AN ABSTRACT OF THE THESIS OF

David J. Thormahlen for the degree of Master of Science in Geology presented on April 25, 1984.

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Abstract approved:

Edward M. Taylor

The northwest one-quarter of the Prineville Quadrangle is underlain by Tertiary and Quaternary volcanic and volcaniclastic rocks of the Columbia River Basalt Group, and the Clarno, John Day, Rattlesnake and Deschutes Formations.

The Clarno Formation is dominated by pyroxene-bearing andesites, but also contains olivine-bearing basalts, oxyhornblende-bearing dacite and rhyodacite flows and intrusives. Many of these rocks are deeply weathered and some have been strongly silicified.

The John Day Formation in the area consists of large rhyolite domes and flows, thick tuffaceous deposits, minor trachyandesite flows and welded ash-flow tuffs. The stratigraphy of these John Day rocks is similar to the section exposed in the Ashwood area but lacks some of the upper ash-flow tuff units. Fossil bearing tuffs

found within the area are similar to tuffs in the John Day and Crooked River basins and contain fossil leaves that are similar to the Bridge Creek flora.

A single flow of the Columbia River Basalt Group is found in the southwest part of the thesis area. This flow has normal magnetic polarity and is similar to the Prineville Chemical type basalt. The entablature of this flow is glassy and very thick. It resembles exposures found at Butte Creek and along the Deschutes River at Pelton Dam and near Gateway.

Exposures of the Rattlesnake Ignimbrite Tongue in the northwest part of the thesis area are the western most recognized outcrops of the ignimbrite. Two other exposures of the Rattlesnake ignimbrite were found to the south in Swartz Canyon and near Little Bear Creek. These exposures indicate a previously unrecognized channel for the ignimbrite, trending northwest from its source, entering the Crooked River drainage, and traveling at least as far northwest as Grizzly.

The Deschutes Formation is represented by a diktytaxitic basalt flow, epiclastic tuffaceous sediments and air-fall pumice. These deposits lie along the eastern margin of the Deschutes Basin.

Structural upwarping along the Blue Mountains Anticline has caused local tilting and folding of the rocks in the area. Most of the Clarno and John Day rocks dip gently to the south. The Deschutes Formation appears to be undeformed.

Hydrothermal activity led to the formation of several mineralized breccias which contain abundant silica, lesser amounts of goethite and manganite, and traces of silver and mercury.

Geology of the Northwest One-Quarter
of the Prineville Quadrangle, Central Oregon

by

David J. Thormahlen

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# GEOLOGY OF THE NORTHWEST ONE-QUARTER
# OF THE PRINEVILLE QUADRANGLE, CENTRAL OREGON

## INTRODUCTION

### Purpose

The primary objective of this investigation was to construct a geologic map of the northwest quarter of the Prineville, Oregon fifteen-minute quadrangle. Other objectives were: 1) to stratigraphically subdivide the Clarno and John Day Formations within the area, 2) to compare isolated exposures of the Columbia River Basalt Group with basalts of the Grande Ronde and Picture Gorge Formations and with the Prineville Chemical type, 3) to decipher the volcanic history of the area and 4) to look for structures within the area which may control geothermal fluids at Powell Buttes, to the south.

### Location

The thesis area is located in northwest Crook County and southeast Jefferson County, central Oregon, about 6 miles northwest of Prineville (see Fig. 1). The area is easily reached via U.S. Highway 26, which passes through the southwest corner of the area. Grizzly Road, a county road, provides the best access to the interior of the area. Other private unimproved roads are only passable on foot or motorcycle. Most of the land within the area is privately owned.

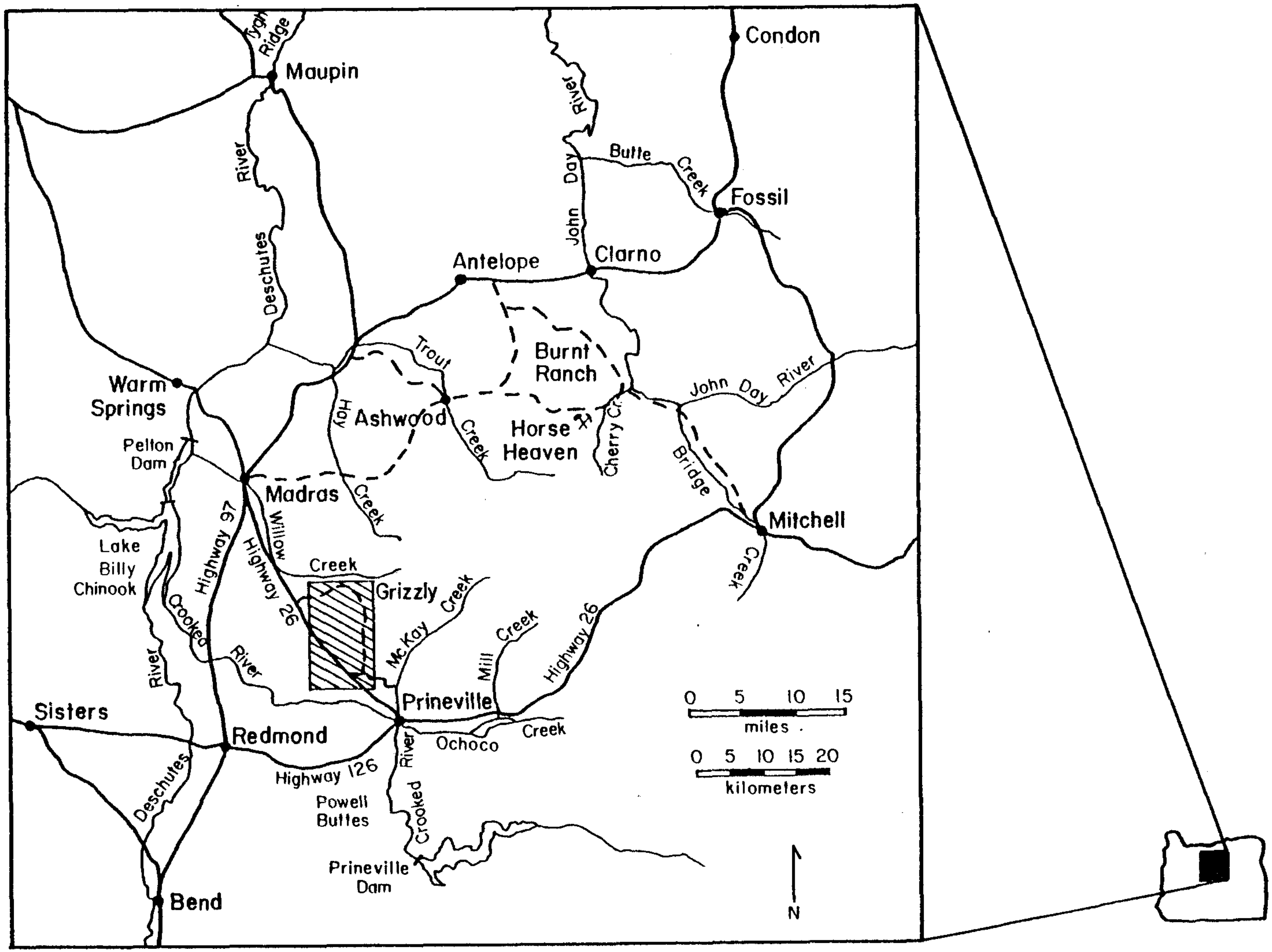


Fig. 1 Location of study area in central Oregon.

## Physiography and Climate

The thesis area lies along the western edge of the Ochoco Mountains and is dominated by Grizzly Mountai . the highest peak in the quadrangle at 5,635 feet. Total relief within the area is 2,715 feet.

The area is dissected by Lytle and Newbill creeks and many other unnamed seasonal streams. The southern part of the quadrangle contains part of the Crooked River Valley.

Because the area lies east of the Cascade Mountains the climate is semi-arid as is much of central and eastern Oregon. Vegetation consists mainly of range grasses, sage and juniper. A few sections are heavily forested with yellow pine and douglas fir. The northern and southern margins of the quadrangle contain fairly flat land cultivated with wheat, alfalfa and mint.

Exposures of bedrock geology are generally good because of the sparse vegetation throughout much of the area. Exposures are poor within the Crooked River Valley and the slopes surrounding Grizzly Mountain due to deposits of talus and alluvium. Thick forest in the northeast corner of the quadrangle restricts exposures.

## Methods of Investigation

The area was mapped during the summer of 1981, using a 1:24,000 advance-print topographic map published by the U.S. Geological Survey. Aerial photographs flown in September, 1953, at an approximate scale of 1:62,500, as well as high altitude U-2 and landsat imagery assisted the delineation of structural trends.

Bedding and jointing attitudes were measured with a Bruton compass. Bedding attitudes were also derived from the map using the three-point method. Approximately 200 samples were collected, eighty of these were made into thin sections and examined petrographically. Plagioclase compositions were determined by the a-normal, Carlsbad-albite and Michel-Levy methods. Nine samples of rhyolite were analyzed, using x-ray diffraction, to determine alkali feldspar compositions. Eleven samples were analyzed for major oxide compositions at the Washington State University x-ray fluorescence lab. All analyses are $H_2O$-free. Four breccia samples were analyzed for gold, silver and mercury contents by Chemical and Mineralogical Services of Salt Lake City, Utah. Magnetic polarities of rocks were determined by using a portable flux gate magnetometer. Colors of specimens were named according to the rock color chart published by the Geological Society of America.

## Regional Geology

The study area is underlain by Tertiary and Quaternary volcanic and volcaniclastic rocks of the Clarno and John Day Formations, the Columbia River Basalt Group and the Rattlesnake and Deschutes Formations (see Plate 1). The study area lies along the western edge of the Blue Mountains Province, where it meets the High Lava Plains Province. Eocene and Oligocene rocks of the Clarno and John Day Formations are exposed as a result of structural upwarping along the Blue Mountains Anticline, a broad uplift that follows a northeast-southwest trend from north of the thesis area to the Wallowa Mountains in northeast Oregon.

The Tertiary rocks are probably underlain by Mesozoic sediments and metasediments which are exposed along the Blue Mountains uplift to the north and east of the thesis area (Oles and Enlows, 1971; Robinson, 1975). Paleozoic metamorphic rocks are also found in the Blue Mountains east of the thesis area (Merriam and Berthiaure, 1943).

The Clarno Formation consists of lava flows, dikes, volcanic breccias, mudflows and tuffs which are largely of calc-alkaline afinity (Noblett, 1981). Andesite is the most abundant rock type within the Clarno Formation but lavas ranging in composition from basalt to rhyolite have been described.

Clarno rocks are found along the Blue Mountains Anticline as far north and east as East Birch Creek, 20 miles south of Pendleton. The southeastern extremity of Clarno exposures is at Ironside Mountain, along the headwaters of Little Malheur River. The Clarno Formation has been described as far west as the Mutton Mountains on the Warm Springs Indian Reservation and as far south as the Crooked River near Post and within 5 miles of Brothers. The Clarno rocks represent a vast calc-alkaline volcanic field that probably covered much of northern Oregon during late Eocene and early Oligocene time. The Clarno Formation marks the end of marine deposition in north-central Oregon and geochemical data suggest that these terrestrial volcanics may be related to subduction tectonics (Rogers and Ragland, 1980).

The John Day Formation unconformably overlies the Clarno Formation in north-central Oregon. The base is marked by a distinctive ash-flow sheet that often lies above a thick saprolite layer at the top of the Clarno Formation. The John Day Formation was originally named for exposures along the John Day River (Merriam, 1901a, and 1901b) where it consists of a thick sequence of varicolored tuffaceous claystones. As these beds are traced to the west they become interbedded with increasing volumes of coarse pumice-lapilli tuffs, lava flows and ash-flow sheets (Peck, 1964).

Robinson and Brem (1981) divided the John Day Formation into 3 facies: the eastern facies or type section, the western facies described by Peck (1964) and the southern facies which is similar to the eastern facies. The eastern and southern facies are dominantly composed of air-fall, wind-blown and water-laid tuffs probably from vents near the present Cascade Range. The John Day Formation is nearly as extensive as the Clarno, but seems to have been confined to depositional basins on the Clarno surface. The western facies contains locally derived rhyolites, trachyandesites and high-titania alkali-olivine basalts as well as ash-flow sheets which probably also orginated from local vents. The western facies also contains abundant air-fall and water-laid tuffs.

/ The Columbia River Basalt Group is a well known accumulation of thick, extensive tholeiitic basalt flows that cover much of southeastern Washington, western Idaho and northern Oregon. The Columbia River basalt flows were extruded over a time period from 16 to 6 m.y. (Swanson et al., 1979). These flows originated from large north to northwest-trending dike swarms (Waters, 1961; Taubeneck, 1970; Swanson et al., 1975).

The Columbia River Basalt Group is divided into 5 formations, in order of decreasing age: the Imnaha, Picture Gorge, Grande Ronde, Wanapum and Saddle Mountains basalts. The Imnaha is thought to be the oldest and is found at the base of the section in northeast Oregon. The Picture Gorge Basalt is almost completely confined to the area south of the Blue Mountains uplift and is coeval with part of the Grande Ronde Basalt. The Grande Ronde, Wanapum and Saddle Mountains basalts make up the Yakima Basalt Subgroup which is the most extensive part of the Columbia River Basalt Group that forms the classic exposures of the Columbia Plateau.

The Rattlesnake Ignimbrite Tongue was first described as pumiceous tuff and rhyolite interbedded with fanglomerates in the John Day Valley. This unit was later recognized throughout much of central Oregon. Wilkinson (1950) recognized that this rhyolite and tuff are actually an ignimbrite with a general source area in the Harney Basin (Enlows, 1976). The Rattlesnake ignimbrite has been traced from the Harney basin into the John Day and Crooked River basins and has been found as far northwest as Sutton Mountain (Enlows, H.E., unpublished mapping). The exposures described in this study mark the western edge of recognized Rattlesnake ignimbrite distribution.

The Deschutes Formation is an accumulation of volcanic debris and some lava flows derived from the ancestral Cascades during late Miocene and Pliocene time. The formation consists of lava flows, air-fall and ash-flow tuffs, mudflows and epiclastic sediments that were deposited in a non-marine back-arc basin environment. Most of this material is exposed in river canyons within the Deschutes Basin on the east side of the Cascades. Thin deposits of this material are found as far east as the western slopes of the Ochoco Mountains.

Young volcanic rocks, including the extensive high-alumina "rimrock" basalts of the High Lava Plains and recent deposits of air-fall ash and pumice are found in the area. These air-fall deposits were probably derived from Cascade volcanoes and represent the most recent volcanic activity in the region.

Folding along the northeast-southwest-trending Blue Mountains Anticline, and related trends has affected the Columbia River Basalt Group and older formations within the area. Minor east-west-trending, high-angle faults within the area are probably related to block faulting which offsets Plio-Pleistocene basalts in the Maury Mountains to the southeast. This faulting is not typical of northwest-southeast-trending Basin and Range fault patterns which die out at the Brothers right-lateral fault zone, south of the Ochoco and Maury Mountains.

## Previous Work

Marsh (1875) and Merriam (1901a, and 1901b) provided the first descriptions of the Clarno and John Day Formations shortly after the discovery and investigation of rich fossil localities in the John Day Basin.

Russell (1905) was the first to describe the geology of the Prineville area, focusing his attention on the basalt plateaus and underlying tuffs. Included in this early report is an evaluation of the hydrologic potential of the Prineville area. Russell (1905) was also the first to comment on the thick section of volcaniclastics exposed in the canyons of the Deschutes Basin. He named these "The Deschutes Sand" and suggested that similar deposits along the western slopes of the Ochoco Mountains and underlying Prineville were equivalent to those found in the canyon walls of the Deschutes and Crooked rivers.

Early papers by Knowlton (1902) and Chaney (1927, 1932) described the wealth of plant fossils found in the Clarno and John Day Formations. These papers were mainly concerned with localities in the John Day Basin, but Chaney (1927) also studied fossiliferous tuffs in the Crooked River Basin, southeast of Prineville.

Hodge (1932) recognized that the John Day Formation extended west of the type locality into the Deschutes Basin, where similar fossiliferous tuffs were found in the canyon walls along the Deschutes River.

Wilkinson (1932) studied under Hodge and mapped the Mutton Mountains on the Warm Springs Indian Reservation. He described a section of "Clarno" rocks which seem, in part, to be very similar to the western facies of the John Day Formation. Wilkinson listed locations of equivalent strata throughout central Oregon and mentioned "Grizzly Butte" as a location for several of the rhyolitic units described in his dissertation.

Hodge (1942) presented a panoramic sketch of the area north of Grizzly Mountain indicating that Grizzly Mountain was formed by tilted resistant strata.

Robinson and Price (1963) reported on the geology and water resources of the Prineville area. This paper was mainly concerned with the hydrogeology of the area and failed to recognize the presence of the John Day Formation. The geology on their map is greatly simplified, showing all tilted strata below the Columbia River Basalt Group as Clarno Formation.

Peck (1964) outlined the stratigraphy of the western facies of the John Day Formation, and demonstrated that many of the silicic lavas assigned to the Clarno Formation were actually correlative with the lower part of the John Day Formation.

Reconnaissance maps by Swanson (1969a) and Walker (1977) show the general geology of the thesis area but fail to recognize the subdivisions of the John Day Formation.

Robinson (1975) mapped the western facies of the John Day Formation in detail. The southern edge of his map coincides with the northern border of this study.

Robinson and Stensland (1980) mapped the Smith Rocks fifteen-minute Quadrangle which is west of the Prineville Quadrangle.

Weidenheim (1981) studied Powell Buttes, directly south of the thesis area. His study was mainly concerned with the silicic extrusives exposed at Powell Buttes which are believed to be part of the John Day Formation.

Bingert (1984) mapped the northeast quarter of the Prineville Quadrangle concurrently with this study.

# CLARNO FORMATION

## Introduction

The Clarno Formation was originally described by Merriam (1901a and 1901b) as a series of lava flows, volcanic breccias, tuffs and tuffaceous sediments exposed along the John Day River at Clarno's Ferry near Fossil, at Cherry Creek and near Burnt Ranch (see Fig. 1).

Waters et al. (1951) studied a thick section of Clarno rocks in and around the Horse Heaven Mining District. They described 5800 feet of volcanic and volcaniclastic material which they mapped as four stratigraphic units. They noted that these units vary greatly in thickness along strike and generally dip north. They also described a section of "Post Clarno" rocks that lie horizontally upon the tilted Clarno section. This angular unconformity is marked by a thick saprolite layer and up to 150 feet of relief. Potassium-argon dates for these "Post Clarno" rocks (Swanson and Robinson, 1968) indicate that they are equivalent in age to much of the Clarno Formation and should be included within the Clarno Formation.

Taylor (1960) studied a 3,200 foot thick section of the Clarno Formation in the Clarno Basin. He was able to divide this section into 10 stratigraphic units composed of varying proportions of mud flows, lava flows, tuffs, and ash-flow tuffs.

Oles and Enlows (1971) described an angular unconformity marked by a thick saprolite within the Clarno Formation in the Mitchell Quadrangle. They were able to relate their "Upper Clarno" section to a local eruptive center at Keyes Mountain.

The Clarno Formation has a high degree of lateral variability. Individual flows and tuffs are difficult to trace and larger stratigraphic units are difficult to correlate from section to section across north-central Oregon.

There is no well exposed vertical section of the Clarno Formation within the study area but from field relationships it is evident that the Clarno Formation here is dominated by at least 1,000 feet of pyroxene-bearing andesite flows and dikes. Subordinate quantities of aphyric rhyodacite and hornblende-bearing dacite are also found in the upper part of the Clarno section. Saprolite layers are found within the pyroxene-bearing andesite unit and at the base of one hornblende-bearing flow where it rests on pyroxene-bearing andesites. Widespread marker beds do not exist within this volcanic pile and it appears that these flows were extruded onto surfaces with variable relief, resulting in a complex arrangement of interfingering flows.

### Pyroxene-Bearing Andesite

The pyroxene-bearing andesite unit (Tcp) contains the oldest rocks in the thesis area. This unit is dominated by porphyritic pyroxene-bearing andesite flows but also contains at least two flows of olivine-bearing basalt. Patchy exposures of the pyroxene-bearing andesites are abundant and nearly all of the area underlain by this unit is covered by blocky talus (Fig. 2). Soil horizons are generally very thin except where saprolite layers are exposed.

In outcrop these flows are commonly fine grained and platy jointed. Porphyritic flows, with large plagioclase phenocrysts,

Fig. 2 Typical exposures of pyroxene-bearing andesite flows of the Clarno Formation, section 10, T13S, R15E.

which weather to coarse grus, are also common. There is a general trend of textural variation within the stratigraphy of the pyroxene-bearing unit. Platy jointed, fine grained flows are more abundant in the upper part of the section while flows with larger phenocrysts are more common in the lower part of the section.

The discontinuous nature of outcrops of the pyroxene-bearing andesite unit make mapping of individual flows impractical. Structural attitudes are based on joint surfaces that closely approximate bedding. Most of the pyroxene-bearing andesites appear to dip 5-20 degrees to the south-southeast. More precise bedding orientations were obtained by mapping portions of flows and saprolite layers.

In hand sample it is evident that most of the flows in the pyroxene-bearing andesite unit are porphyritic, usually with plagioclase phenocrysts in fine- to medium-grained groundmasses. Flows with large augite phenocrysts are also common.

Colors range from grayish black (N 2) to greenish black (5 G 2/1) for fresh samples. Weathered samples are reddish brown (10 R 3/4) or medium bluish gray (5 B 5/1). Fresh samples commonly contain minor amounts of smectite, imparting a greenish cast to the rocks. Weathered samples are commonly iron stained and may contain zeolites in addition to abundant clays.

Five mineralogical varieties were observed within various flows of the pyroxene-bearing andesite unit: two-pyroxene andesite, augite-bearing andesite, hypersthene-bearing andesite, olivine-and hypersthene-bearing basalt and olivine-and augite-bearing basalt. Modal analyses for selected samples of each type are shown in

Appendix 1. All five varieties commonly have intersertal textures and are almost always porphyritic. Only one aphyric flow was observed.

Andesites containing two pyroxenes make up the bulk of the pyroxene-bearing andesite unit. In thin section these andesites commonly show glomeroporphyritic textures and variable amounts of groundmass crystallization. These rocks contain 10 to 31 percent, 0.5 to 4 mm subhedral to euhedral $An_{50-65}$ labradorite phenocrysts which commonly display oscillatory zoning, 1 to 7 percent, 0.1 to 5 mm anhedral to subhedral augite phenocrysts, 0.5 to 3.5 percent, 0.1 to 2 mm subhedral to euhedral hypersthene phenocrysts and minor amounts of subhedral, primary magnetite. Groundmasses are often glassy with minute $An_{42-47}$ andesine laths but coarser groundmasses may be nearly holocrystalline with plagioclase and pyroxene microlites surrounded by secondary quartz.

Augite-bearing andesites were found to be very similar to the two-pyroxene andesites except for the apparent lack of hypersthene. One sample was point counted (DT-132) and found to contain 14.4 percent, $An_{53}$ labradorite phenocrysts, and 5 percent anhedral to subhedral augite phenocrysts commonly grouped together to form glomerocrysts dominated by augite. These augite-dominated glomerocrysts were also found in some two-pyroxene andesites. Groundmass microlites were found to be $An_{37}$ andesine.

One sample of hypersthene-bearing andesite was examined in detail (DT-106). This sample is texturally similar to many fine-grained porphyritic flows in the upper part of the pyroxene-bearing andesite unit. This rock contains 32 percent $An_{52}$ labradorite phenocrysts and 5 percent hypersthene phenocrysts in a glassy groundmass with minute plagioclase laths which are too small to give precise An contents by optical techniques.

Two distinctly different olivine-bearing basalt flows were found interlayered with pyroxene-bearing andesite flows and are included within the pyroxene-bearing andesite unit. Both flows are dark gray (N 2) and appear fresh in hand sample.

One sample (DT-25) is a coarse-grained holocrystalline rock with a very shiny appearance due to many large plagioclase cleavage surfaces. In thin section it is seen that the rock contains 34 percent, 1 to 5 mm euhedral $An_{60}$ labradorite phenocrysts and 0.6 percent, 1 to 3 mm anhedral olivine phenocrysts in a coarse groundmass of $An_{50}$ labradorite laths, anhedral augite and subhedral magnetite.

The other olivine-bearing flow is a fine-grained, porphyritic flow with 8.3 percent, 1 to 3 mm, anhedral olivine phenocrysts in a fine grained groundmass of $An_{50}$ labradorite laths and small granular crystals of hypersthene.

Weathering and alteration of flows within the pyroxene-bearing andesite unit have produced variable amounts of smectites, iron oxides and hydroxides and secondary silica phases.

Labradorite phenocrysts are often partly replaced by smectite, especially in the calcic cores of zoned crystals. Smectite is also a common alteration product of pyroxenes, found mainly around crystal margins and along cracks through pyroxene phenocrysts. Groundmasses also weather to smectite and usually contain small specks and fibrous masses of the highly birefringent pleochroic green clay. Huggins (1978) found these clays to be mixed-layer smectites by using x-ray diffraction techniques.

Thin coatings of hematite and goethite are common in these flow rocks. Most magnetite has been oxidized to hematite and appears red under reflected light. Olivine phenocrysts are strongly altered to a mixture of smectite and iron oxides, often leaving only a small unaltered core surrounded by dark brown alteration products.

Secondary silica phases are usually seen as groundmass devitrifaction products. Most commonly groundmass glass is replaced by quartz, which fills the spaces between groundmass microlites. Tridymite was observed as vesicle fillings in one sample (Fig. 3). Fan shaped, twinned crystals of tridymite line cavities which are filled with concentric layers of minute vapor-phase minerals, most likely silica and alkali feldspar. Quartz-magnetite bands were observed in one silicified andesite giving these rocks a peculiar green and black streaked appearance (Fig. 4).

Veinlets of stilbite were found in some deeply weathered samples.

## Pyroxene-Bearing Andesite Dikes

Two lithologically similar dikes are exposed in sections 35 and 36, T12S, R15E. In outcrop these are characterized by well developed horizontal columnar jointing. The dikes are 15 to 30

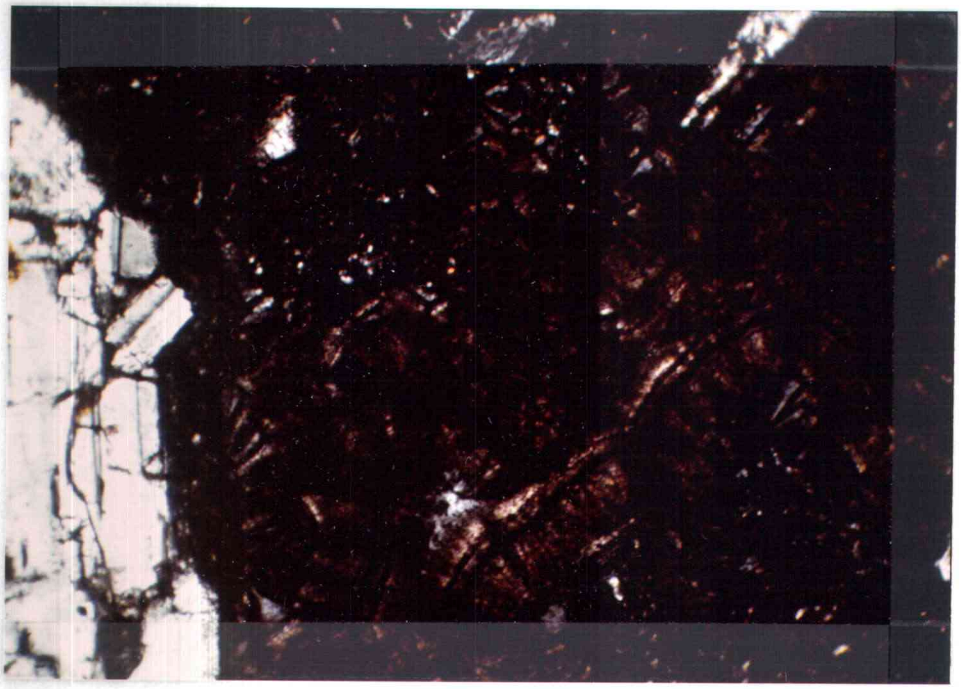

Fig. 3 Photomicrograph of fan-shaped, twined crystals of tridymite filling cavities along with minute vapor-phase intergrowths of silica and alkali feldspar in Clarno andesite. Cross-polarized light, field width 1.2 mm.

Fig. 4  Clarno andesite containing quartz-magnetite bands.

feet wide and stand 30 feet above the surface of surrounding flows (Fig. 5).

Hand samples of these dike rocks appear very fresh. They are dark gray (N 2) and contain large 5 to 8 mm plagioclase phenocrysts as well as smaller augite phenocrysts. Minor amounts of smectite give the phenocrysts a slight green cast.

In thin section these rocks are seen to contain 15 to 23 percent, 1 to 5 mm euhedral to subhedral $An_{52}$ labradorite phenocrysts, which commonly display oscillatory zoning, 3 to 3.5 percent, 0.5 to 3 mm subhedral augite phenocrysts, and 2.6 to 3.1 percent, 0.2 to 1 mm subhedral hypersthene phenocrysts. These phenocryst phases are commonly grouped together forming 3 to 8 mm glomerocrysts in a groundmass of $An_{45}$ andesine laths, minute pyroxene crystals and glass. These rocks are very fresh with only minor smectite and iron oxide staining, affecting mainly the pyroxenes and groundmass glass.

## Rhyodacite Flows and Intrusives

Flows, dikes and plugs of flow-banded, light brownish gray (5YR 6/1) slightly porphyritic rhyodacite are found in sections 11, 12 and 13, T13S, R15E. In hand sample these rocks are nearly aphyric with rare plagioclase phenocrysts that usually weather out leaving tabular cavities. Minor iron staining highlights the flow-banding in hand sample while outcrops are platy jointed along the flow banding.

In thin section it is seen that these rocks are composed of less than 1 percent, $An_{20}$ oligoclase and oxyhornblende phenocrysts

Fig. 5 Columnar jointed pyroxene-bearing andesite dike from the Clarno Formation, NW 1/4 of SW 1/4, section 36, T12S, R15E.

in a pilotaxitic glassy groundmass which contains minute $An_{15}$ oligoclase and quartz. The flow-banding is defined in thin section by zones where devitrification has produced more quartz than is present between these zones.

Flows of rhyodacite have nearly horizontal, parallel flow-banding whereas dikes and plugs of the same material have more contorted, vertical flow-banding. Two dikes of this rhyodacite are present cutting older pyroxene-bearing andesites (Fig. 6). These dikes trend nearly east-west and continue off of the map to the east. A cylindrical plug of rhyodacite crops out on the southern spur of hill 4797 in the south half of section 12, T13S, R15E. This plug appears to be connected to the dikes although continuous exposures are lacking.

It is difficult to differentiate between flows and intrusives of the rhyodacite because they appear to merge in section 12. Part of the rhyodacite in section 12 cuts pyroxene-bearing andesite flows and is clearly intrusive. The rhyodacite capping hill 4470 in section 13 has nearly horizontal flow banding and was evidently emplaced as a flow.

### Oxyhornblende-Bearing Dacite

Oxyhornblende-bearing dacite flows are found in sections 11, 12 and 2, T13S, R15E. These flows overlie pyroxene-bearing andesites and may be related to nearby rhyodacite intrusives, which also contain minor amounts of oxyhornblende. A 100 foot thick saprolite layer is found locally between the oxyhornblende-bearing flows and

Fig. 6 Rhyodacite dikes of the Clarno Formation intrude older pyroxene-bearing andesites, SW 1/4, section 12, T13S, R15E.

the pyroxene-bearing andesites. The oxyhornblende-bearing dacite also appears to overlie rhyodacite near the summit of hill 4797 in section 12, T13S, R15E. Because some of the rhyodacite is intrusive this could be an intrusive contact.

In hand sample these rocks range from medium gray (N 5) to dark reddish brown (10 R 3/4). They are conspicuously porphyritic with 1 to 2 mm tabular plagioclase phenocrysts and 1 to 2 mm acicular hornblende phenocrysts. All samples examined in the field were very fresh. Many samples appear to be typical fine-grained, platy pyroxene-bearing andesites but upon close inspection are seen to contain hornblende. Light gray (N 7), vesicular samples representing flow top material are also abundant.

In thin section these rocks are markedly pilotaxitic, with both phenocryst and groundmass crystals aligned. All six samples of oxyhornblende-bearing dacite examined in thin section had remarkably similar compositions and textures (see Appendix 1), with 5 to 10 percent, 1 to 3 mm corroded $An_{42}$ andesine phenocrysts, and 0.8 to 0.9 percent, 0.5 to 2 mm oxyhornblende phenocrysts often rimmed or replaced by magnetite (Fig. 7). These phenocrysts are set in a groundmass of $An_{30-34}$ andesine and glass. Smectite alteration is common in the cores of andesine phenocrysts and less abundant in the groundmass glass.

Similarities in composition and distribution of the oxyhornblende-bearing andesites and rhyodacites suggest that they are genetically related. It seems likely that the area now underlain

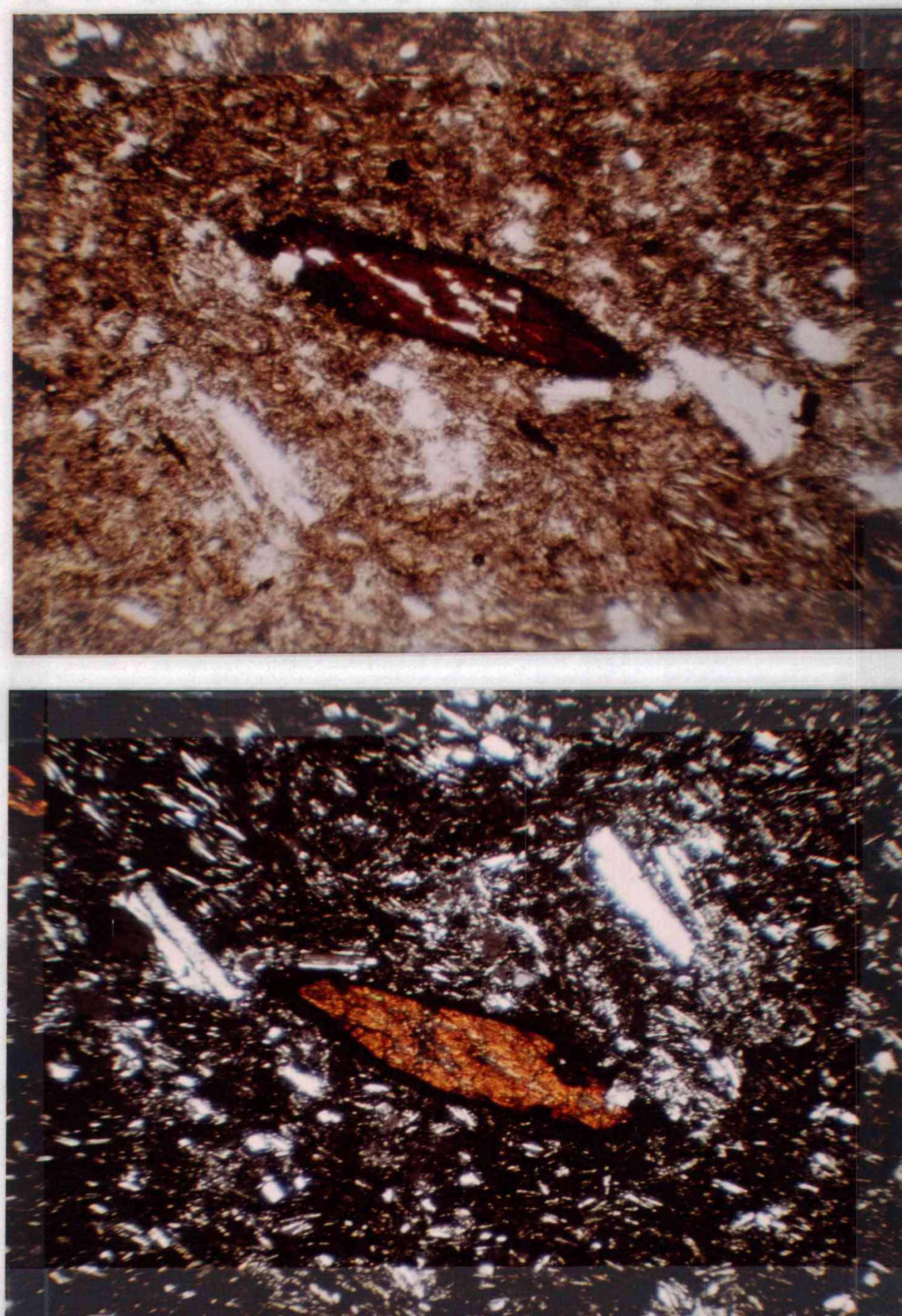

Fig. 7 Photomicrographs of oxyhornblende phenocryst, rimmed by magnetite. Upper photo plane-polarized light, lower photo cross-polarized light, field of view 1.2 mm.

by rhyodacite intrusives represents a dissected late Clarno eruptive center.

Bingert (1984) found an eastward extension of similar dacite and rhyodacite flows and intrusives in the northeast one quarter of the Prineville quadrangle. A large hornblende-bearing dike is also found in the northeast one quarter of the Prineville quadrangle. This band of late Clarno silicic volcanism was clearly controlled by east-west structures.

Paleontology and Age

O.C. Marsh (1875) first referred to the Clarno Formation as "the Eocene beds containing fossil plants."

Early paleobotanical work by Knowlton (1902) and Chaney (1927 and 1932) focused on the Cherry Creek and Bridge Creek floras, which were thought to represent lower and upper Clarno beds respectively. Chaney (1927) recognized that the Bridge Creek flora was from the John Day Formation. The Cherry Creek flora was first assigned to the lower Eocene but by 1938 Chaney (1938b) referred to the Clarno as upper Eocene.

Stirton (1944) described a fossil rhinoceros tooth and tentatively placed it within the early-middle Eocene.

A review of the plant fossils from the Clarno Formation by Hergert (1961) suggests a range of middle-upper Eocene to middle-upper Oligocene ages.

An early Oligocene age is supported by mammalian fossils (Mellett, 1969) and fossil fruits and seeds (McKee, 1970) from the University of California Mammal Quarry near Clarno.

K-Ar ages reported in Evrenden and James (1964) and Evrenden et al. (1964) indicate that the Clarno nutbeds are 34.0 m.y. old. Dates of 36.5 ± 0.9 m.y. and 37.5 m.y. were obtained from underlying bentonite beds and andesite flows respectively. Along with the nutbeds these units were thought to be at the top of the Clarno Formation.

Swanson and Robinson (1968) dated a porphyritic rhyolite flow, described as post-Clarno Formation by Waters et al. (1951) and found it to be 41.0 ± 1.2 m.y. old. This flow overlies a saprolite mantled unconformity but the K-Ar age indicates that the unconformity and overlying rhyolite belong within the Clarno Formation.

Enlows and Parker (1972) reported on the geochronology of the Clarno rocks in the Mitchell quadrangle and found that the lower Clarno yielded dates from 46.1 m.y. to 36.5 m.y. Rocks from the upper Clarno were dated as 33.3 m.y. to 29.4 m.y. Taylor (1981) dismisses these young dates pointing out that the dikes which yielded the 29.4 m.y. age are most likely related to mafic lavas of the John Day Formation. Taylor (1981) also discussed problems of stratigraphic position of lavas which were dated as 32.8 m.y. and suggested that an unpublished age of 48.9 m.y. for a flow in nearly the same stratigraphic position is indicative of problems with the data presented by Enlows and Parker (1972). The question of concurrent volcanism in the John Day and Clarno Formations is best resolved by considering the quality of the reported radiometric dates. The 36.4 m.y. age of the basal ash-flow tuff of the John Day

Formation (Swanson and Robinson, 1968) seems to be the most reliable of these dates when one considers the fresh, strongly welded character of this unit and its consistent stratigraphic position. Because the John Day and Clarno Formations are not found interbedded with each other the possibility of concurrent deposition does not seem likely.

# JOHN DAY FORMATION

## Introduction

Fossiliferous strata in the John Day Basin were first discovered in 1861. Thomas Condon collected fossils from these beds and in 1870 he sent some fossil teeth to Dr. O.C. Marsh of Yale. Early accounts of this rich fossil discovery were published by Leidy (1870), Marsh (1873), and LeConte (1874). Marsh (1875) provided the first general description of the geology of the area and was the first to apply the name "John Day" to the principal fossiliferous beds. Merriam (1901a and 1901b) formally named these beds the John Day Series and was the first to describe the geology of the area in detail.

Calkins (1902) provided important petrographic descriptions of many rocks from the John Day Basin including samples of the Clarno and John Day formations. Lavas described by Calkins included a rhyolite near Antelope.

Hodge (1932) noted fossil localities along the Deschutes River that contained Upper Oligocene-Lower Miocene faunas. He suggested that this represented a westward extension of the John Day Formation. The discovery of younger fossils in the western John Day section indicated to Hodge that this material represented late John Day deposition and was probably restricted to this area, near the Cascade Mountains which he believed to be its source.

Waters (1954) noted that when traced to the west, the fine-grained water-laid tuffs of the John Day Basin begin to alternate with increasing amounts of air-deposited pumice-lapilli tuffs and coarse rhyolite breccias, and especially with great volumes of welded and sintered tuffs. He also noted the appearance of rhyolite domes and flows in the western section. Waters (1954) stated that the vents for these welded tuffs and lavas are exposed as both dikes and central vents in the Burnt Ranch, Eagle Rock and Ashwood areas.

The stratigraphy of this western facies was described by Peck (1964) from exposures in the Antelope-Ashwood area. Peck divided the western facies of the John Day into nine conformable units marked by distinctive lava flows and widespread ash-flow sheets. Two of these ash-flow sheets have been correlated with distinctive units in the eastern facies of the John Day Formation (Swanson and Robinson, 1968).

Robinson and Brem (1981) discussed the distribution of John Day exposures and briefly described a third, southern facies which is exposed to the south of the Ochoco Mountains. Chaney (1927) collected and described fossils from the John Day Formation in the Crooked River Basin, part of the southern facies. His brief description of the geology of this area indicates that it is very similar to the eastern facies of the John Day Basin. Robinson and Brem (1981) note that the southern facies contains two ash-flow sheets that have not been correlated with the western or eastern facies. They suggest that these ash-flow tuffs originated from separate vents, south of the Ochoco Mountains.

The thesis area lies along the southern edge of the western facies. The John Day Formation within the thesis area is divided into five stratigraphic units: a basal ash-flow tuff, trachyandesite flows, rhyolite domes and flows, a lithophysal ash-flow tuff, and bedded and massive tuffs. The early John Day units correlate with Peck's (1964) western facies stratigraphy but later ash-flow tuffs are missing from this area making correlation of the poorly exposed bedded and massive tuffs difficult.

Basal Tuffs

The base of the John Day Formation within the thesis area is formed by a porphyritic, densely welded ash-flow sheet that has been traced from just west of Grizzly to Clarno (Swanson and Robinson, 1968). This distinctive ash-flow tuff is overlain by up to 100 feet of poorly exposed white to yellow tuff and a sparsely porphyritic ash-flow tuff. This is the same sequence described by Peck (1964) as member A of the western facies of the John Day Formation.

The basal ash-flow tuff is poorly exposed in section 36, T12S, R14E where it is overlain by yellow and gray tuffs. The upper ash-flow tuff is also exposed in this area along the edge of the pond in the NW 1/4 of the SE 1/4 of section 36. The best exposures of the basal ash-flow tuff are found along the north bank of Newbill Creek, near the border between sections 28 and 32 T12S, R15E. At this locality a nearly complete section through the ash-flow sheet is exposed (Fig. 8). This 50-foot-thick section is divided into two 25-foot-thick cooling units that are lithologically identical. Each cooling unit is locally lithophysal at the base, densely welded with highly flattened pumice fragments near the middle and less welded and less flattened near the top. The rock is typically

Fig. 8 Basal ash-flow tuff of the John Day Formation near Grizzly, SE 1/4, section 29, T12S, R15E.

yellowish-gray (5Y 7/2), conspiculously porphyritic with about 5 percent, 2-3 mm phenocrysts of quartz and feldspar, and contains abundant pumice and rock fragments.

In thin section these samples show typical vitroclastic textures. 1-3 mm equant phenocrysts of quartz, $Or_{30}$ soda-sanidine and $An_{15}$ sodic-oligoclase lie in a matrix of compressed glass shards along with abundant 5-15 mm pumice and rock fragments. The groundmass glass is only slightly altered to clay. Zoned oligoclase phenocrysts display normal zoning.

This basal ash-flow sheet is overlain by up to 100 feet of poorly exposed tuffs throughout the region. These tuffs are exposed in the outlet race of the small pond in the NW 1/4 of the SE 1/4 of section 36, T12S, R14E. They are poorly bedded, yellow, gray and white, highly weathered deposits that probably represent air-fall and wind-blown ash.

The sequence defined by Peck (1964) as member A of the John Day Formation is capped by a sparsely porphyritic, densely welded ash-flow sheet. This ash-flow tuff is exposed in the northern part of the SW 1/4 of section 29, T12S, R15E and in the NE 1/4 of section 4, T12S, R15E. The rock is light gray (N 7) to pale olive gray (5Y 5/2) and contains less than 3 percent phenocrysts of quartz and feldspar along with abundant 5 mm rock fragments and less abundant pumice fragments.

In thin section this ash-flow tuff is similar to the basal ash-flow tuff. 1-3 mm equant phenocrysts of quartz, sodic-oligoclase and less abundant soda-sanidine form about 3 percent of the rock.

Small, 5 mm rock fragments are common but slightly flattened pumice fragments are less abundant. The matrix is composed of angular glass shards that are commonly devitrified and often show axiolitic intergrowths of alkali-feldspar and silica. A few minute 0.1 - 0.2 mm crystals of zircon were observed in one sample from this unit. Alteration is more apparent in this ash-flow tuff than in the basal ash-flow tuff. Clots of clay are seen within the matrix of these samples, probably indicating alteration of the glass.

Trachyandesite

Trachyandesite was first noted in the John Day Formation by Peck (1964) who defined member B of the western John Day Formation as a sequence of trachyandesite flows and interbedded tuffs up to 1500 feet thick. Trachyandesite is found in the north-central part of the thesis area in sections 28 and 29, T12S, R15E, and along the creek in the SW 1/4 of section 31, T12S, R15E, and the SE 1/4 of section 36, T12S, R14E. Outcrops of trachyandesite are rare but slopes covered with rounded blocks of this material indicate its presence. The rock is very hard and dense, black (N 1) and nearly aphyric in hand sample.

At one location along the creek in the SW 1/4 of section 31, T12S, R15E, a flow of trachyandesite is overlain by a hyaloclastite composed of trachyandesite fragments in a palagonitic matrix. All of the clasts appear to be trachyandesite with varying textures from dense, platy fragments to highly vesicular fragments. These fragments range in size from 1 cm to 30 cm and are surrounded by light brown palagonite. The contact with the underlying trachyandesite is fairly sharp with a lack of clasts near the base of the hyaloclastite (Fig. 9). This material has been mapped as part of member B because it is compositionally similar to the trachyandesite flows and because it was most likely formed with these flows.

In thin section the trachyandesites are made up of 0.1 - 0.5 mm euhedral $An_{48}$ andesine laths and 0.1 - 0.5 mm subhedral pigeonite ($2V = 10^{o}$) that encloses small andesine crystals. Glass is abundant between crystals and in patches where it is partly devitrified. Opaque, dendritic magnetite-ilmenite intergrowths are common within the larger patches of glass.

Robinson (1969) discussed the somewhat peculiar chemistry of these rocks. Chemical analyses of these rocks (Appendix 2) indicate that they contain relatively large amounts of $TiO_2$ and iron with low $Al_2O_3$ and MgO contents. These characteristics are also found in alkali olivine basalts and quartz latites from elsewhere in the John Day Formation. Robinson (1969) concluded that the trachyandesites and quartz latites were derived by differentiation of an alkali olivine basalt magma.

## Rhyolite Domes and Flows

A complex of nested rhyolite domes, flows and associated tuffs extends from Grizzly Mountain to the southeast corner of the thesis area. Domes are marked by thick accumulations of rhyolite, often exposed in cliff faces up to 400 feet high (Fig. 10). Individual flows are usually 30 to 100 feet thick. Poorly exposed pumice-lapilli

Fig. 9 Hyaloclastite overlying trachyandesite flow from member B of the John Day Formation, SW 1/4, section 31, T12S, R15E.

Fig. 10 Dike like bodies forming the interior of a John Day rhyolite dome, NW 1/4, NW 1/4, section 27, T13S, R15E.

tuffs underlie some of the rhyolite flows. A variety of textures is seen in these rhyolites, ranging from aphyric and often vesicular in the lower flows, to strikingly flow-banded and lithophysal flows along the summit of Grizzly Mountain.

The most extensive flows in the area are composed of punky, vesicular, pale red, aphyric rhyolite and are exposed along the southern contact with John Day tuffs in section 28, T13S, R15E and along the base of the gently sloping plateau that forms the southern half of section 22, T13S, R15E. These rhyolites are commonly altered to yellowish gray (5Y 8/1) with the abundant small vesicles being filled by chalky white opal and quartz. These vesicular flows have a crude flow banding defined by aligned vesicles (Fig. 11).

In thin section it is confirmed that most of these lower rhyolites are nearly aphyric with very rare relict phenocrysts of $An_{15}$ sodic-oligoclase lying in devitrified groundmasses now composed of fine-grained mosaics of quartz and anorthoclase. The remaining glass is found in irregular clumps scattered throughout the samples.

Many of the lower vesicular rhyolites appear to be highly bleached and altered. When viewed in thin section these rocks are seen to contain euhedral crystals of quartz which have grown in the numerous vesicles. Isotropic opal is often seen filling the remaining space between these crystals (Fig. 12). The opal is responsible for the chalky white appearance of these rocks.

Strikingly flow-banded, lithophysal rhyolites are exposed along the summit ridge of Grizzly Mountain. These upper flows are conspicuously porphyritic with 3 to 5 percent phenocrysts of quartz,

Fig. 11 Flow-banded rhyolite from the John Day Formation, NE 1/4, SE 1/4, section 28, T13S, R15E.

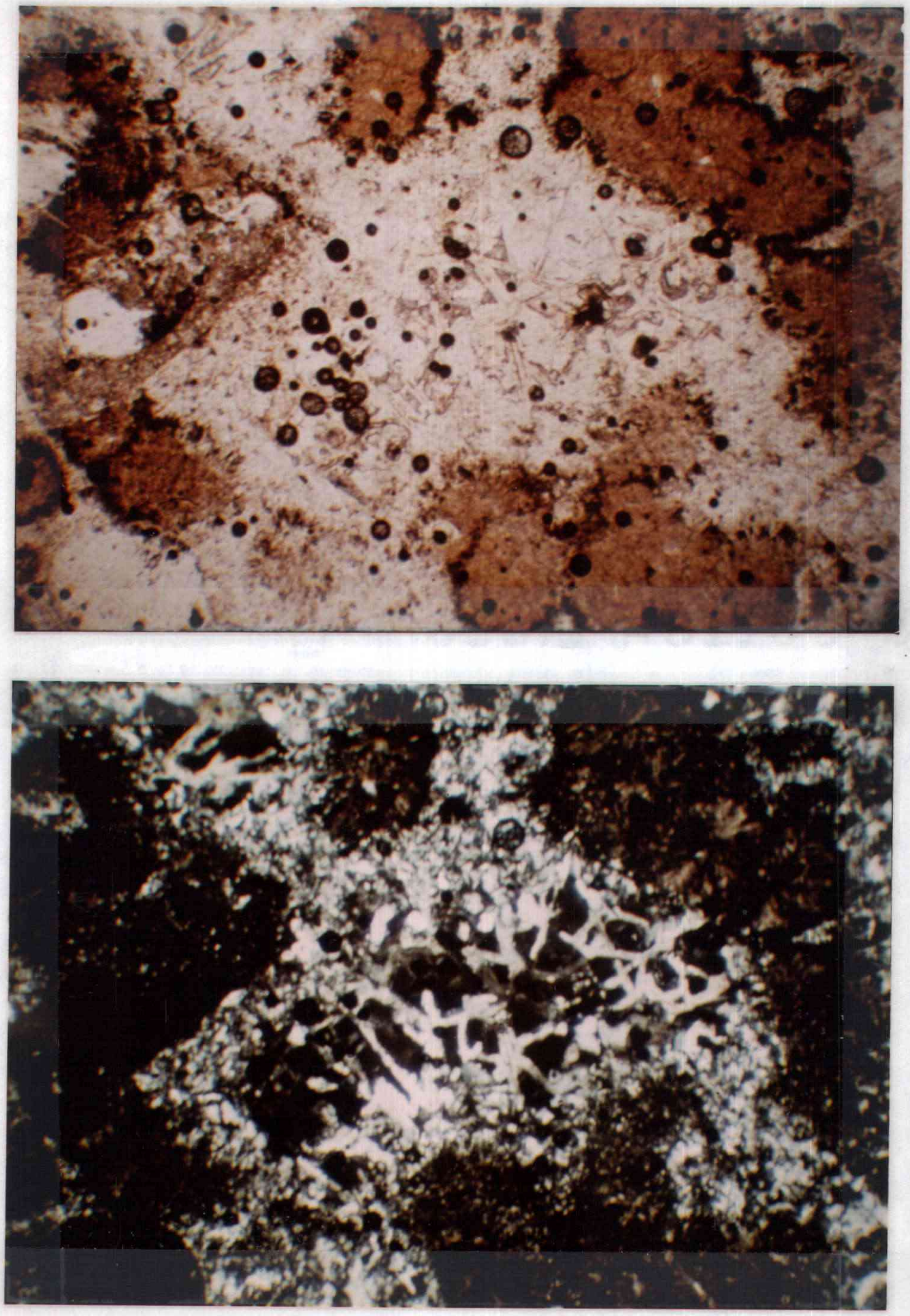

Fig. 12 Photomicrograph showing isotropic low-relief opal in John Day rhyolite. Upper photo plane-polarized light; lower photo cross-polarized light. Field of view 1.2 mm.

$Or_{35}$ anorthoclase and less abundant sodic-oligoclase. In thin section the flow banding is seen as distinct zones of quartz and feldspar crystals separated by thicker zones of fresh glass.

A dark gray (N 2) vitrophyre with a pitchy luster is poorly exposed along the base of a rhyolite flow in sections 22, 28 and 29 T13S, R15E. This vitrophyre contains 2 to 3 percent phenocrysts of $An_{15}$ sodic-oligoclase. The groundmass is largely devitrified to spherulitic aggregates of cristobalite and $Or_{45}$ soda-sanidine.

Flow breccias are often seen at the bases of flows along the contact with the Clarno Formation in section 22, T13S, R15E. These are limited in extent and usually consist of vesicular rhyolite fragments in a more massive rhyolite matrix.

Flow banded rhyolites are also found in the northwest part of the thesis area. In the northwest corner of section 31, T12S, R15E, a flow banded rhyolite lies directly above a 10 foot thick saprolite layer developed on top of very deeply weathered Clarno andesites. These northwestern rhyolite flows contain 2 to 3 percent phenocrysts of anorthoclase and 1 to 2 percent relict mafic phenocrysts which are now replaced by smectites and iron oxides. The glassy groundmasses of these rocks are almost always completely devitrified. Micropoikilitic devitrification is seen in Figure 13 where feldspar microlites are enclosed in larger anhedral quartz crystals.

X-ray diffraction patterns were examined for fresh and altered samples of rhyolite to help determine the nature of the alteration. The main difference seen in these patterns was the diminishing of feldspar peaks and intensification of alpha quartz peaks. This

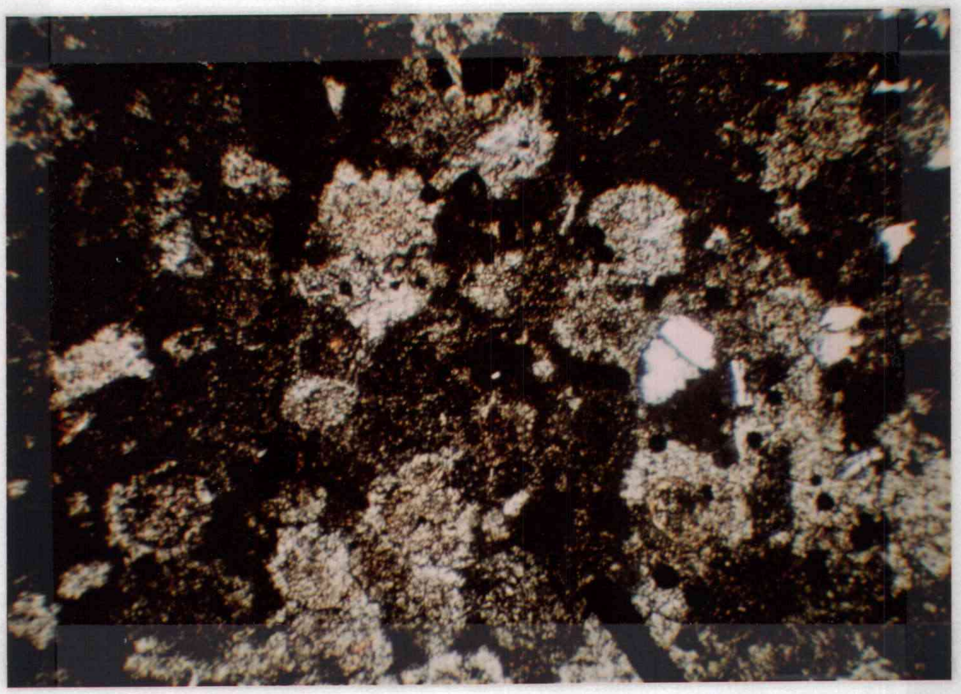

Fig. 13 Photomicrograph showing micropoikilitic devitrification texture in John Day Rhyolite. Small plagioclase microlites enclosed within anhedral quartz crystals. Cross-polarized light, field of view 3.8 mm.

verifies the introduction of secondary silica which is also seen in thin section as euhedral quartz crystals lining vesicles. The secondary opal is not seen on x-ray patterns because it is amorphous. A detailed analysis of the clay mineralogy was not undertaken for these rocks but peaks indicating kaolinite or alunite, which would indicate intense hydrothermal alteration, were not seen. It is most likely that the small amounts of clay seen in thin section are mixed layer smectites and are probably a result of weathering or deuteric processes.

The x-ray patterns were also used to determine the composition of alkali-feldspars. The d-spacing revealed by the position of the 201 peak is indicative of the Or content of the feldspar (Orville, 1967). Alkali feldspars from the lower, vesicular rhyolites are $Or_{10-20}$ anorthoclase. The upper, flow banded rhyolites contain $Or_{30-35}$ anorthoclase and the basal vitrophyre contains $Or_{45}$ soda-sanidine. The Or values for the upper, flow banded rhyolites are consistent with values determined optically using 2V estimates from phenocrysts.

The abundance of alkali feldspar seen in the porphyritic flows indicates that these may be classified mineralogically as rhyolites. A chemical analysis of an aphyric flow confirms this classification with over 77 percent $SiO_2$ and over 4 percent $K_2O$ (Appendix 2).

These rhyolites overlie poorly exposed tuffs which are often highly altered and weathered. In section 4, T12S, R15E the rhyolite lies on the upper ash-flow tuff of member A. The tuffs that underlie most of the rhyolite near Grizzly Mountain are pumice-lapilli tuffs which are deeply weathered to a pale olive color (10 Y 6/2). These are exposed along Dehler Road in the NE 1/4 of the SW 1/4 of section 28, T13S, R15E and in a road cut near the dam on Lytle Creek in section 26, T13S, R15E. The ash-flow tuffs of unit A are not found this far south and may never have been deposited here. The tuffs that underlie the rhyolite flows are thicker than those reported from the middle of member A and probably represent locally derived material that was erupted prior to the rhyolite flows.

The thick sequence of rhyolites found in the thesis area is probably correlative with the rhyolites described by Peck (1964) as member C of the western John Day, which is typically exposed along Trout Creek near Ashwood. The section exposed on Grizzly Mountain is also similar to that mapped by Robinson and Stensland (1981) in the Smith Rocks quadrangle along the western border of the thesis area. In the Smith Rocks area a thick section of ash-flow tuffs is found between two types of rhyolite, a lower, aphyric rhyolite and an upper, lithophysal, flow-banded rhyolite. The interlayered tuffs are missing in the thesis area and thick domes, which mark the vents for much of this material, complicate the stratigraphy, making the contact between lower and upper rhyolites less distinct. Grizzly Mountain appears to be similar to Juniper Butte, another rhyolite dome complex that occurs in the Smith Rocks quadrangle (Robinson and Stensland, 1981).

## Upper Ash-Flow Tuff

Sparse outcrops of a lithophysal, welded ash-flow tuff overlie rhyolite flows in the southeast 1/4 of section 26, T13S, R15E. These rocks are dark reddish-brown (10 R 3/4) to dark yellowish-brown (10 YR 4/2). Lithophysae are particularly common in the dark yellowish-brown samples. Dark reddish-brown samples have white bands of devitrified, flattened pumice.

In thin section these rocks are seen to have pronounced eutaxitic textures with fused glass shards wrapped around abundant devitrified pumice lumps and rare phenocrysts of $An_{17}$ sodic-oligoclase. The flattened pumice is completely devitrified, forming spectacular axiolites (Fig. 14), while the groundmass shards remain glassy and fresh.

This ash-flow tuff resembles the highly lithophysal ash-flow tuff described by Peck (1964) as unit E of the western John Day Formation.

### Bedded and Massive Tuffs

Fine-grained, white, water-laid bedded tuffs are found overlying rhyolite in the south half of section 26, T13S, R15E and lapping onto rhyolite flows in sections 27, 28, 34 and 35, T13S, R15E. These tuffs are poorly exposed except where excavations reveal thick sections of laminated, fine-grained tuff. Slopes underlain by these tuffs are littered with platy, white fragments of this material. Good exposures in various pits in the SW 1/4 of the NW 1/4 of section 33, T13S, R15E, reveal that coarse sandy material is locally interbedded with the fine-grained tuffs. Fossil leaves and wood chips were also observed in several localities (Fig. 15). Fossil forms identified are: *Metasequoia oxidentalis*, *Fagus pacifica* and *Typha sp*.

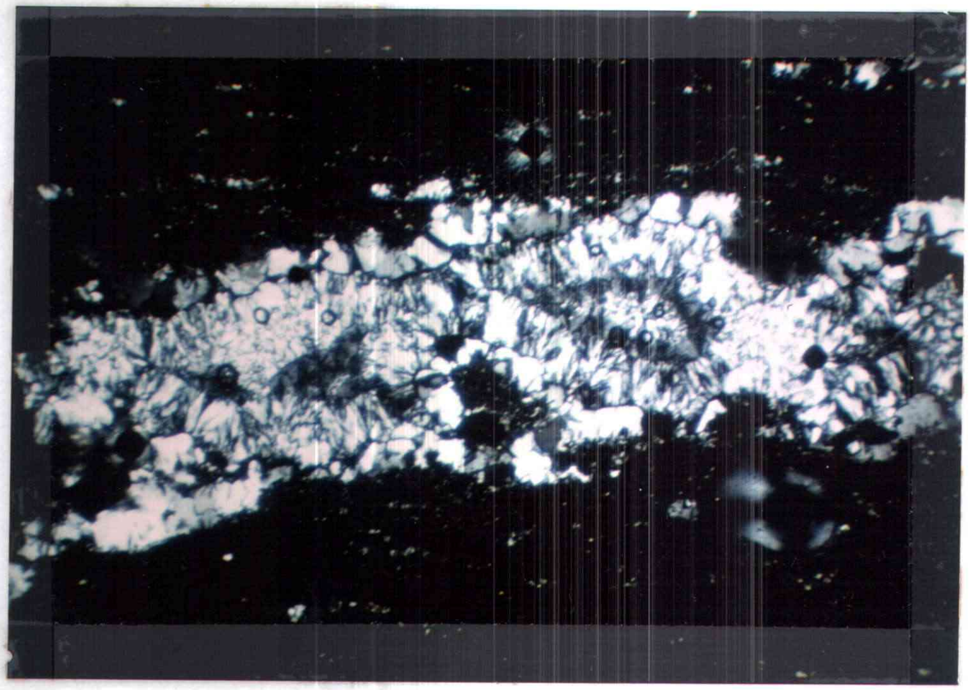

Fig. 14 Photomicrograph of eutaxitic welded ash-flow tuff from member E of the John Day Formation. Note the axiolitic, devitrified pumice fragment. Cross-polarized light, field of view, 3.8 mm.

Fig. 15 Samples of John Day bedded tuffs containing fossil leaves (L to R Fagus pacificus, Metasequoia oxidentalis, Typha sp.).

From: SW 1/4, SW 1/4, SE 1/4, section 26, T13S, R15E;
SE 1/4, SW 1/4, section 33, T13S, R15E; and
SW 1/4, NW 1/4, section 34, T13S, R15E, respectively.

The tuffs range from white (N 9) to light olive gray (5 Y 5/2). The white material is chalky and often fairly soft. The olive gray material has a cherty appearance and is very hard. This olive gray material is more abundant toward the southeast part of the area. Silicification of the tuffs caused the cherty appearance and may be related to hot spring activity in the western half of section 35, T13S, R15E.

A sintered breccia composed of fragments of bedded tuff in a siliceous matrix is exposed in the SE 1/4 of the SW 1/4 of section 35, T13S, R15E, along an irrigation ditch. This breccia contains traces of pyrite and is similar to breccias seen at active hot springs. This breccia probably marks a source for siliceous hot waters that caused local silicification of the bedded tuffs.

Other mineralized breccias were found in the NE 1/4 of the NW 1/4 of section 34 and in the NW 1/4 of the NE 1/4 of section 28, T13S, R15E. These breccias are not flooded with siliceous sinter but are cemented with sooty deposits of manganite and goethite (Fig. 16). Samples of each type of breccia were analyzed for gold, silver and mercury (Appendix 3).

The nonsintered, mineralized breccias probably represent ancient fumerolic activity. The lack of large quantities of secondary silica in these breccias indicates that they were formed in a slightly different manner than the siliceous breccia. The presence of abundant manganite and anomalous quantities of mercury suggest that these are epithermal deposits which are the result of near surface hydrothermal activity.

Fig. 16 Sample of mineralized breccia containing manganite and goethite, NW 1/4, NE 1/4, NE 1/4, section 28, T13S, R15E.

Nearly 400 feet of massive pumice-lapilli tuff is poorly exposed at the base of the Columbia River basalt and in road cuts in the southwest part of the area.

This tuff is light brownish gray (5 YR 6/1) and consists of 2 to 15 mm white pumice-lapilli in a matrix of ash and minute feldspar crystals. This material underlies a pediment surface that extended from Grizzly Mountain south at least as far as the present-day Crooked River. This surface was partly covered by Columbia River basalt flows and is deeply eroded elsewhere.

This massive tuff matches member I, described by Peck (1964) as the youngest unit in the western facies of the John Day Formation.

Paleontology and Age

Marsh (1875) initially described the John Day lake basin as Miocene in age, citing the vertebrate fauna as evidence for this assignment. Later paleontological work by Merriam and Sinclair (1907) provided evidence that the John Day Formation is actually Oligocene and possibly early Miocene.

Paleobotanical studies led Chaney (1927) to conclude that the Bridge Creek flora is from the John Day Formation and represents the Upper Oligocene. K-Ar dates published by Evrenden and James (1964) indicate that the Bridge Creek beds are 31.5 m.y. old which corresponds to an early Oligocene age.

A review of the stratigraphy of the John Day Formation by Fisher and Rensberger (1972) shows that the Haystack Valley member of the John Day eastern facies is early Hemingfordian in age.

Woodburne and Robinson (1977) described the Warm Springs local fauna from the John Day Formation west of the Deschutes River as early late Hemingfordian. These assignments would extend John Day deposition well into the Miocene.

Swanson and Robinson (1968) defined the base of the John Day Formation in the western facies as a distinctive ash-flow tuff which they dated as 36.1 m.y. (K-Ar). Evrenden and James (1964) dated the bentonite which underlies the basal ash-flow tuff as 32.0 m.y. (K-Ar). The date for the bentonite is probably less reliable than that for the ash-flow tuff because the bentonite is more likely to have lost argon. Hay (1963) obtained a K-Ar date of 25.3 m.y. for the Picture Gorge ignimbrite which is the youngest reliable radiometric age reported for the John Day Formation.

When both radiometric and fossil ages are considered, it is evident that John Day deposition began about 36.1 million years ago and continued up until perhaps 18 to 19 million years ago. It also seems likely that deposition may have continued longer in the western part of the formation than in the John Day Basin because the youngest material was recovered from the western facies.

# COLUMBIA RIVER BASALT GROUP

## Stratigraphy

The term Columbia River basalt has long been used to refer to the basaltic lavas of the Columbia Plateau (Russell 1893 and 1901). Waters (1961) summarized earlier attempts at stratigraphic subdivision of the seemingly monotonous basalts and defined the Columbia River Group by dividing the basalts into two formations: the Picture Gorge Basalt and the Yakima Basalt. The group name was later changed (Griggs, 1976) to the Columbia River Basalt Group in order to exclude interbedded, non-basaltic units. Waters (1961) thought that the Picture Gorge Basalt was unconformably overlain by the Yakima Basalt but these two formations were rarely found in contact. The Picture Gorge Basalt is almost completely restricted to the John Day basin while the Yakima Basalt is almost always found north of the Blue Mountains. The distribution of these lavas was restricted by the Blue Mountains uplift which formed a topographic barrier at the time the basalts were extruded.

Wright, Swanson and Grolier (1973) discussed the relationship of chemical variations to stratigraphy of the Columbia River Basalt Group and proposed informal subdivisions based on chemical types and distribution. Further mapping and sampling has led to an accepted system of formal and informal stratigraphic nomenclature based on chemical types and paleomagnetic polarities (Swanson et al., 1979). This system of subdivision raises the Yakima Basalt to a sub-group which is divided into three formations in order of decreasing age: the Grande Ronde, Wanapum and Saddle Mountains basalts. The Picture Gorge Basalt is shown to be coeval with part of the Grande Ronde Basalt and the Imnaha Basalt is considered to be older than the Grande Ronde and Picture Gorge basalts based on magneto-stratigraphy (Fig. 17).

The contact between the Picture Gorge and Grande Ronde basalts has been observed in only 3 exposures. At Butte Creek the two formations are interlayered (Cockerham and Bentley, 1973; Nathan and Fruchter, 1974). At Camus Creek and near Dale, Grande Ronde flows conformably overlie Picture Gorge flows.

Description

A single flow of the Columbia River Basalt Group is found in the southwest portion of the thesis area. This flow caps a prominent plateau which extends off of the map to the south and west. Good exposures always consist of a single colonnade overlain by a thick, glassy, hackly jointed entablature. This flow rests on poorly exposed John Day tuffs which are obscured by abundant basalt talus. The contact appears to undulate locally, indicating some relief in the John Day surface. In one road cut, just south of the thesis area (center of NW 1/4, section 8, T14S, R15E) there is good evidence that the basalt flowed over a wet, muddy surface (Fig. 18). At this locality the basalt appears to be partly invassive into the underlying tuffs and is surrounded by a palagonitic rind. The basalt at the contact is very glassy and contains inclusions of palagonite well

| SERIES | | GROUP | SUB-GROUP | FORMATION | MEMBER | MAGNETIC POLARITY |
|---|---|---|---|---|---|---|
| MIOCENE | Upper Miocene | COLUMBIA RIVER BASALT GROUP | Yakima Basalt Subgroup | Saddle Mountains Basalt | Lower Monumental Member | N |
| | | | | | Unconformity | |
| | | | | | Ice Harbor Member | N R N |
| | | | | | Unconformity | |
| | | | | | Buford Member | R |
| | | | | | Elephant Mountain Member | N T |
| | Middle Miocene | | | | Unconformity | |
| | | | | | Pamona Member | R |
| | | | | | Unconformity | |
| | | | | | Esquatzel Member | N |
| | | | | | Unconformity | |
| | | | | | Weissenfels Ridge Member | N |
| | | | | | Asotin Member | |
| | | | | | Unconformity | |
| | | | | | Wilbur Creek Member | N |
| | | | | | Umatilla Member | |
| | | | | | Unconformity | |
| | | | | Wanapum Basalt | Preist Rapids Member | $R_3$ T |
| | | | | | Roza Member | |
| | | | | | Frenchman Springs Member | $N_2$ |
| | | | | | Eckler Mountain Member | |
| | | | | Grande Ronde Basalt | | |
| | Lower Miocene | | | | | $R_2$ |
| | | | | Picture Gorge Basalt -?-?- | (Basalt of Dayville) | |
| | | | | | (Basalt of Monument Mt.) | $N_1$ |
| | | | | | (Basalt of Twickenham) | |
| | | | | | | $R_1$ |
| | | | | Imnaha Basalt | | T, $N_0$, $R_0$ |

Fig. 17 Columbia River Basalt Group stratigraphy from Swanson, et. al., 1979.

Fig. 18 Columbia River basalt flow overlying tuffs of the John Day Formation. Note glassy pillow structures at the base of the flow and brown palagonite inclusions. NE 1/4, NW 1/4, section 8, T14S, R15E.

above the contact surface. This feature was noted by Russell (1905) in his pioneering study of central Oregon.

In thin section this flow is seen to contain rare phenocrysts of olivine, up to 0.3 mm across. Most of the rock is composed of 0.3 to 1 mm $An_{50}$ labradorite laths, 0.1 to 0.3 mm anhedral olivine crystals, 0.1 mm equant magnetite crystals and abundant 0.5 to 1 mm needle shaped apatite crystals. Groundmass glass is commonly altered to a yellow clay material. Samples of the entablature of this flow are similar mineralogically but are much glassier than those from the colonnade. Thin sections from this part of the flow are largely opaque, with transparent minerals surrounded by dark black glass (Fig. 19). This distinctive feature has been noted by Jay (1982) and Hayman (1983) in a similar flow found along the Deschutes River, near Pelton Dam and Gateway, respectively.

Oriented samples were collected from several localities in and near the thesis area. These were all found to show normal magnetic polarities. Major oxide analyses (Appendix 2) resemble the Prineville chemical type defined by Uppuluri (1974) and reported by Nathan and Fruchter (1974) and Jay (1982). This chemical type is characterized by high contents of $P_2O_5$ and Ba.

Discussion

Flows of Prineville chemical type have been found in widely distributed exposures in central Oregon as well as in the western Cascades. Uppuluri (1974) described a section of thirteen Prineville type flows, one normal overlain by twelve reversed, at the

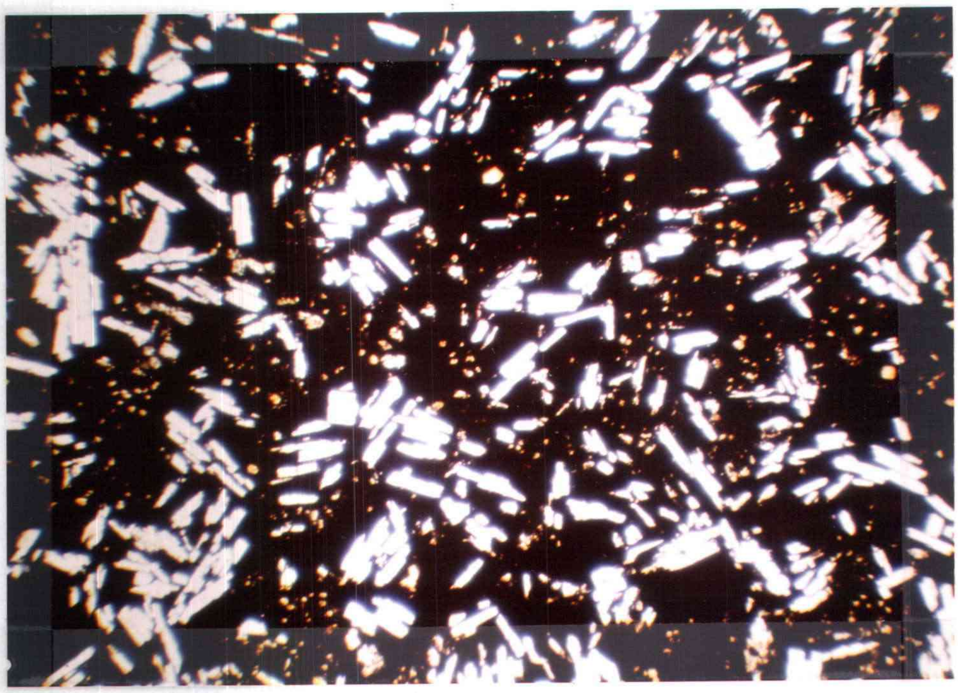

Fig. 19 Photomicrograph showing black glassy groundmass from the entablature of the Columbia River basalt flow near Prineville. Plane-polarized light, field of view 3.8 mm.

Prineville Dam. Nathan and Fruchter (1974) described a Prineville type flow exposed near Butte Creek as a distinctive flow with a very thick, hackly jointed entablature, that has a normal magnetic polarity. This flow is interlayered with low-MgO Grande Ronde flows. Nathan and Fruchter also described a normal flow found at Tygh Ridge which is also interlayered with low-MgO Grande Ronde flows. Jay (1982) described two normal flows of Prineville chemistry, that are separated by a fluvial interbed, exposed in the Deschutes River canyon, near Pelton Dam. The lower flow described by Jay has a thick, glassy entablature similar to the flow described in this study.

Flows of Prineville chemical type found in western Oregon were described by Hammond, Anderson and Manning (1980) and by Beeson and Moran (1979). Two reversed polarity flows were found interlayered with low-MgO Grande Ronde flows along the Clackamas River and a single flow with normal polarity was found in a drill hole at Old Maid Flat, west of Mount Hood.

It is often difficult to determine which magnetozone is represented by a particular flow unless its stratigraphic position is well defined. The Butte Creek section is perhaps the least confusing, stratigraphically. At Butte Creek the section contains three high-MgO Picture Gorge flows overlain by two low-Mgo Picture Gorge flows with one low-MgO Grande Ronde flow between them. These six flows are all normally magnetized. Above the six normal flows are two reversed low-MgO Grande Ronde flows which are overlain by one normal, low-MgO Grande Ronde flow, the Prineville type flow and two more normal, low-MgO Grande Ronde flows. It would seem that this section contains sufficient variety to establish a unique magneto-stratigraphic position for these flows.

Swanson et al. (1979) recognized that the interbedded Picture Gorge and Grande Ronde flows at Butte Creek must belong to the upper part of the $N_1$ magnetozone (Fig. 17). They are overlain by two Grande Ronde flows that represent the $R_2$ magnetozone in this section. The three Grande Ronde flows and the Prineville type flow, that form the upper part of this section belong to the $N_2$ magnetozone. These observations are consistent with the position of the $R_2$-$N_2$ contact, which consistently occurs three to five flows below the low-MgO high-MgO transition in the western part of the Columbia Plateau (Swanson et al., 1979).

At Tygh Ridge a basal low-Mgo, reversed polarity Grande Ronde flow is overlain by two normal polarity, low-MgO Grande Ronde flows which are in turn overlain by a normal polarity Prineville type flow. This sequence is overlain by eight low-MgO and six high-MgO, normal Grande Ronde flows. The section is capped by a reversed Frenchman Springs type flow (Nathan and Fruchter, 1974). It seems likely that the normal interval represented in the Tygh Ridge section is also the $N_2$ magnetozone because it contains the low-MgO high-MgO Grande Ronde transition, although there are a few extra low-MgO flows, compared with the section in the western Columbia Plateau.

Beeson and Moran (1979) placed the reversed polarity Prineville type flows found along the Clackamas River within the $R_2$ magnetozone. This assignment is based on the fact that these flows are interbedded with low-MgO Grande Ronde flows. The normal polarity Prineville type flow encountered in the Old Maid Flat drill hole is also interbedded with low-MgO Grande Ronde flows and probably represents the $N_2$ magnetozone.

Uppuluri (1973) suggested that the lower, normal polarity flow in the Prineville Dam section represents the $N_2$ magnetozone. This conclusion was based on the similarity between this flow and the Prineville type flow at Butte Creek. If this conclusion is correct the twelve overlying, reversed flows at Prineville Dam must be assigned to the $R_3$ magnetozone. This would be consistent with Uppuluri's (1973) contention that these flows are chemically similar to the Roza and Frenchman Springs types which occur near the top of the Wanapum Basalt, within the $R_3$ magnetozone.

The basal Prineville type flow found in the Deschutes River canyon, near Pelton Dam, is texturally similar to the flow found in the thesis area, with its thick, glassy, hackly jointed entablature. Both exposures display normal polarities and lie unconformably on John Day tuffs, as does the basal flow at Prineville Dam. It seems likely that these three exposures are all of the same flow, which probably represents the $N_2$ magnetozone. The upper flow along the Deschutes River also has normal magnetic polarity and probably belongs within the $N_2$ magnetozone as well. These assignments are speculative because the long range correlation of the lower, normal polarity flows with the flow at Butte Creek is based on very little data. The alternative is that these lower, normal flows belong within the $N_1$ magnetozone, with the twelve reversed flows at Prineville

Dam representing the $R_2$ magnetozone. This problem may be resolved in the future if exposures of Prineville type basalts are found betweeen Butte Creek and the Deschutes River area.

Age

Although the Columbia River Basalt Group was extruded over a 10 million year period (Swanson et al., 1979) the flows in the Prineville area can probably be restricted to the $N_2$ and $R_3$ magnetozones. The $N_2$ magnetozone corresponds to the upper part of the Grande Ronde Basalt. K-Ar dates for the Grande Ronde Basalt range from 16.5 m.y. to 14 m.y.; consequently the normal polarity flow in the thesis area is probably close to 14 m.y. old.

# RATTLESNAKE IGNIMBRITE TONGUE

## Introduction

J.C. Merriam (1901b) named the Rattlesnake Formation of the John Day Valley from exposures along Rattlesnake Creek near Cottonwood, and described it as a sequence of gravels, tuff and rhyolite. In the John Day Valley the Rattlesnake rests with angular unconformity on the Miocene Mascall Formation and was considered by Merriam (1901) to be Pliocene in age.

Calkins (1902) stated that somewhere near the middle of the Rattlesnake section there occurs a widespread sheet of light colored pumiceous tuff, overlain by a glassy gray rhyolite.

The Rattlesnake Ignimbrite Tongue was first described in the Harney Basin as the tuff breccia member of the Danforth Formation by Piper et al. (1939). The occurrence of the Rattlesnake ignimbrite along the Crooked River was first reported by Chaney (1927).

Wilkinson (1950) suggested that this widespread sheet of pumiceous tuff and glassy gray rhyolite was actually an ignimbrite. Campbell et al. (1958) suggested that the Rattlesnake ignimbrite in the John Day Valley and the tuff breccia member of the Danforth Formation in the Harney Basin are both part of the same ash-flow sheet.

In the Harney Basin Green et al. (1972) referred to this unit as the ash-flow tuff of Double O Ranch. Enlows, Parker and Davenport (1973) suggested that the name Rattlesnake Ignimbrite Tongue be retained throughout its entire extent in keeping with the definition of a formation tongue given in the code of stratigraphic nomenclature. Walker (1979) stated that he preferred the name Rattlesnake Ash-flow Tuff but because this unit has the characteristics of a formation tongue the older term Rattlesnake Ignimbrite Tongue will be used here.

## Description

Three exposures of the Rattlesnake Ignimbrite Tongue are found in the northwest part of the thesis area. The best exposure is found on a southeast-facing hillside along a small creekbed in the SW 1/4 of the SW 1/4 of section 33, T12S, R15E. Smaller outcrops are found in a streambed just upstream from the pond in the center of section 31, T12S, R15E and in the wash that passes through the SW 1/4 of the SW 1/4 section 31, T12S, R15E.

Within the thesis area, the Rattlesnake Ignimbrite is light brownish gray (5 YR 6/1), unzoned and only slightly welded (Fig. 20). The matrix is composed mainly of fresh glass shards and less than 1 percent phenocrysts of quartz and feldspar. Dense white pumice lapilli and accidental lithic fragments make up 1 to 2 percent of the rock by volume. Lithic fragments are mainly angular, lapilli-sized pieces of andesite and rhyolite from the underlying Clarno and John Day Formations.

In thin section it can be seen that the matrix is composed of both clear and brown glass shards and contains euhedral to

Fig. 20 Fine-grained, nonwelded ash-flow tuff with angular inclusions of Clarno andesite. Represents the western end of the Rattlesnake Ignimbrite Tongue, SW 1/4, SW 1/4, section 33, T13S, R15E.

subhedral 1-2 mm phenocrysts of anorthoclase, quartz and rare green clinopyroxene (Fig. 21).

Phenocrysts separated from pumice extracted from the exposure in section 33 were identified by Taylor (personal communication, 1983) as hedenbergite, magnetite and zircon, as well as small amounts of quartz and feldspar.

Additional exposures of the Rattlesnake Ignimbrite Tongue were found in Swartz Canyon and near Little Bear Creek within the Crooked River drainage south of the thesis area. At Little Bear Creek, a ridge covered with strongly welded boulders of Rattlesnake ignimbrite at an elevation of 4060 feet, leaves little doubt that the ignimbrite was emplaced here even though none of the material appears to be in place now. Within Swartz Canyon outcrops are abundant at elevations of 3160 to 3200 feet. The ignimbrite in both of these areas contains black, white and mixed pumice and phenocrysts of quartz and anorthoclase in the matrix. Taylor (personal communication) separated white pumice from the exposures in Swartz Canyon and found that it also contains phenocrysts of hedenbergite, magnetite and zircon. Chemical analyses of the white pumice from Swartz Canyon and from the thesis area (Appendix 2) are remarkably similar to analyses reported by Davenport (1971) from the Rattlesnake Ignimbrite Tongue in the Harney Basin.

The magnetic polarity of samples from Swartz Canyon and from the thesis area are both reversed, in agreement with polarities reported from other exposures of the Rattlesnake Ignimbrite Tongue (Parker, 1974).

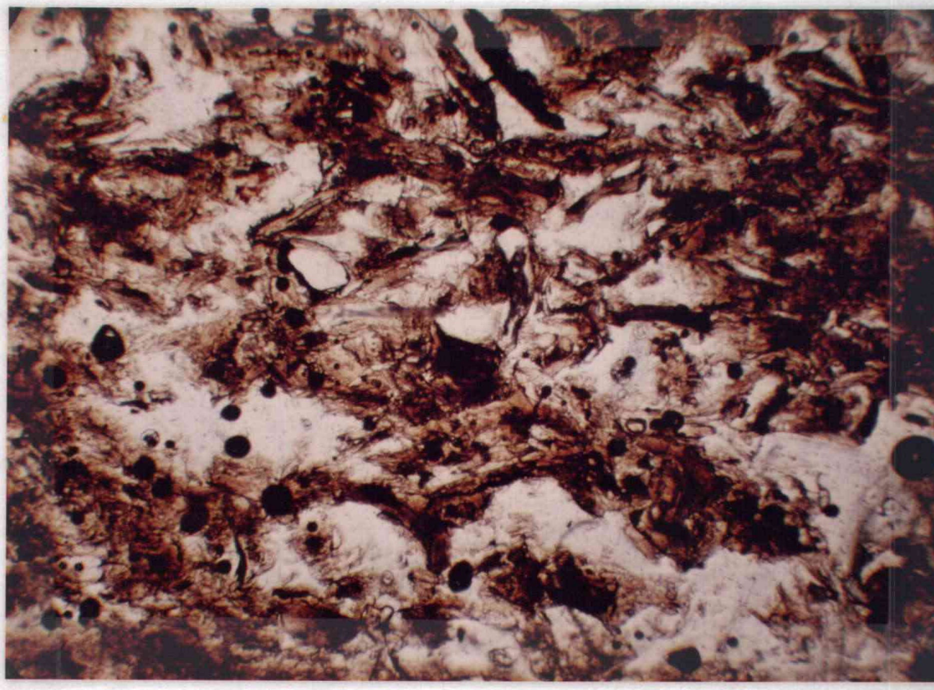

Fig. 21 Photomicrograph showing brown and clear glass shards in Rattlesnake ignimbrite. Plane-polarized light, field of view 3.8 mm.

Walker (1979) mapped and described a possible vent area for the Rattlesnake ignimbrite along Buzzard Creek, about 10 miles southwest of Harney Lake. In this area steeply inclined foliation and lineation defined by flattened and stretched pumice fragments in the basal part of the ash-flow are suggestive of fissure vents related to a northwest trending graben. This graben is spatially and probably genetically related to the Brothers fault zone. These structures within the ignimbrite could also have orginated by compaction, welding and draping of the ash flow over pre-existing fault scarps or by turbulent flow within the basal part of the ash flow.

Thickness variations within the Rattlesnake Ignimbrite Tongue also suggest a source area within the Harney Basin. Parker (1974) presented a pre-erosion isopach map of the Rattlesnake ignimbrite, showing the thickest part to be in the area around Buzzard Creek (Fig. 22).

The Rattlesnake ignimbrite has long been considered to be Pliocene in age (Merriam, 1901; Merriam, Stock and Moody, 1925; Chaney and Axelrod, 1959). Potassium-argon age dates from several exposures of the Rattlesnake Ignimbrite Tongue indicate an average age of 6.6 ± .2 m.y. (Parker, 1974; Davenport, 1970).

## Emplacement

The Rattlesnake ignimbrite was erupted from fissure vents within the Harney Basin about 6.6 million years ago. It is found as far north as Sutton Mountain and Monument and as far south as Hart

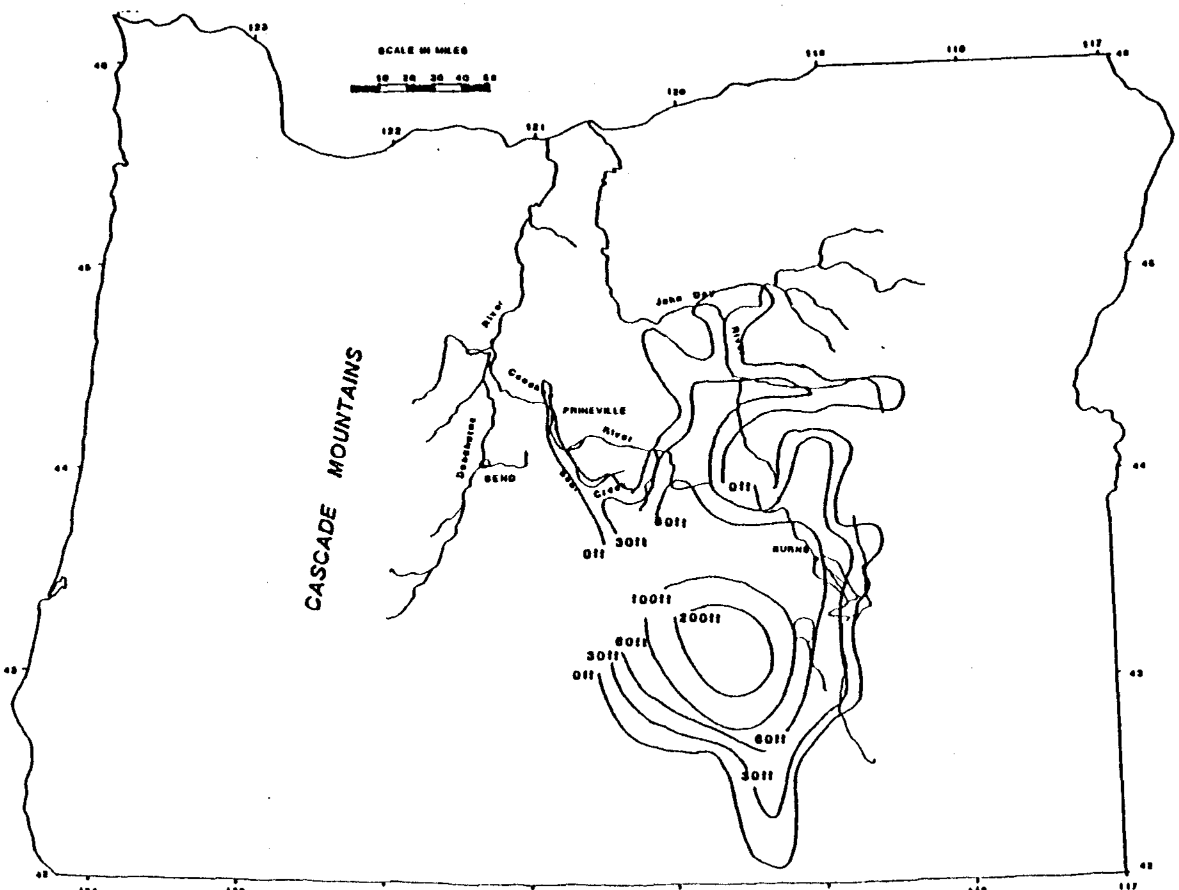


Fig. 22 Pre-erosion isopach map of the Rattlesnake Ignimbrite Tongue. Adapted from Parker (1974).

Mountain Antelope Refuge. It is thickest in the Harney Basin but is not found very far east of Burns. The western limit of Rattlesnake distribution has been a subject of speculation (Parker, 1974).

As the ignimbrite traveled north it entered the John Day and upper Crooked River drainages. To get to the area near Grizzly the ignimbrite must have traveled northwest across the plateau now occupied by Hampton Butte and Glass Buttes, then entered the southern part of the Crooked River drainage near the present site of Little Bear Creek. Following the ancestral Crooked River, the ignimbrite tongue reached the Prineville Valley. The deposits of Rattlesnake ignimbrite near Grizzly lie at elevations of 3680 and 3480 feet. If the ash-flow entered this area by way of the Crooked River, the deposits document at least 500 feet of post 6.6 m.y. uplift for the Grizzly area relative to Swartz Canyon. The lowest pass on the divide between Prineville and Grizzly is 4160 feet. If the 500 feet of uplift is removed this point is still 500 feet higher than the Rattlesnake ignimbrite in Swartz Canyon. If the amount of uplift was closer to 1000 feet the ash-flow could have traveled downhill all the way from Swartz Canyon to Grizzly. The ash-flow apparently dropped 900 feet from Little Bear Creek to Swartz Canyon; another 500 feet of descent between Swartz Canyon and Grizzly would not be unreasonable.

Although the exposures of Rattlesnake ignimbrite near Grizzly are far removed from their source it is likely that the ash-flow traveled still farther to the northwest. The largest outcrop near Grizzly is 15 feet thick and still contains many lithic fragments.

The matrix shards are slightly welded and flattened although the pumice fragments are undeformed.

The likelihood of finding more of the Rattlesnake ignimbrite to the northwest and southwest is hampered by a general lack of exposures of older rocks beneath much of the High Lava Plains.

The extreme distal ends of this ignimbrite may have been overlooked in the Deschutes Basin and in wells drilled in the areas west and northwest of the Harney Basin. The most obvious clue to the identification of this ash-flow sheet is the presence of dipyramidal quartz phenocrysts in the matrix which are not typical of Deschutes Formation ash-flows. These crystals are easily recognized in crushed samples and cuttings from wells. The presence of hedenbergite is the most important mineralogical fingerprint of the Rattlesnake ignimbrite but unfortunately it is only seen in 60 percent of the thin sections.

# DESCHUTES FORMATION

## Tuffaceous Sediments

An assortment of tuffs and tuffaceous sediments is exposed in the washes surrounding Grizzly Mountain and probably underlies much of the alluvial fan in that area. These rocks are of post John Day age and probably correlative, at least in part with the Deschutes Formation (Russell, 1905).

Light brownish-gray (5 YR 6/1) epiclastic tuffaceous sediments make up the bulk of this material. The best exposures are in the washes that pass through the NE 1/4 section 1, T13S, R15E and the SE 1/4 section 6, T13S, R15E, where the sediments consist of cross-bedded fine-to coarse-grained tuffaceous sandstones with interbedded pebble and cobble conglomerates (Fig. 23).

Exposures of Deschutes sediments on the southwest side of Grizzly Mountain are nearly structureless and consist of massive fine-to coarse-grained tuffaceous sands with interbedded lenses of sandy pumiceous tuff.

Continuous exposures of Deschutes sediments are lacking on the southern flanks of Grizzly Mountain but enough outcrops of this tuffaceous material were found in the washes south and west of Grizzly Mountain to suggest that a 250-300' thick wedge of volcaniclastic debris underlies the alluvial fans and talus piles on the southwest side of Grizzly Mountain.

The occurrence of Deschutes sediments between 3400 and 3600 feet in this area indicates that pyroclastic material from the

Fig. 23 Typical exposure of epiclastic tuffaceous sediments which probably represent part of the Deschutes Formation, NE 1/4, NE 1/4, section 1, T13S, R14E.

ancestral Cascades was deposited in the western Ochoco Mountains. Some of this material was washed downstream into the Deschutes Basin and it appears that a gently sloping wedge of sediment formed between the western Ochocos and the central part of the Basin.

Russell (1905) and Robinson and Price (1963) suggested that much of the Prineville Valley is underlain by thick poorly consolidated tuffs which they considered to be part of the Deschutes Formation. It is likely that the Prineville Valley acted as a higher restricted basin separated from the main Deschutes Basin by older lavas of the John Day Formation and Columbia River Group.

### Pumice-Lapilli Tuff

Several small exposures of pumice-lapilli tuff are found in road cuts and excavations of the dissected pediment surface that forms the south flank of Grizzly Mountain. These deposits are 3 to 5 feet thick and are composed of 5 to 10 mm light brownish-gray hydrated pumice lapilli overlain by thin layers of reworked pumice lapilli. The reworked layers are slightly cemented by iron hydroxides which also stain these zones.

### Rimrock Basalt

A single flow of diktytaxitic, high-alumina basalt is exposed along Newbill Creek, at the northern edge of the map. This flow can be traced on aerial photographs to within 2 miles of Madras, a distance of 10 miles. Boulders of similar basalt were found in the creekbed in the SE 1/4 of section 25, T12S, R14E, indicating that the basalt flow once covered part of that area as well.

The high-alumina basalt flow is not well exposed within the thesis area, where it is found as water-worn outcrops in a creekbed. A thickness of over 30 feet was observed downstream, northwest of the thesis area.

In hand sample the rock is medium gray (N 5) and has the diktytaxitic texture that characterizes similar high-alumina basalts throughout the High Lava Plains province.

In thin section it is seen that this rock is composed mainly of $An_{45}$ andesine laths and anhedral augite crystals with rare phenocrysts of olivine and strongly zoned labradorite. Magnetite makes up nearly 5 percent of the rock.

The chemical composition compares with Waters' (1962) average composition of 21 high-alumina basalts from Oregon (Appendix 2).

The high-alumina basalts that form the rims of many of the canyons within the Deschutes Basin have been included within the Deschutes Formation (Forooqui et al., 1981). Most of the high-alumina basalts can be traced to source vents that are marked by low shield volcanoes which rest on the basalt plateaus. The high alumina basalt flow that is found within the thesis area was extruded from a shield volcano that lies 1 mile north of the thesis area.

Paleontology and Age

Hodge (1928) was the first to recognize that the Deschutes Formation is equivalent to the Dalles and Satsop Formations which are exposed along the Columbia River. He consolidated these units into his Madras Formation which he considered to be late Pleistocene or post-Pleistocene based on its undisturbed position.

Chaney (1938a) discussed the Deschutes flora which was discovered in 1936. Only 5 forms were found but when considered with evidence from the Satsop and Dalles beds and structural and stratigraphic similarties between the Deschutes and Rattlesnake Formations, Chaney (1938a) concluded that the Deschutes Formation is lower to middle Pliocene in age.

K-Ar dates of 4.3 m.y. and 5.3 m.y. for the tuff that yielded the Deschutes flora confirm the middle Pliocene Age assignment (Evrenden and James, 1964). K-Ar dates of 5.8 ± 1.0 m.y and 4.9 ± 0.5 m.y. were obtained from two basalt flows which are interlayered with the upper part of the Deschutes Formation (Armstrong <u>et al</u>., 1975). The Pelton basalt, which is found near the base of the Deschutes Formation, yielded an $^{40}Ar/^{39}Ar$ age of 7.6 ± 0.3 m.y. (Smith and Snee, 1984).

# QUATERNARY DEPOSITS

## Landslides

Landslides with characteristic hummocky topography and jumbled talus piles are seen on the oversteepened slopes of Grizzly Mountain and along the contact between John Day rhyolites and the underlying Clarno Formation. The rhyolites form a resistant cap rock that is underlain in places by deeply weathered Clarno andesites and saprolite layers. These soft clay rich horizons weather easily leading to landsliding of the oversteepened slopes.

## Terrace Deposits

Terrace deposits of rounded boulders of Clarno andesites and John Day welded tuffs are found overlying rhyolite and tuff of the John Day Formation in sections 28 and 35, T13S, R15E. These gravels were deposited by streams that were once active at these elevations.

## Alluvial Fans

Alluvial fans surround most of Grizzly Mountain and are also found on the slopes below outcrops of Columbia River basalt. These fans are composed of blocky angular talus that conceals the underlying geology. The fans around Grizzly Mountain are dissected in places, revealing the underlying tuffs and tuffaceous sediments.

## Pumice-Lapilli Tuff

A small outcrop of fresh white pumice-lapilli tuff is found along the creek in the SE 1/4 of section 25, T12S, R14E (Fig. 24).

Fig. 24 Outcrop of fresh air-fall and reworked pumice-lapilli tuff, probably of Quaternary age, SW 1/4, section 25, T12S, R14E.

This outcrop has a 10 cm thick basal ash layer which rests on stream gravels. The thin ash layer is overlain by 10 feet of fresh white 5 to 10 mm pumice lapilli. This section of fresh pumice is overlain by 8 feet of reworked pumice lapilli which is slightly cemented and stained with iron hydroxides.

### Alluvium

Two remnants of older alluvium form small hills within the flat Prineville Valley. This alluvial material overlies John Day tuffs which are exposed in road cuts in section 5, T14S, R15E. South of the thesis area it is evident that similar hills represent an old alluvial surface that has since been dissected. Robinson and Price (1963) suggested that this surface was the result of a filled-in lake which formed behind a late Pleistocene lava dam across the Crooked River, 8 miles west of Prineville.

# STRUCTURAL GEOLOGY

Flows of the Clarno Formation generally dip to the south within the thesis area, forming part of the southern limb of the Blue Mountains anticline, which is actually an anticlinorium with associated synclinal basins. The axial trace of this broad uplift has a northeast to southwest-trend with its axis passing to the north of the thesis area.

The basal ash-flow tuff of the John Day Formation dips 42$^{o}$ to the northwest in section 29, T12S, R15E. The trachyandesite flow in section 29, T12S, R15E, appears to have followed a channel developed in the soft tuff above the basal John Day ash-flow sheet. This flow now dips gently to the southwest indicating either a change in fold trends or an episode of faulting between the emplacement of member A and member B of the John Day western facies.

Rhyolites and the upper John Day tuffs generally dip to the south conforming with the attitude of member B trachyandesites. This angular unconformity between members A and B of the John Day Formation is probably related to folding along the Blue Mountains uplift which restricted all younger John Day ash-flows to the western facies.

The Columbia River basalt flow in the southwest corner of the area is folded into a broad syncline that plunges to the south. The western limb of this fold is shown in Figure 25. The complete section from Clarno and John Day rocks at Gray Butte on the west to

Fig. 25 View from Grizzly Mountain looking southwest toward Gray Butte and Smith Rocks. Gray Butte and Grizzly Mountain represent opposing limbs of a broad syncline which has also folded the Columbia River basalt flow in the left part of the picture.

the Columbia River basalt on the east dips to the east. The Columbia River basalt can be followed into the thesis area. The dips gradually change from east to south to west while driving from Smith Rocks to Highway 26 and into Prineville.

Shortly after the emplacement of the Rattlesnake ignimbrite, the northern part of the thesis area was uplifted 500 to 1000 feet. This episode probably represents renewed unplift along the Blue Mountains Anticline. Tuffaceous deposits of the Deschutes Formation lie relatively undisturbed within the area indicating a lack of significant deformation since these sediments were deposited.

The occurrence of east-west trending dikes in the northeast one quarter of the Prineville quadrangle indicates the presence of east-west structures within the Clarno formation and dikes which are consistent with an east-west compressional stress field. Bingert (1984) also found small east-west trending faults and dikes in the northeast one quarter of the Prineville quadrangle.

It does not appear that faulting has had much of an effect on the area. Lawrence (Simonson _et al_., 1974) noted east-west-trending lineaments within the Clarno Formation in the area. These may represent high angle faults like those found cutting Pliocene basalts in the Maury Mountains (Walker 1977). Field checking of the lineaments in the area did not reveal noticeable displacement, but with the discontinuous nature of the Clarno Formation a minor fault could remain undetected.

# ECONOMIC GEOLOGY

## Geothermal Energy

One of the objectives of this study was to see if geologic features exposed in the area could help explain the occurrence of warm water wells at Powell Buttes. Structural control of the geothermal anomaly at Powell Buttes has been suggested by Brown et al. (1980). The only major structure exposed in the thesis area is the southward plunging syncline to the west of the map boundary. This syncline plunges directly toward Powell Buttes but Brown et al. (1980) suggested that the anomaly was caused by convective circulation of thermal waters along a fault zone. The syncline does not help explain the thermal anomaly but may control potential reservoir depths.

## Silver

Four samples of mineralized breccias were analyzed for gold, silver and mercury (Appendix 3). Minor silver and mercury anomalies are associated with manganite-bearing breccias from SW 1/4, SE 1/4, SE 1/4, section 21 and NE 1/4, NE 1/4, NW 1/4, section 34, T13S, R15E (Fig. 16). Lesser values of silver and mercury were found in a siliceous pyrite-bearing breccias from SW 1/4, SE 1/4, SW 1/4, section 35, T13S, R15E.

The 470 ppb mercury anomaly is an order of magnitude greater than the 40 ppb average, and the 7.3 ppm silver anomalies are nearly

200 times the average value for granitic rocks (Rose, Hawkes, and Webb, 1979).

Mercury is typically associated with epithermal mineralization and geothermal activity. The minor silver anomalies with almost no associated gold may indicate a type of disseminated silver deposit that is also characteristically associated with managanese oxides (Graybeale, 1981). Because silver is usually leached from supergene zones it is possible that the silver content is greater at depth. Further sampling of these breccias and related rocks throughout the region may lead to the discovery of economic silver deposits in central and eastern Oregon.

# GEOLOGIC HISTORY

The oldest rocks found in the thesis area are mafic lavas of the Clarno Formation. Similar lavas from the Mitchell area have yielded K-Ar ages as old as 46.1 m.y. (Enlows and Parker, 1972). The Clarno Formation rests unconformably on Mesozoic and Paleozoic sediments and metamorphic rocks which are exposed to the east and north of the thesis area. The presence of lawsonite blueschists and serpentines near Mitchell (Swanson, 1969b) suggests that part of the pre-Tertiary sequence formed in a subduction zone.

The presence of lake beds and land flora, and the complete lack of pillow structures indicate that the Clarno Formation is entirely terrestrial and marks the end of marine deposition in central Oregon.

Chemical properties of Clarno lavas indicate that the formation is dominantly calc-alkaline, suggesting that it may have formed above an ancient subduction zone. The relationship between $K_2O$ and $SiO_2$ has been used to estimate depth to subduction zones and crustal thicknesses (Dickinson, 1975). Rogers and Novitsky-Evans (1977) concluded that the Clarno rocks could have formed 120 km above a $45^\circ$ subduction zone, placing the trench near the present location of the Siletz River volcanics in the Coast Range. They also noted that the $K_2O$ and $SiO_2$ values were more typical of island arc suites than they were of continental margin assemblages. This led to the conclusion that the Clarno formed on a thin continental crust near the continental margin, because the geologic evidence precludes an island arc setting.

Paleobotanical evidence compiled by Chaney (1956) indicates that a sub-tropical climate undoubtedly contributed to the deep weathering of Clarno lavas and the development of thick saprolite layers within the formation.

Individual lavas within the Clarno Formation can rarely be traced for more than a few miles and local stratigraphic relationships indicate that many flows were emplaced on surfaces with considerable relief. Local eruptive centers and thick deposits of lake beds are indicative of a region dominated by closely spaced volcanic cones with intervening lakes of various sizes.

Local angular unconformities within the Clarno Formation (Oles and Enlows, 1971; Waters et al., 1951) indicate that deformation was taking place during late Eocene and early Oligocene time. The unconformity at Keyes Mountain described by Oles and Enlows (1971) indicates that folding occurred between 37.5 and 32.7 m.y. ago. The angular unconformity found in the Horse Heaven Mining District (Waters et al., 1951) is overlain by rhyolite that was dated as 41.0 ± 1.2 m.y. (Swanson and Robinson, 1968). The abundance of saprolites found in the Clarno Formation is consistent with local volcanic episodes separated by periods of weathering. The apparent difference in age of the angular unconformities suggests that folding may have been fairly continuous with angular unconformities developing only where long periods of quiescence were followed by renewed volcanic activity.

A silicic late Clarno eruptive center within the thesis area indicates a change in local magma chemistry within the later stages of Clarno activity. This late Clarno silicic activity formed along an east-west trend and similar domes and flows are found to the east of the thesis area.

The John Day Formation represents the second major Tertiary volcanic episode in central Oregon. Local discordance and the presence of saprolite layers between the Clarno and John Day Formations indicate that there was a hiatus between these two major episodes of volcanism. K-Ar dates suggest that this period of quiescence was probably short, and some dates suggest an overlap in activity. There is no evidence of interlayering of Clarno and John Day rocks, so it does not seem likely that there was overlapping volcanic activity.

The beginning of John Day activity is marked by a 36.1 m.y. old ash-flow sheet in the western facies which is represented in the eastern facies by air fall deposits of the same composition (Swanson and Robinson, 1968). The John Day is typified by thick air-fall, water-laid, and wind-blown tuffs in the John Day and Crooked River basins. Locally derived lavas and extensive ash-flow sheets accumulated in the western Ochoco mountains at the same time and it is likely that much of the eastern material was derived from activity in the western Ochocos. Major ash-flow sheets were mainly deposited between Grizzly and Antelope, while the thesis area was dominated by large rhyolite dome complexes. Thick tuffs accumulated along the margins of the domes. During the later stages of John Day activity the area was covered by layers of ash from western sources. The ash accumulated in lake basins which were lined with redwood forests and had local swampy areas with cattails growing in them.

Hot springs and fumeroles were probably active during the later part of John Day time. This hydrothermal activity drew heat from the cooling rhyolite domes and produced traces of silver and mercury.

Fossil leaves from the area are similar to those found in the Bridge Creek flora. Dawn redwood, cattail and beech indicate a moist, increasingly temperate climate similar to the climate of northern California where redwoods grow today (Chaney, 1956).

The area was eventually covered by thick deposits of pumice-lapilli tuff which were derived from western volcanoes.

The mammal fauna from the upper John Day tuffs at Warm Springs has been interpreted to be as young as 18 m.y. old (Woodburne and Robinson, 1977). These tuffs are covered by a thick Prineville type Columbia River basalt flow which is probably between 14 and 15 m.y. old. This flow encountered wet clayey tuffs in the thesis area which may have been a lake at that time. Thirteen basalt flows are found at the Prineville Dam to the south and it seems likely that more flows once covered part of the thesis area.

The Columbia River basalt and older rocks were folded into a broad syncline that plunges to the south. Dips of flows become steeper lower in the section suggesting that folding was more or less continuous throughout the Oligocene and Miocene.

The Rattlesnake Ignimbrite Tongue was erupted from vents in the Harney Basin approximately 6.6 million years ago. The ignimbrite swept over a broad, relatively flat plateau, now the site of Glass Buttes and Hampton Butte, and entered the southern part of the ancestral Crooked River drainage. The ignimbrite traveled downstream to the north and probably passed over a small divide between Prineville and Grizzly. From the thickness found near Grizzly it seems likely that the distal end of this ignimbrite tongue is well out in the Deschutes Basin. Following the deposition of the ignimbrite the northern part of the thesis area was uplifted 500 to 1000 feet.

The Deschutes Formation began to accumulate above the folded rocks during the Pliocene. Most of this tuffaceous material originated in the west, near the present Cascade Range. The deposits near Grizzly and Prineville mark the eastern edge of the Deschutes Basin. The Deschutes Formation near Grizzly is capped by a high-alumina basalt flow that was extruded from a shield volcano just north of Willow Creek. K-Ar dates for other rocks found near the top of the Deschutes Formation indicate that the Deschutes is as young as 4.3 m.y. old (Evrenden and James, 1964).

The Deschutes flora indicates that the climate had become much drier by Pliocene time (Chaney 1956). The increasing aridity of central Oregon was a direct response to the growth of the ancestral Cascades which restricted the moist ocean air to western Oregon.

The youngest volcanic event recorded in the thesis area is represented by deposits of air-fall pumice-lapilli tuff. These local deposits were derived from explosive eruptions in the high Cascades.

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# APPENDICES

Appendix 1: Modal analyses of selected Clarno rocks. Sample numbers appear on Plate 1 for location purposes.

Volumetric modal analyses of phenocryst phases for selected rocks from the Clarno Formation. Pyroxene bearing andesite flows:

| sample | labradorite | augite | hypersthene | magnetite |
|---|---|---|---|---|
| DT-94 | 10.1% | 2.8% | 0.5% | 0.3% |
| DT-53 | 31.4% | 7.0% | 0.6% | 0.7% |
| DT-46 | 18.5% | 1.2% | 1.1% | — |
| DT-103 | 25.0% | 5.7% | 3.6% | 0.5% |
| DT-106 | 31.8% | — | 5.3% | — |
| DT-132 | 14.4% | 5.0% | — | — |

Pyroxene bearing andesite dikes:

| sample | labradorite | augite | hypersthene | magnetite |
|---|---|---|---|---|
| DT-168A | 23.2% | 3.0% | 3.1% | 0.5% |
| DT-171 | 15.0% | 3.6% | 2.6% | 0.2% |

Olivine bearing basalts:

| sample | labradorite | olivine | magnetite |
|---|---|---|---|
| DT-23 | 33.9% | 0.6% | — |
| DT-86 | — | 8.3% | 1.2% |

Oxyhornblende-bearing andesites:

| sample | andesine | oxyhornblende | magnetite |
|---|---|---|---|
| 184A | 9.7% | 0.8% | 0.2% |
| 159 | 5.7% | 0.9% | 0.2% |

Sample locations

| | |
|---|---|
| DT-94 | SW 1/4, NE 1/4, Sec. 10, T13S, R15E. |
| DT-53 | NE 1/4, NW 1/4, Sec. 25, T13S, R15E. |
| DT-46 | SW 1/4, SW 1/4, Sec. 25, T13S, R15E. |

| | |
|---|---|
| DT-103 | NW 1/4, NW 1/4, Sec. 14, T13S, R15E. |
| DT-106 | NE 1/4, NE 1/4, Sec. 15, T13S, R15E. |
| DT-132 | SW 1/4, SE 1/4, Sec. 11, T13S, R15E. |
| DT-168A | NW 1/4, SW 1/4, Sec. 36, T12S, R15E. |
| DT-171 | NW 1/4, SE 1/4, Sec. 35, T12S, R15E. |
| DT-23 | SW 1/4, NE 1/4, Sec. 1, T13S, R15E. |
| DT-86 | SW 1/4, SE 1/4, Sec. 28, T12S, R15E. |
| DT-184A | NE 1/4, SW 1/4, Sec. 12, T13S, R15E. |
| DT-159 | NE 1/4, NE 1/4, Sec. 11, T13S, R15E. |

Appendix 2: Chemical analyses.

Sources: Jay (1982), Nathan and Fruchter (1974), Peck (1964), Robinson (1969), Robinson and Brem (1975), Taylor (personal communication 1983), Thormahlen (this study), analysed at Washington State University x-ray fluorescence lab, and Waters (1961).

Major oxide analyses of trachyandesites from the John Day Formation, member B:

| sample | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $SiO_2$ | 54.42 | 54.65 | 57.78 | 54.32 | 55.84 |
| $TiO_2$ | 2.86 | 2.86 | 1.75 | 2.87 | 1.84 |
| $Al_2O_3$ | 13.44 | 13.72 | 14.18 | 13.97 | 13.47 |
| $Fe_2O_3$ | 14.16* | 14.52* | 2.69 | 4.48 | 1.74 |
| FeO | — | — | 9.22 | 8.92 | 11.64 |
| MnO | 0.22 | 0.21 | 0.17 | 0.17 | 0.29 |
| MgO | 3.37 | 2.95 | 1.70 | 2.77 | 1.94 |
| CaO | 7.72 | 7.85 | 5.51 | 7.03 | 6.33 |
| $Na_2O$ | 2.74 | 2.19 | 3.78 | 3.34 | 2.86 |
| $K_2O$ | 1.43 | 1.40 | 1.66 | 1.57 | 2.04 |
| $P_2O_5$ | 0.43 | 0.46 | 0.55 | 0.57 | 0.69 |
| $CO_2$ | — | — | — | — | 1.33 |
| Total | 100.79 | 100.81 | 98.99 | 100.01 | 100.01 |

1 DT-78B from NE 1/4, SE 1/4, Sec. 29, T12S, R15E.

2 DT-191 from SE 1/4, SE 1/4, Sec. 36, T12S, R14E.

3 648-181 from Robinson (1969) NW 1/4, SE 1/4, Sec. 23, T7S, R19E.

4 648-578 from Robinson (1969) SE 1/4, SE 1/4, Sec. 20, T8S, R17E.

5 DLP-58-41 from Peck (1964) Sec. 10, T10S, R16E.

* All iron shown as $Fe_2O_3$

Major oxide analyses of rhyolites from the John Day Formation:

| sample | 6 | 7 |
|---|---|---|
| $SiO_2$ | 77.76 | 76.30 |
| $TiO_2$ | 0.27 | 0.29 |
| $Al_2O_3$ | 12.53 | 12.50 |
| $Fe_2O_3$* | 0.57* | 2.17* |
| MnO | 0.01 | 0.12 |
| MgO | 0.25 | 0.06 |
| CaO | 0.26 | 0.46 |
| $Na_2O$ | 3.61 | 3.10 |
| $K_2O$ | 4.72 | 5.10 |
| $P_2O_5$ | 0.05 | 0.02 |
| Total | 100.03 | 100.12 |

6 DT-26 rhyolite flow from SE 1/4, SW 1/4, Sec. 22, T13S, R15E.

7 648-27 and 648-5 - average of two analyses from Robinson and Brem (1981).

* All iron shown as $Fe_2O_3$, recalculated $H_2O$ free.

Major oxide analyses of Prineville type basalts from central Oregon:

| sample | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|
| $SiO_2$ | 50.54 | 52.38 | 54.48 | 51.31 | 50.35 | 49.70 |
| $TiO_2$ | 2.66 | 2.58 | 2.66 | 2.78 | 2.69 | 2.64 |
| $Al_2O_3$ | 13.59 | 13.76 | 15.64 | 14.57 | 13.68 | 14.69 |
| MgO | 4.35 | 3.74 | 3.51 | 4.55 | 4.38 | 4.80 |
| $Fe_2O_3$* | 13.38 | 13.27 | 11.26 | 13.83 | 13.55 | 13.25 |
| MnO | 0.24 | 0.23 | 0.24 | 0.24 | 0.24 | 0.25 |
| CaO | 7.96 | 7.80 | 6.24 | 7.86 | 7.88 | 7.85 |
| $Na_2O$ | 3.29 | 3.50 | 2.70 | 2.84 | 3.27 | 3.31 |
| $K_2O$ | 1.98 | 2.08 | 2.96 | 1.95 | 1.86 | 1.90 |
| $P_2O_5$ | 1.36 | 1.39 | 1.23 | 1.25 | 1.37 | 1.40 |
| Total | 99.35 | 99.41 | 100.92 | 101.18 | 99.28 | 99.79 |

8 Average of 13 flows from Prineville Dam section (Uppuluri, 1974).

9 Average of 6 analyses from one flow SW 1/4, SW 1/4, Sec. 5 and NW 1/4, NW 1/4, Sec. 8, T14S, R15E and NW 1/4, NE 1/4, Sec. 19, T14S, R15E (this study).

10 126-2 Upper flow near Pelton Dam (Jay, 1982).

11 128 Lower flow near Pelton Dam (Jay, 1982).

12 13-11 Butte Creek flow (Nathan and Fruchter, 1974).

13 Ty-4 Tygh Ridge flow (Nathan and Fruchter, 1974).

* All iron recalculated as $Fe_2O_3$.

Major oxide analyses of high-alumina basalts:

| sample | 14 | 15 |
|---|---|---|
| $SiO_2$ | 50.93 | 49.15 |
| $TiO_2$ | 1.14 | 1.52 |
| $Al_2O_3$ | 17.92 | 17.73 |
| $Fe_2O_3$ | 10.16* | 2.76 |
| FeO | — | 7.20 |
| MnO | 0.16 | 0.14 |
| MgO | 5.97 | 6.91 |
| CaO | 11.14 | 9.91 |
| $Na_2O$ | 2.70 | 2.88 |
| $K_2O$ | 0.28 | 0.72 |
| $P_2O_5$ | 0.18 | 0.26 |
| $H_2O$ | | 0.65 |
| $CO_2$ | | 0.06 |
| Total | 100.01 | 99.89 |

14 DT-184b from SE 1/4, NE 1/4, Sec. 30, T12S, R15E.

15 Average of 21 high-alumina basalts from Oregon (Waters, 1962).

* All iron shown as $Fe_2O_3$.

Major oxide analyses of the Rattlesnake Ignimbrite:

| sample | 16 | 17 | 18 | 19 |
|---|---|---|---|---|
| $SiO_2$ | 75.0 | 75.3 | 77.1 | 75.4 |
| $TiO_2$ | 0.22 | 0.22 | 0.10 | 0.11 |
| $Al_2O_3$ | 13.4 | 12.2 | 11.3 | 11.5 |
| FeO* | 2.04 | 0.21 | 0.86 | 1.28 |
| MnO | 0.039 | 0.041 | — | — |
| MgO | 0.6 | 0.58 | 0.3 | 0.5 |
| CaO | 0.61 | 0.30 | 0.56 | 0.49 |
| $Na_2O$ | 3.5 | 3.36 | 2.8 | 2.6 |
| $K_2O$ | 4.7 | 3.74 | 5.90 | 5.71 |
| $P_2O_5$ | 0.04 | 0.01 | — | — |
| Total | 100.15 | 96.46 | 98.92 | 97.59 |

16 Average of three analyses from the Paulina Basin (Davenport, 1971).

17 Average of five analyses from the John Day Valley (Enlows' unpublished data *in* Davenport, 1971).

18 Swartz Canyon Exposure (Taylor, unpublished).

19 DT-177 from exposure near Grizzly (Taylor, unpublished).

* All iron recalculated to FeO.

Appendix 3: Gold, silver and mercury analyses of John Day breccias.

Gold, silver and mercury contents of mineralized breccias:

| sample | Au (ppm) | Ag (ppm) | Hg (ppb) |
|---|---|---|---|
| DT-28A | * | 2.3 | 230 |
| DT-28B | * | 7.3 | 60 |
| DT-61 | * | 7.3 | 470 |
| DT-110 | * | 1.0 | 130 |

* less than 0.02 ppm.

DT-28A Manganite-and goethite bearing rhyolite breccia from SE 1/4, SE 1/4, Sec. 21, T13S, R15E.

DT-28B Quartz rich breccia from same location as DT-28A.

DT-61 Manganite-and goethite-bearing tuff breccia from NE 1/4, NW 1/4, Sec. 34, T13S, R15E.

DT-110 Siliceous pyrite-bearing breccia from SE 1/4, SW 1/4, Sec. 35, T13S, R15E.