenocrysts	40
Quartz phenocrysts	11
Biotite	5
Iron oxides	2

Plagioclase occurs in two generations: as phenocrysts of andesine An_{48}, and as small grains with a subparallel arrangement. Biotite occurs as dark brown, tabular crystals, in part altered to a green-brown, ferruginous clay mineral. Magnetite is present as subhedral grains scattered throughout the rock. Hematite fills fractures in andesine phenocrysts.

QUATERNARY ALLUVIUM

Quaternary alluvium includes landslide, fluvial, and terrace deposits.

Landslide Deposits

Deposits composed of blocks of various rock types are found near the base of many steep slopes. Hummocky surfaces and rarely dry ponds characterize these slides.

The majority of the deposits have an area that is on the order of one-quarter to one-half a square mile. Others, as on the south flank of Stevenson Mountain, in the central parts of sections 3 and 4, T. 12 S., R. 19 E., and on the lower slopes of Horse Heaven Mountain in section 7, and in the NW$\frac{1}{4}$ NE$\frac{1}{4}$ section 18, T. 10 S., R. 19 E., have an areal distribution of at least a square mile.

The larger slide deposits consist of rhyolite blocks, whereas smaller, but more numerous, slide deposits consist of rocks of the Clarno Formation.

Fluvial Deposits

Fluvial deposits occur in all stream valleys. The largest are found along the John Day River, Cherry Creek, and Muddy Creek, and attain a thickness of at least 30 feet. The deposits consist of massive to stratified sediments of various sizes derived from rocks in the drainage systems.

Layers of white ash with small rounded pebbles are locally interbedded with fluvial deposits. This ash is conspicuous throughout the Mitchell quadrangle and adjacent parts of central Oregon. In the mapped area the layers are 2 to 6 feet thick and have limited lateral extent.

The association of ash with Recent alluvium suggests that it was derived from a volcanic eruption during this epoch. It is possible that most of the ash was originally deposited on high, broad areas, and was subsequently washed into stream valleys during accumulation of the alluvium.

Terrace Deposits

Terrace deposits are best exposed in two localities along the John Day River. One of these is at the junction of Cherry Creek and the John Day River in the NE$\frac{1}{4}$ section 25, T. 9 S., R. 19 E. The deposit consists of sand, silt and some pebbles on two broad terraces sloping gently toward the river. The other deposit is in the central part of section 12, T. 9 S., R. 19 E. It consists of rounded pebbles and cobbles derived from the various rock units which the river and its tributaries drain.

STRUCTURAL GEOLOGY

Structural features exposed in the mapped area include a homocline in pre-Tertiary rocks, and an anticline, two synclines and faults in Tertiary rocks.

A homoclinal structure has been formed in the Muddy Ranch Phyllite of questionable Permian age. The rocks strike N. 70° E., and have an average dip of 45 degrees southeast. A similar trend is reported north of the mapped area by Taylor (28, p. 13).

Tertiary deformation has produced an anticline and two flanking synclines in the Clarno Formation within the mapped area (Map, Plate 2). The John Day rhyolite flows and lithic tuffs were not affected by this orogeny. Therefore, this brackets the deformation between early and late Oligocene.

The trace of the surface axis of the nearly symmetrical anticline trends N. 60° E., approximately through the center of the mapped area. Rocks of the Clarno Formation range in dip from 10 to 35 degrees northwest on the northwest limb of the anticline, and from 12 to 23 degrees southeast on the southeast limb. Higher dips occur adjacent to intrusive bodies, or are a result of slumping.

The trace of the surface axis of the syncline in the southern part of the thesis area trends N. 50° E. This fold is a southwest continuation of the Sutton Mountain syncline previously described in the eastern part of the Mitchell quadrangle (4, 5, 27). This northeasterly plunging syncline is continuous for more than 30 miles in the Mitchell quadrangle (29).

The small syncline in the northern part of the area plunges northeast and is asymmetrical. The trace of the surface axis strikes N. 40° E. The Clarno Formation on the northwest limb dips 26 to 33 degrees southeast off the southeast limb of an anticline mapped by Taylor (28, p. 174). Lava flows of the Clarno Formation dip 8 to 13 degrees northwest on the southeast limb of this fold. The nose of the syncline is delineated by dip slopes of Clarno lava flows.

Post-early Miocene, pre-middle Miocene, and post-middle Miocene, pre-early Pliocene folding is reflected in the Tertiary formations exposed east of the mapped area (32, p. 10). This deformation cannot be detected in the area investigated because no formations younger than the John Day Formation are present.

Five faults are shown on the geologic map, Plate 2. Four of these are nearly vertical strike faults in which the fault traces trend N. 60° E., and the fourth is a cross fault trending N. 30° W. Vertical displacements range from 50 to 200 feet. A strike fault has brought the Lower and Upper Members of the Clarno Formation into fault contact in the SE$\frac{1}{4}$ section 2, and S$\frac{1}{2}$ section 17, T. 10 S., R. 19 E.

The faults can be dated only as post-early Oligocene.

GEOMORPHOLOGY

The following discussion concerns prominent geomorphic features in the thesis area.

Terraces

Two wide, gently sloping terraces occur at the junction of Cherry Creek and the John Day River in the NE$\frac{1}{4}$ section 25, T. 9 S., R. 19 E. (Figure 20). They are developed on the Clarno tuff breccia member and slope gently toward the river and downstream. The lower terrace has a mean elevation of 1450 feet above sea level and the upper terrace is 50 to 75 feet above this at 1500 to 1525 feet above sea level. The upper terrace is present only at the junction of Cherry Creek and the John Day River and the lower terrace is continuous for about three miles upstream from the junction. Two terraces also are present in section 12, T. 9 S., R. 19 E. The lowest is between 1400 and 1500 feet above sea level, and probably corresponds to the lower terrace mentioned above. The second terrace is mostly eroded, but remnants occur between 1500 and 1600 feet above sea level.

Cuestas

Cuestas occur wherever a dipping lava flow, either intercalated with the Lower Member of the Clarno Formation, or in a series of other flows, caps a ridge. Obvious cuestas developed in the Lower Member are present in the NW$\frac{1}{2}$ section 27, and SW$\frac{1}{4}$ section 26,

Figure 20. TERRACES AT THE JUNCTION OF CHERRY CREEK AND THE JOHN DAY RIVER. NE$\frac{1}{4}$ SECTION 25, T. 9 S., R. 19 E.

T. 10 S., R. 19 E. Cuestas are common in the Clarno lavas. Well-defined exposures occur in sections 8 and 9, T. 9 S., R. 19 E., outlining the southern limb of a syncline.

Volcano

A dissected Clarno volcano occurs in section 26, T. 10 S., R. 19 E. It has a symmetrical profile, a maximum elevation of 4400 feet above sea level, and maximum relief of 1800 feet. A radial drainage pattern developed on the volcano defines it on the map (Plate 2). Lava flows, flow breccia and some tuffs were extruded from this volcano. They have an estimated thickness of 1500 to 1800 feet.

Landslides

Landslides and related phenomena are very common in the region. Slumping is characteristic of the Clarno Formation. In the NW$\frac{1}{4}$ section 26, T. 9 S., and in the northcentral portion of section 5, T. 9 S., R. 19 E., huge blocks of lava have moved 200 to 300 feet downslope on the tuff breccia. Minor slumps within the tuff beds are quite common and may be detected by offsets of the thinly bedded shale. Small landslides within Clarno lavas occur along many steep valley walls. These slides are facilitated by the presence of thin tuff beds intercalated with the lava flows.

Landslides in rhyolite flows may often lead to an erroneous structural interpretation. Such is the case on Stevenson Mountain, where the Clarno lavas dip gently southeast and the rhyolite flows dip ten to twenty degrees slightly west of north. This relation produces an apparent angular unconformity. However, these flows are large slump blocks, the inclination of which varies from nearly horizontal to twenty degrees. The slumping is facilitated by the presence of tuff and possibly perlitic glass along almost the entire length of the basal contact. As these blocks slumped and slid downhill on this natural lubricant, they rotated through a horizontal axis to produce the anomalous northward dip.

John Day River

Even though the John Day River flows through only a small part of the thesis area it is discussed here because it is the dominant perennial stream of the region.

Incised meanders are a conspicuous feature of the John Day River Valley. The meander pattern is best developed in Columbia River basalts north and east of the map area. However, some meanders exist in Clarno rocks in section 12, T. 9 S., R. 19 E., within the thesis area, (Map, Plate 2) and also in the Clarno Basin (28, p. 147).

The John Day River is probably a superposed stream which was "let down" on various buried folds of the region. The surface upon which the ancestral John Day River flowed is uncertain.

It was either the surface of the Columbia River Basalt (28, p. 148) or a late Pliocene surface (12, p. 70). Erosion was hastened wherever the river encountered the less-resistant John Day Formation or the Clarno tuffs and mudflows. In this way large portions of the Columbia River basalts were undermined causing them to collapse. The larger pieces were then broken into "brickbats" (12, p. 66) which were easily rolled along stream beds.

Cherry Creek

Cherry Creek is a perennial stream, but is quite low during late summer. It is a complex stream which is partly subsequent and partly consequent. The consequent part occurs in Clarno lavas and forms narrow, steep walled valleys. The subsequent part of the stream flows in less resistant rocks of the Clarno tuff breccia member and produces a wide, alluviated valley.

The easily eroded Lower Member of the Clarno Formation was probably the controlling factor in determining the location of the stream. When rocks of this member were uncovered, the overlying lava flows were undercut causing large blocks to fall off the main mass. These were subsequently broken into smaller, more easily transported fragments.

Muddy Creek

Muddy Creek is an intermittent stream, flowing only eight or nine months of the year. A temporary base level is recorded in sections 20 and 30, T. 9 S., R. 19 E., by a thinly bedded alluvial deposit fifteen to twenty feet thick, and 1000 to 3000 feet wide. The feature that caused the temporary halt in downcutting is not definitely known. It may have been the small basaltic dike in section 5, T. 9 S., R. 19 E., some structure farther down stream, or it may be a reflection of previous levels of the John Day River.

HISTORICAL GEOLOGY

The earliest event recorded by the rocks in the mapped area is a Permian (?) sea in which muds and subordinate sands were deposited. Following lithification these sediments were deformed and metamorphosed forming the Muddy Ranch Phyllite.

A record of the time between formation of the Muddy Ranch Phyllite and the Tertiary is lacking in the area investigated. However, Cretaceous marine sedimentary rocks crop out in the vicinity of Mitchell and were discovered in the subsurface of the Clarno Basin. These rocks were deformed and eroded prior to the beginning of the Tertiary.

The Clarno Formation marks the debut of volcanism in central Oregon. A humid subtropical climate existed during this time which encouraged the growth of a thick plant cover and animals characteristic of this climate.

The first phase of Clarno volcanism produced the varied Lower Member. Pyroclastic material, mudflows, fluvial sediments and local flows of basalt and andesite succeeded each other intermittently in time and space producing a complex stratigraphy.

Volcanic ash erupted during Clarno "time" accumulated rapidly in valleys and lakes burying the various plants growing in these habitats. Rapid deposition of ash on high slopes, and accompanying heavy precipitation, overcame the ability of the prolific vegetation to prevent large-scale mass movement of surface material. These tuffaceous mudflows, with included fragments of lavas, flowed down slopes and stream channels burying lowlands and filling small valleys.

High relief as well as the climate gave rise to an extensive drainage system. Volcanic rocks and several areas of metamorphic rocks were rapidly eroded. The resulting clastic particles were deposited rapidly, forming the compositionally, and in some cases, texturally immature fluvial sedimentary rocks.

Basalt and andesite flows of the Upper Member of the Clarno Formation were extruded over the Lower Member with very little or no time lapse. Extrusion of this great volume of lava flows was attended by a reduction in pyroclastic activity.

Middle Oligocene diastrophism succeeded the volcanic activity. In the mapped area the Clarno Formation was folded into a broad anticline and two synclines with northeasterly trends. Small-scale strike faulting and intrusions of dikes and plugs accompanied the folding.

The faulted and upturned Clarno Formation was eroded producing a moderately dissected topography. A soil layer formed on the erosion surface and is preserved locally as a "red clay layer" on the Lower Member of the Clarno Formation.

During some uncertain part of the late Oligocene and early Miocene, flows of rhyolite were extruded over the Clarno erosion surface filling canyons carved in lava flows of the Upper Member of the Clarno Formation. A nuees ardente-type eruption also occurred during this eruptive period, forming the lithic tuff.

No rocks younger than the John Day Formation are present in the mapped area. However, east of the area middle and late Miocene and in some places Pliocene rocks are exposed. These formations show evidence of mild late Tertiary folding.

The modern topography and present stream courses were initiated following this late Tertiary deformation. Streams flowed northward over either the Columbia River Basalt surface or a late Pliocene surface. The John Day River became entrenched in resistant lava flows of the Columbia River Basalt, but widened its course in less-resistant tuffs of the John Day and Clarno Formations.

During the Pleistocene, temporary base levels of the John Day River produced terraces along the river and along the lower part of Cherry Creek.

Recent volcanism is recorded by layers of white ash interbedded with alluvium. The source of the ash is unknown.

At the present time, erosion is the dominant process. Fluvial deposits are generally thickest upstream from narrow constrictions in the valleys. The streams have cut through this material to flow in their present courses.

ECONOMIC GEOLOGY

Cinnabar

Deposits of cinnabar, from the Horse Heaven Mining district, are the most important geologically economic products. Most of the district is located west of the Mitchell quadrangle in ranges 17 and 18 east, but three of the six mines and prospects are within the mapped area. These are: part of the Horse Heaven mine in section 7, T. 10 S., R. 19 E.; (2) the Horse Creek prospect in the west half of section 9, T. 11 S., R. 19 E.; and (3) the Cherry Creek prospect in the S½ section 16, and the N½ section 21, T. 10 S., R. 19 E.

The mineral deposits are closely related to rhyolite or andesite plugs (31). In the Horse Heaven mine and in the Horse Creek prospect the ore occurs as steeply dipping shoots in autobrecciated zones of a rhyolite plug, and in minor faults cutting the wall rocks. The Cherry Creek prospect is small, and the limited development that was accomplished is in andesite plugs intruding the Clarno Formation.

Production of cinnabar began in September 1934, and continued until the end of 1944. The total quicksilver production for this period was 15,241 flasks, 15,097 of which were from the Horse Heaven mine. The remaining 144 flasks were produced by the Axe Handle mine located in section 35, T. 9 S., R. 17 E.

According to Waters (31) the Horse Heaven and Axe Handle mines still contain abundant cinnabar which may be mined at a profit, if the development is carefully planned and if the geological principles governing ore localization are understood.

Semi-Precious Stones

The many varieties of opal and chalcedony are a small, but relatively important aspect of the economic geology in the mapped area and vicinity. There are about a dozen public and private "agate and thunder egg" claims scattered throughout the Bear Creek area. The most numerous, and the best claims are associated with rhyolite flows and small rhyolite intrusions.

BIBLIOGRAPHY

1. American Society for Testing Materials. Index to the X-ray powder data file. Philadelphia, 1961. 338 p. (ASTM Special Technical Publication 48-K).

2. Anderson, Charles A. The Tuscan Formation of northern California, with a discussion concerning the origin of volcanic breccias. University of California Publications in Geological Sciences 23:215-275. 1936.

3. Bailey, E. H. and R. E. Stevens. Selective staining of K-feldspar and plagioclase on rock slabs and thin sections. The American Mineralogist 45:1020-1025. 1960.

4. Bedford, John W. Geology of the Horse Mountain area. Master's thesis. Corvallis, Oregon State College. 1954. 90 numb. leaves.

5. Bowers, Howard E. Geology of the Tony Butte area and vicinity, Mitchell quadrangle, Oregon. Master's thesis. Corvallis, Oregon State College, 1952. 152 numb. leaves.

6. Calkins, Frank C. A contribution to the petrography of the John Day Basin. University of California Publications in Geological Sciences 3:109-172. 1902.

7. Chaney, Ralph W. The ancient forests of Oregon. Eugene, 1956. 56 p. (Oregon State System of Higher Education, Condon Lecture Publications No. 3).

8. ______________ Age of the Clarno Formation. Pan American Geologist 64:71. 1935.

9. ______________ Ancient forests of Oregon: a study of earth history in western America. Washington, D. C. 1938. p. 631-648. (Carnegie Institution of Washington Publications 501).

10. ______________ Geology and paleontology of the Crooked River Basin, with special reference to the Bridge Creek flora, Remington Kelloggs, Additions to the Paleontology of the Pacific Coast and Great Basin region of North America. Washington, D. C., 1927. p. 45-138. (Carnegie Institution of Washington Publications 346).

11. Coleman, Robert G. The John Day Formation in the Picture Gorge quadrangle, Oregon. Master's thesis. Corvallis, Oregon State College, 1949. 211 numb. leaves.

12. Hodge, Edwin T. Geology of north central Oregon. Oregon State College Studies in Geology 3:1-72. 1927.

13. Irish, Robert J. The geology of the Juniper Butte area, Spray quadrangle, Oregon. Master's thesis. Corvallis, Oregon State College, 1955. 73 numb leaves.

14. Johannsen, Albert A. A descriptive petrography of the igneous rocks. 2d ed. Vol. 1. Chicago, University of Chicago Press, 1939. 318 p.

15. Keller, W. D. and Romaine F. Littlefield. Inclusions in quartz of igneous and metamorphic rocks. Journal of Sedimentary Petrology 20:74-84. 1950.

16 Knowlton, Frank Hall. Fossil flora of the John Day Basin, Oregon. 1902. 153 p. (U. S. Geological Survey. Bulletin 204).

17. Larsen, Esper S., et al. Petrologic results of a study of the minerals from Tertiary volcanic rocks of the San Juan region, Colorado. The American Mineralogist 23: 417-429. 1938.

18. McIntyre, Loren B. Geology of the Marshall Butte area and vicinity, Mitchell quadrangle, Oregon. Master's thesis. Corvallis, Oregon State College, 1954. 90 numb. leaves.

19. Merriam, John C. A contribution to the geology of the John Day Basin. University of Calfironia Publications in Geological Sciences 2:270-314. 1901.

20. ______________ A geologic section through the John Day Basin. Geological Society of America Bulletin 12:496-497. 1901.

21. Merriam, John C., and William J. Sinclair. Tertiary faunas of the John Day region. University of California Publications in Geological Sciences 5:171-205. 1907.

22. Ross, Clarence S. and Robert L. Smith. Ash-flow tuffs: their origin, geologic relations, and identification. 1961. 81 p. (U. S. Geological Survey. Professional Paper 366).

23. Schultz, C. B. and C. H. Falkenbach. Promenycochoerinae, a new subfamily of Oreodonts. Bulletin of the American Museum of Natural History 93:69-198. 1949.

24. Scott, R. A. Fossil fruits and seeds from the Eocene Clarno Formation of Oregon. Paleontographica 96B:66-67. 1954.

25. Snook, James R. Geology of the Bald Mountain area and vicinity, Richmond quadrangle, Oregon. Master's thesis. Corvallis, Oregon State College, 1957. 70 numb. leaves.

26. Stirton, R. A. A rhinoceros tooth from the Clarno Eocene of Oregon. Journal of Paleontology 18:265-267. 1944.

27. Swarbrick, James C. Geology of the Sheep Mountain area and vicinity, Mitchell quadrangle, Oregon. Master's thesis. Corvallis, Oregon State College, 1952. 100 numb leaves.

28. Taylor, Edward M. Geology of the Clarno Basin, Mitchell quadrangle, Oregon. Master's thesis. Corvallis, Oregon State College, 1960. 174 numb leaves.

29. U. S. Geological Survey, Mitchell quadrangle, Oregon. 1926. 1 sheet.

30. Waters, A. C. Stratigraphic and lithologic variations in the Columbia River Basalt. American Journal of Science 259:583-611. 1961.

31. Waters, A. C. et al. Quicksilver deposits of the Horse Heaven mining district, Oregon. 1949-1950. p. 105-149. (U. S. Geological Survey Bulletin 969E).

32. Wilkinson, W. D. Field guidebook to geologic trips along Oregon highways. Salem, 1959. 148 p. (Oregon Department of Geology and Mineral Industries. Bulletin 50).

33. Wilmarth, Grace M. Lexicon of geologic names of the United States. Part 1. 1938. 1244 p. (U. S. Geological Survey. Bulletin 896).