THE GEOLOGY OF THE JUNIPER BUTTE AREA
SPRAY QUADRANGLE, OREGON

by

ROBERT JAMES IRISH

A THESIS

submitted to

OREGON STATE COLLEGE

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1954

APPROVED:

Redacted for privacy

Professor of Geology

In Charge of Major

Redacted for privacy

Chairman of Department of Geology

Redacted for privacy

Chairman of School Graduate Committee

Redacted for privacy

Dean of Graduate School

Date thesis is presented May 6, 1954

Typed by Betty M. Cohen

ACKNOWLEDGEMENT

The writer wishes to thank his major professor, Dr. W. D. Wilkinson, for the many hours that he spent advising the author, and constructively criticizing the author's work.

Another word of thanks is directed to Dr. L. F. Hintze, who directed the writer's attention to the Juniper Butte area.

Dr. A. E. Aho gave his time freely to help the author petrographically study the rocks of the Juniper Butte area; Mr. Harold Boyd identified the one fossil collected from the area; and Messrs. Harold Hess and Lawrence Brown of the Albany Bureau of Mines analysed a specimen of the John Day altered tuff for the author.

A special word of appreciation is directed to Dr. I. S. Allison, who edited the manuscript.

TABLE OF CONTENTS

ILLUSTRATIONS

GEOLOGY OF THE JUNIPER BUTTE AREA

SPRAY QUADRANGLE, OREGON

INTRODUCTION

Purpose of the Investigation

The study of the geology of the Juniper Butte area is devoted to pure science and is intended to further the knowledge of the geologic history of north-central Oregon.

Special emphasis has been placed upon the petrographic study of Clarno and Columbia River basalts in an attempt to establish distinguishing criteria.

History of the Investigation

The field work was completed during the summer of 1953. Slightly more than two months were spent in the field.

Laboratory work, conducted during the following winter, consisted of microscopic analysis of specimens representative of the rock types of the area. Modal analyses were estimated.

The base map is a preliminary blue-line sheet produced from aerial photographs and issued by the U. S. Geological Survey. The township, range, and section lines were plotted on the map as carefully as possible by referring to a U. S. Forest Service map of the same area.

The geology was plotted originally on aerial photographs. These photographs, taken in 1951, at a scale of 1:20,000, were obtained from the Production and Marketing Administration of the U. S. Department of Agriculture.

Rock colors have been described by reference to the Rock-Color Chart prepared by the Rock-Color Chart Committee of the National Research Council.

Previous Work

No one previously had worked specifically in the Juniper Butte area. However, a few regional studies of the John Day basin, of which the Juniper Butte area is a part, have been conducted.

The initial work in the John Day basin was done by Thomas Condon, an Irish-born Congregational missionary to the Oregon country. From 1865 to 1873, Condon took several excursions into central Oregon to collect fossils and to study the geology. The stratigraphic sequence established by Condon has remained unchanged; only the ages of the formation have been defined more accurately by later, more detailed study.

John C. Merriam (22), a University of California paleontologist, published a classical paper on the stratigraphy and paleontology of the John Day basin in 1901.

Calkins (5) was the first to study petrographically the rocks of the John Day basin.

Recently, graduate students from Oregon State College have mapped much of the area adjacent to the Juniper Butte area. To the west Bowers (3), Swarbrick (28), McIntyre (20), and Bedford (2) studied the geology of the Mitchell quadrangle. Dobell (11), Dawson (10), and Taubeneck (29) studied the geology of areas in the Dayville quadrangle that border the Juniper Butte area on the south.

Coleman (8) studied the geology of an area that borders the Juniper Butte area on the east.

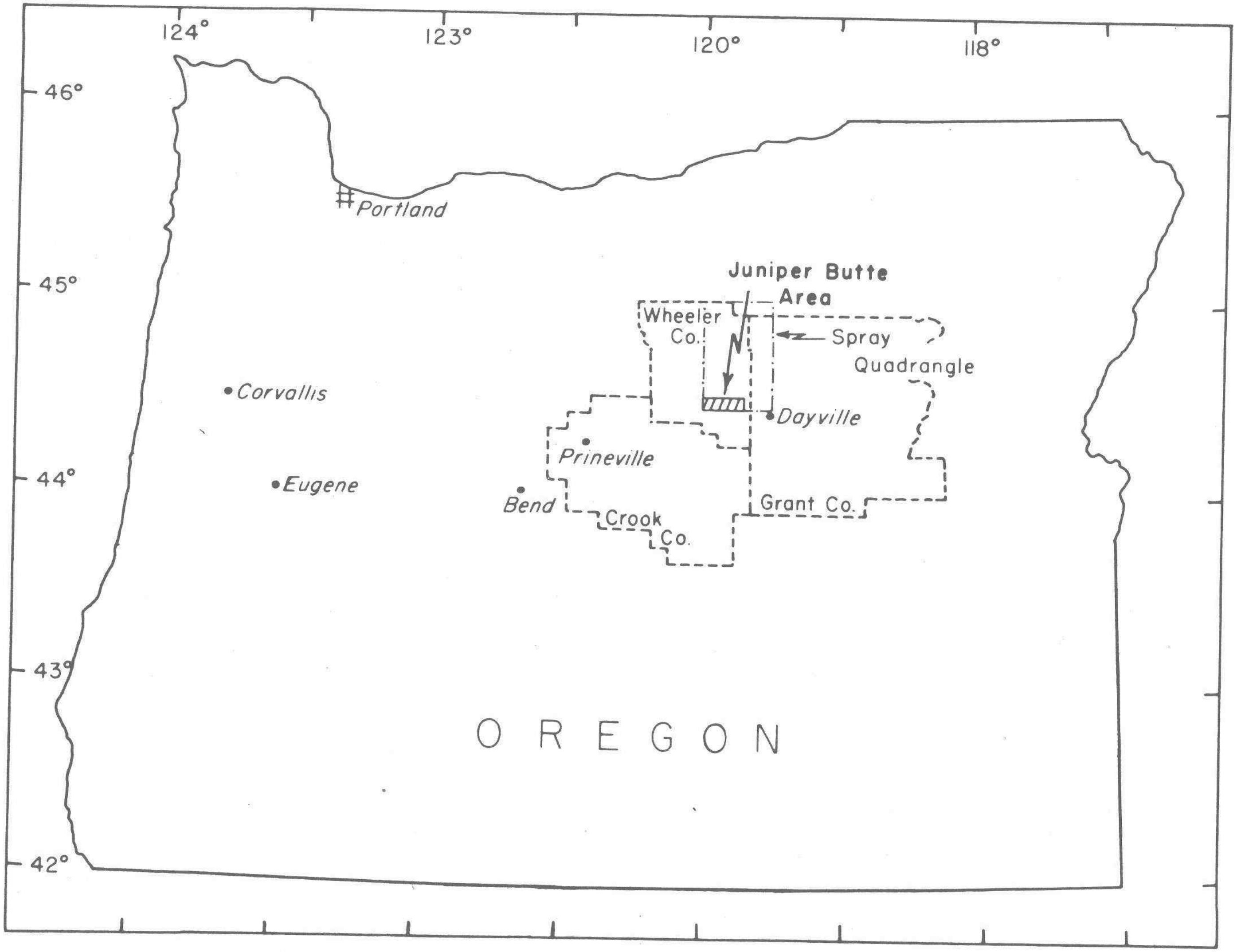


Plate I Index map showing the location of the Juniper Butte area, Oregon.

GEOGRAPHY

Location and Size

The Juniper Butte area covers 97.5 square miles in southeast Wheeler County, in north-central Oregon. The area lies between 119° 41'48" and 120° 00'00" west longitude, and 44° 30'00" and 44° 35'35" north latitude. The area is in Fenneman's Walla Walla Plateau section of the Columbia River Plateau physiographic province.

The geographic location is indicated by plate I.

Accessibility

The Ochoco Highway, U. S. 28, follows the course of Mountain Creek, which flows eastward through the area. This macadam highway connects the Juniper Butte area with Prineville on the west and with Dayville on the east. Dirt and gravel logging roads, entering from both the north and south, join the main highway. Most of these roads are kept in excellent condition, but those no longer needed for logging are not maintained and fall rapidly into disrepair.

Topographic Relief

Juniper Butte, with an elevation of 5537 feet, is the highest point in the area (see fig. 1); Rock Creek, at its intersection with the east boundary of the area, has the lowest elevation, 2566 feet. The maximum relief is 2971 feet. The average elevation is about 3400 feet.

Erosion has reached the stage of late youth or early maturity. Short, narrow, flat patches of ground remain on a few of the

Figure 1. A view northeastward to Juniper Butte, which stands in the center background. Thirteen flows of Columbia River basalt can be counted on the south side of the butte.

basalt-capped hills; generally, all traces of a former land surface have been removed.

Climate

Jensen (14, pp. 7-10) states that the semi-arid climate of central Oregon is characterized by a growing season of 120-159 days; rainfall of 10-20 inches per year principally from October to April; and average temperatures of 28 degrees in winter and 63 degrees in summer.

The climate is controlled primarily by three factors: first, the average elevation is about 3400 feet; second, the Rocky Mountain System effectively blocks the invasion of interior dry air masses; and third, the Cascade Range similarly blocks the entrance of most of the water-laden air from the Pacific Ocean.

Drainage

Three eastward-flowing streams drain the Juniper Butte area. Two, Rock Creek and Indian Creek, are tributaries of the northward-flowing John Day River, which runs about three miles east of the eastern boundary of the area. The third, Mountain Creek, is a tributary of Rock Creek. The junction of these two streams is in the NW$\frac{1}{4}$ sec. 22, T. 12 S., R. 25 E.

Rock Creek is the direct recipient of the drainage from the south-central, southeastern, and eastern parts of the area. Rock Creek also receives the discharge of Mountain Creek, which drains the north-central, east-central, and entire western parts of the area; therefore, Rock Creek drains all the area except the northeast one-ninth, which is drained by Indian Creek.

TABLE I

SUMMARY OF EXPOSED ROCK FORMATIONS

Age	Formation	Character	Thickness in feet
QUATERNARY		Silt, sand, gravel, and andesitic ash.	0-50
		Unconformity	
UPPER PLIOCENE (?)		Olivine basalt. Arcuate dike with a thin, local flow, and small plug.	
		Unconformity	
MIDDLE (?) PLIOCENE	Rattlesnake formation	Basal gravel separated from overlying fanglomerate by a rhyolitic ignimbrite.	10-500+
		Unconformity	
UPPER MIOCENE	Mascall formation	White, gray, and yellow rhyolitic tuff of ash, clay, and silt.	0-320
		Unconformity	
MIDDLE MIOCENE	Columbia River basalt	Normal and olivine-bearing basalt flows.	350-1800+
		Unconformity	
LOWER MIOCENE	John Day formation	Green and buff andesitic tuffs overlain by a rhyolitic ignimbrite and a highly altered tuff.	740+
		Unconformity	
MIDDLE (?) EOCENE	Clarno formation	Volcanic breccia, and andesite and basalt flows. Dacite dike.	750-1800+
		Unconformity	
CRETACEOUS (?)		Pebble conglomerate with arenaceous shale and subgraywacke sandstone lenses.	?

GENERAL GEOLOGY

Cretaceous (?) Sediments

Pebble conglomerate, sandstone, and shale are exposed in a highway cut in the SW¼ NE¼ sec. 17, T. 12 S., R. 25 E. Lithology and stratigraphic position suggest that these non-fossiliferous sediments are comparable in age and origin to the Cretaceous marine beds in the Mitchell and Dayville quadrangles.

The base of the outcrop is hidden by alluvium; otherwise, Clarno andesite, in place on the sides and as detritus on top, nearly surrounds the outcrop.

The face of the cut is triangular. The base, measured along the roadbed, is about 100 feet long. The rounded apex is about 25 feet above the road; the upper ten feet is andesite detritus.

A dip of 21 degrees, S. 5° W., was measured on the base of a conglomerate lense, but the dependability is questionable.

Lithology

The conglomerate, composed of pebbles, is compact and well-indurated. The pebbles are poorly sorted, sub-angular to sub-rounded, and are moderately spherical. They consist of basalt, quartz, and meta-sedimentary and meta-volcanic rocks. The matrix is a mixture of quartz and feldspar sand, together with clay, chlorite, and a minor amount of carbonate.

The light olive gray (5Y 6/1) sandstone is a moderately compacted, moderately indurated, fine-grained sub-graywacke that is composed of poorly sorted, sub-angular quartz and feldspar grains (in part altered to carbonate), with minor amounts of magnetite, sphene, apatite, mica (well-altered to chlorite), and chalcedony in a matrix of silt, clay, and chlorite. Sutured contacts within some of the quartz grains suggest a previous quartzite as source for these grains.

The finest clastic material is a dark olive gray (5Y 4/1), arenaceous shale composed of small quartz, feldspar, and mica grains in a matrix of clay and chlorite. The quartz and feldspar particles are sub-rounded and moderately spherical; the mica is platy and relatively fresh.

The shale, forming small, thin-bedded lenses in the sandstone and conglomerate, is fissile, fairly well indurated, and laminated. The lamination is produced by thin tabular concentrations of parallel mica plates.

Clarno Formation

Name

Merriam (21, p. 71) named the tuffs, gravels, and volcanic flows overlying Cretaceous beds the Clarno formation for Clarno's Ferry, which is near their typical exposure in the northwest corner of the Mitchell quadrangle.

Distribution and Topographic Expression

Forming rounded, grass-covered hills, the Clarno formation outcrops over an area of about 7.5 square miles in the northeast corner of the Juniper Butte area. In the southwest corner, the Clarno formation outcrops, covering about two square miles, are divided into three small patches by a cover of younger formations. These patches of Clarno volcanics also form rounded hills but have either a grass or a forest cover.

A strip of Clarno basalt, andesite, and volcanic breccia is exposed on both sides of Mountain Creek in the east-central part of the area. North of the creek, the slope of Clarno volcanics is highly dissected by steep-walled, shallow, narrow gulleys which are separated by narrow, detritus-covered divides. A few large slump blocks of Columbia River basalt, broken away from the basalt cliff as it receded northward, lie, with noticeable tilts, on the Clarno volcanics. These blocks form a protective cap over the more easily eroded Clarno lavas.

On the south side of Mountain Creek in the same valley, the strip of Clarno volcanics is narrower and is steep-walled between the creek bed and one of two terraces that developed along the contact between the Clarno formation and either the John Day formation or Columbia River basalt as these overlying strata were eroded southward. One terrace, at the west end of the valley where the John Day formation overlies the Clarno volcanics, has an elevation of about 3600 feet; the other terrace, near the center of the valley where Columbia River basalt overlies the Clarno formation, has an elevation of about 3360 feet.

Thickness

Within the Juniper Butte area, the Clarno formation has a wide range of thickness, owing both to the manner of deposition (numerous flows deposited on an uneven surface) and to subsequent erosion, which has produced a highly irregular surface.

In the northwest and southwest corner of the area, neither the bottom nor the original top of the formation is found. Erosion has removed part of the top and valleys have not been cut deeply enough to expose the base, which is hidden by younger, although topographically lower, formations that nearly surround the Clarno outcrop.

A knob of Cretaceous (?) sediments is exposed in the eastern reaches of Mountain Creek, but inasmuch as andesite is not usually the basal unit of the Clarno formation, a section measurement begun at the top of the knob would not necessarily begin at the true base of the Clarno formation. The contact between the Cretaceous sediments and the Clarno volcanics here is an erosional unconformity.

The top of the Clarno formation in this vicinity is well-defined either by the base of a steep scarp of Columbia River basalt or by the base of colorful John Day tuff.

The exposed thickness of the Clarno in the northwest corner of the area as scaled from the geologic map is about 750 feet; the exposed thickness at the southeast end of the east-central valley of Mountain Creek is about 1800 feet. The maximum thickness is unknown.

Lithology

The Clarno formation in the Juniper Butte area consists of volcanic breccia, and andesite and basalt flows. A dacite dike, which was probably a Clarno feeder dike, crops out in the southwest corner of the area.

-Volcanic Breccia-

Megascopic

A well-consolidated, medium grained, grayish red (5YR 4/2) matrix, which is mottled by green specks of chlorite, surrounds sub-angular to sub-rounded fragments of a similar material. These blocky inclusions often show baked contacts.

Microscopic

The holocrystalline matrix is an andesite porphyry consisting of plagioclase (68%), augite (12%), hypersthene (9%), and magnetite (11%). Chloritization is extensive.

Phenocrysts of calcic andesine, augite, hypersthene, pseudomorphs of chlorite after hypersthene, and magnetite lie in a relatively scanty groundmass of normal andesine microlites, with magnetite dust, anhedral plagioclase, and chlorite in the interstices. The texture is intersertal.

Augite phenocrysts are light brown, corroded, anhedral to subhedral, non-pleochroic, and occasionally twinned.

Hypersthene shows light to dark pink pleochroism; the crystals are anhedral to subhedral, usually broken, generally corroded, and extensively altered to chlorite.

Andesine phenocrysts often have corroded centers filled with chlorite or magnetite. The anhedral to euhedral crystals are universally twinned and usually zoned.

Magnetite phenocrysts are subhedral, small and generally have an alteration rim of hematite.

The blocky inclusions are andesitic. Texture variations are numerous but the composition of all these fragments inspected is essentially the same as the composition of the matrix.

-Andesite-

The andesite flows are of three varieties: hornblende- and quartz-bearing andesite; quartz-bearing hornblende andesite; and augite andesite with pseudomorphs of magnetite, in part altered to hematite, after amphibole.

Only slight variations in crystallinity, granularity, and fabric are displayed by the andesites. Differences in mineral percentages and mineral assemblages are also slight. The ferromagnesian mineral is either hornblende or augite; quartz is present in some in quantities varying from a trace to four percent.

The textures of the groundmass include pilotaxitic (most common), felty, intersertal, and intergranular. The flows are either holocrystalline or hypocrystalline.

Megascopically, the andesites are medium light gray (N6) to medium gray (N5), fine-grained, and sub-conchoidally to irregularly fractured. The flows that contain hornblende, which occasionally clusters into groups of radiating needles, are more coarsely porphyritic than those that contain augite.

Microscopically, the andesites consist essentially of plagioclase and hornblende or augite. Occasionally quartz is present in sufficient quantities to be classified as essential. Apatite, which is sometimes smoky, and magnetite are accessory minerals. Chlorite, hematite, limonite, and sericite are the alteration products.

Plagioclase, augite, and magnetite occur in two generations; hornblende, quartz, and apatite are restricted to the groundmass.

The plagioclase phenocrysts are usually calcic andesine. The crystals are subhedral to euhedral, broken, twinned, and zoned. Either light brown glass, magnetite, or chlorite fill the corroded centers of a few of these crystals.

Hornblende shows light to dark olive green pleochroism. The typically monoclinic outline is modified by resorption rims of magnetite, a part of which has altered to hematite.

Augite phenocrysts are euhedral to subhedral, pale brown, nonpleochroic, and occasionally twinned.

Magnetite phenocrysts are small in comparison with the other phenocrysts. Its crystals are usually subhedral.

The groundmass consists mainly of microlites of subhedral, twinned normal andesine, with various combinations of anhedral quartz, subhedral magnetite, anhedral augite, and euhedral apatite in the interstices.

Magnetite has altered in part to hematite and limonite, which have migrated to the adjacent groundmass and have invaded phenocrysts along cracks and cleavage. This alteration is the cause of the characteristic red-dotting of the andesites.

Andesine has altered in part to sericite; augite has altered to chlorite. Except for resorption rims, hornblende is fresh. Neither quartz nor apatite have been altered.

-Basalt-

Clarno basalts were found to be divisible into four varieties: hypersthene basalt, augite-bearing hypersthene basalt, diopside-bearing hypersthene basalt, and diopside-hypersthene basalt.

The basalts are essentially holocrystalline; all are porphyritic or microporphyritic. The groundmass has an intergranular texture most commonly, but intersertal and felty textures are also displayed.

In the Juniper Butte area, Clarno basalt can be distinguished petrographically from Columbia River basalt by five criteria: (1) Clarno basalts always contain hypersthene and (2) occasionally contain diopside, neither of which is present in Columbia River basalt; (3) alteration of the pyroxenes in Clarno basalt is more advanced; (4) chlorophaeite, a late magmatic alteration product, occurs universally in Columbia River basalt but was not observed in any Clarno basalt; (5) in Clarno basalt, much of the hematite and limonite, which result from the alteration of magnetite, have diffused into the adjacent groundmass and into cracks and cleavages of phenocrysts. This diffusion phenomenon, if not totally absent in Columbia River basalt, is very rare.

Although some repetition results, an example of each variety of Clarno basalt will be described.

1. Microporphyritic hypersthene basalt.

Near the top of a hill and on its northeast side, in the NW$\frac{1}{4}$ sec. 17, T. 12 S., R. 23 E., a flow of very platy Clarno basalt can be traced laterally for about 30 yards until it is covered, at both ends, by grass and detritus. A specimen of hypersthene basalt was collected from this flow, near the northwest end of the exposure.

The southeast side of the hill has slumped. From a distance, the detritus, which is platy and weathers pale yellowish brown (10YR 5/2), resembles Rattlesnake ignimbrite fragments.

Megascopic

The grayish yellow green (4GY 4/2) basalt is very fine-grained. A few patches of red hematite give the only hint to the mineral composition of the groundmass.

Microscopic

The essential minerals of this microporphyritic basalt are plagioclase (78%) and hypersthene (16%). The accessory minerals are magnetite (5%) and clinopyroxene (less than 1%), and the alteration products are green biotite, hematite, and limonite. Microphenocrysts constitute about 4% of the rock. All the essential and accessory minerals occur in two generations.

Plagioclase microphenocrysts have an average composition near intermediate labradorite. The euhedral laths are nearly always twinned but are rarely zoned; they are commonly broken but not usually corroded. These crystals generally do not exceed 1 mm in length.

Hypersthene microphenocrysts are anhedral, commonly corroded, and show light to dark pink pleochroism.

Clinopyroxene, although rare in either generation, is more common in the groundmass. The crystals are small, anhedral, generally corroded, rarely twinned, and much less altered than hypersthene.

In the groundmass, subhedral to euhedral sodic labradorite laths predominate, with minor amounts of anhedral plagioclase, hypersthene, clinopyroxene, and subhedral magnetite in the interstices. The groundmass exhibits an intergranular texture and microfluxion is well developed.

Hypersthene microphenocrysts generally are altered to green biotite along the edges and cleavages but hypersthene in the groundmass is almost completely altered. The green coloring of the rock is due to this alteration.

Alteration of magnetite to hematite and the subsequent invasion of the adjacent matrix by hematite, so characteristic of the Clarno andesites, also occurs in this rock.

2. Porphyritic diopside-bearing hypersthene basalt.

A basalt specimen was collected from an outcrop on the bare top of a rounded, mostly grass-covered hill in the NW$\frac{1}{4}$ sec. 28, T. 12 S., R. 23 E.

Megascopic

Small irregular-shaped patches of hematite and stubby crystals of plagioclase lie in a dense, grayish black (N3) groundmass. Unlike the smooth and sub-conchoidally fractured surface of the andesites, the freshly fractured surface of this basalt is very rough and irregular. The weathered surface is grayish red (5Y 4/2), and is slightly pitted on account of the disintegration of numerous phenocrysts by weathering.

Microscopic

The essential minerals are plagioclase (74%), hypersthene (12%), and diopside (3%). Magnetite (9%) is an accessory mineral. Alteration products are hematite, limonite, and chlorite. Phenocrysts compose 24% of the rock.

The plagioclase phenocrysts, which are calcic labradorite, are often twinned, broken, and corroded. Zoning is shown by rims of gas bubbles or chlorite within the crystal, by corroded centers surrounded by fresh rims, and by progressive extinction. The corroded centers are filled by glass, chlorite, or magnetite.

Other phenocrysts include hypersthene in pleochroic subhedral laths that often are rimmed by green chlorite; anhedral to subhedral diopside, which is commonly twinned; and subhedral magnetite.

Many laths of labradorite are 2 mm long; some are as much as 3 mm long. The average size of the diopside crystals is about 1 mm, but the longest crystals are 3 mm. The average size of the hypersthene phenocrysts is about 0.5 mm, but some are 2.5 mm long. Magnetite crystals rarely exceed 0.5 mm in width.

The groundmass, which exhibits an intergranular texture, is composed of twinned, randomly oriented microlites of normal labradorite, with magnetite, hypersthene, and anhedral labradorite in the interstices.

Chlorite rims nearly all the hypersthene phenocrysts. Much of the hypersthene in the matrix is nearly completely altered to chlorite. Diopside is not usually affected.

Hematite is diffused characteristically in this rock also.

3. Porphyritic augite-bearing hypersthene basalt.

The hand specimen was chipped from an outcrop near the top of a small, oval, residual hill of Clarno basalt that stands above the surrounding John Day tuff in the valley in the SE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 28, T. 11 S., R. 23 E. The flanks of the hill are covered by grass but the nearly barren top exposes jagged, much weathered, irregularly jointed basalt.

Megascopic

Small, angular phenocrysts of pyroxene and plagioclase, occasionally discolored by hematite, lie in a fine-grained, greenish black (5GY 2/1) groundmass. The fresh surface is uneven and very rough. The weathered surface is stained red, brown, and black.

Microscopic

The essential minerals are plagioclase (74%), hypersthene (13%), and augite (3%). Magnetite (11%) is an accessory mineral. Chlorite, hematite, and limonite are the alteration products. Phenocrysts constitute 21% of the rock. The holocrystalline groundmass exhibits an intergranular texture.

Except that phenocrysts are slightly larger on the average, and augite takes the place of diopside, the microscopic characteristics of this rock very closely parallel those of Clarno basalts already described.

4. Porphyritic diopside-hypersthene basalt.

A steep, sparsely timbered exposure of Clarno basalt rises from the bed of Keeton Creek in the NW$\frac{1}{4}$ sec. 29, T. 12 S., R. 23 E. A specimen was collected near the top of this exposure. Widely spaced, irregular, roughly vertical joints split the otherwise massive outcrop.

Megascopic

A medium dark gray (N4) groundmass surrounds phenocrysts of light colored plagioclase and dark colored pyroxene. A few streaks and patches of hematite are distinctive because of their bright red color. The moderate grayish brown (5YR 3/3) weathered surface is fairly smooth; it lacks the pitting that is prominent in other basalts.

Microscopic

This holocrystalline basalt consists of plagioclase (75%), hypersthene (8%), and diopside (8%), which are the essential minerals; and magnetite (7%), an accessory mineral. The alteration products are hematite and limonite from magnetite; chlorite and limonite from the ferro-magnesian minerals; and sericite from plagioclase. Phenocrysts constitute 43% of the rock. The groundmass exhibits an intergranular texture.

The plagioclase phenocrysts are calcic labradorite; the plagioclase in the groundmass is normal labradorite. Hypersthene and diopside phenocrysts occasionally are poikilitic with subhedral magnetite.

-Dacite-

A porphyritic dacite dike, striking N31°W and dipping vertically, crops out in the NW$\frac{1}{4}$ sec. 28, T. 12 S., R. 23 E. The outcrop, which is about 20 feet wide and 100 feet long, shows poorly developed, essentially horizontal polygonal columns. The northwest extension of the dike is concealed by trees; its southeast extension is hidden beneath an andesite flow and detritus.

Megascopic

A light bluish gray (5B 7/1) groundmass, streaked by hematite, surrounds phenocrysts of rounded to tabular plagioclase and acicular hornblende. The hornblende is fresh but weathering has dulled much of the original luster of the plagioclase phenocrysts.

Microscopic

The essential minerals are plagioclase (81%), and quartz (10%); the accessory minerals are magnetite (8%), hornblende (1%), apatite (a trace), and light brown glass (a trace). Hematite and limonite are the alteration products.

The very fine-grained hypocrystalline groundmass exhibits an intersertal texture. Small subhedral crystals of magnetite sprinkled throughout the groundmass give it a peppered appearance. Narrow, unoriented, subhedral, often twinned laths of calcic oligoclase constitute most of the groundmass, with anhedral quartz, euhedral apatite, and a minor amount of glass filling the interstices.

The phenocrysts, constituting 24% of the rock, include sodic andesine, which is usually twinned and commonly zoned; subhedral magnetite; and hornblende, which shows light to dark olive green pleochroism. Nearly all of the hornblende crystals have a reaction rim of magnetite. A core of hornblende is surrounded by an inner ring of magnetite, an intermediate ring of hematite, and an outer ring of limonite. The rings have gradational contacts and each is an alteration of the next inner ring.

Magnetite phenocrysts have alteration rims of hematite, and nearly always some of the hematite has migrated to the adjacent groundmass to coat the microlites and to invade plagioclase phenocrysts along cracks and cleavage.

Origin and Conditions of Deposition

The vast extent of the Clarno volcanics, the presence of numerous dikes, and the lack of shield structure suggest fissure eruption. Tuff, although not exposed in the Juniper Butte area, and volcanic breccia suggest eruption from volcanoes.

The presently known, albeit scanty, evidence indicates a combination of these two types of outlets as the source of the Clarno volcanics.

Age and Stratigraphic Relations

Stirton (27, p. 265) dates the Clarno formation as early middle Eocene by a tooth from a rhinoceros, *Hyrochyrus* sp., although admitting "the evidence afforded by a single tooth . . . is not as conclusive as one would wish it to be."

To Chaney (6, p. 348), the close resemblance of fossil plants found in the Clarno formation to Comstock flora of western Oregon indicates an upper Eocene age for the Clarno formation.

McIntyre (20, p. 49) reports that the Clarno volcanics rest upon Cretaceous beds with both an angular and erosional unconformity. Other workers in the Mitchell quadrangle agree. Presumably this stratigraphic relation is true in the Juniper Butte area.

The John Day tuffs overlie the Clarno volcanics with an angular and erosional unconformity. The regional dip of the tuffs is about eight degrees to the southwest; the regional dip of the Clarno volcanics is about thirteen degrees to the southeast.

John Day Formation

Name

The varicolored tuffs lying between the Clarno formation and the Columbia River basalt were named the John Day formation by Merriam (22, p. 291). O. C. Marsh (19, p. 52) had suggested earlier the name "John Day" for the basin in which the tuffs are found, although he failed to define the borders of this basin.

Distribution and Topographic Expression

The outcrops of John Day tuff are characterized primarily by two topographic features: relatively wide, broad-bottomed valleys, and hummocky hills and slopes of slump material.

After erosion has pierced the resistant cap rock of Columbia River basalt, the underlying tuffs are removed rapidly. Valleys form quickly. The slope immediately below the cap rock of basalt is steep, particularly where an ignimbrite rim rock is present within the John Day formation. The radius of curvature of the slope then increases rapidly to its maximum value at the bottom of the valley.

The slopes are grass-covered and the lower parts of some are cultivated.

The most extensive area of slumping occurs east of Tubb Creek and west and northwest of Juniper Butte, in the north-central part of the area. Over an area of about 3½ square miles, erosion of the weak John Day tuffs has undermined large blocks of basalt, which have broken from the overlying mass and now repose at various angles upon the green tuff. The resulting topography is highly irregular. Intermittent streams have cut deeply into the tuff, leaving basalt-capped hills with steep, detritus-covered slopes.

A minor erosion feature in this area, although very characteristic of outcrops of John Day tuff in other areas, is the "badland" topography. In only two areas is it prominent: one, the slope to the northwest of Tubb Creek in the NW$\frac{1}{4}$ sec. 34, T. 11 S., R. 24 E., at the site of the section measurement (see plate II); the other, north of Rock Creek in the N$\frac{1}{2}$ sec. 26, T. 12 S., R. 24 E.

Spines, hoodoos, narrow terraces, and thin ledges are erosional features of the tuffs. Numerous narrow, shallow gullies dissect the steep slopes, which at times are covered by a layer of dried mud that holds small angular fragments of detritus. When the mud is rain-soaked, it rapidly washes off the slope; wherever vegetation has taken root, the erosion is greatly impeded, and the "badland" topography changes to smooth, grass-covered slopes.

Lithology

In the Picture Gorge quadrangle to the east, Coleman (8, p. 61) has described a full section of the John Day formation. He has divided the tuffs into four units: the lower red beds; the middle green beds, which include all the tuff between the red beds and ignimbrite flow; the ignimbrite flow; and the upper buff beds, which include all the tuffs between the ignimbrite flow and the overlying Columbia River basalt.

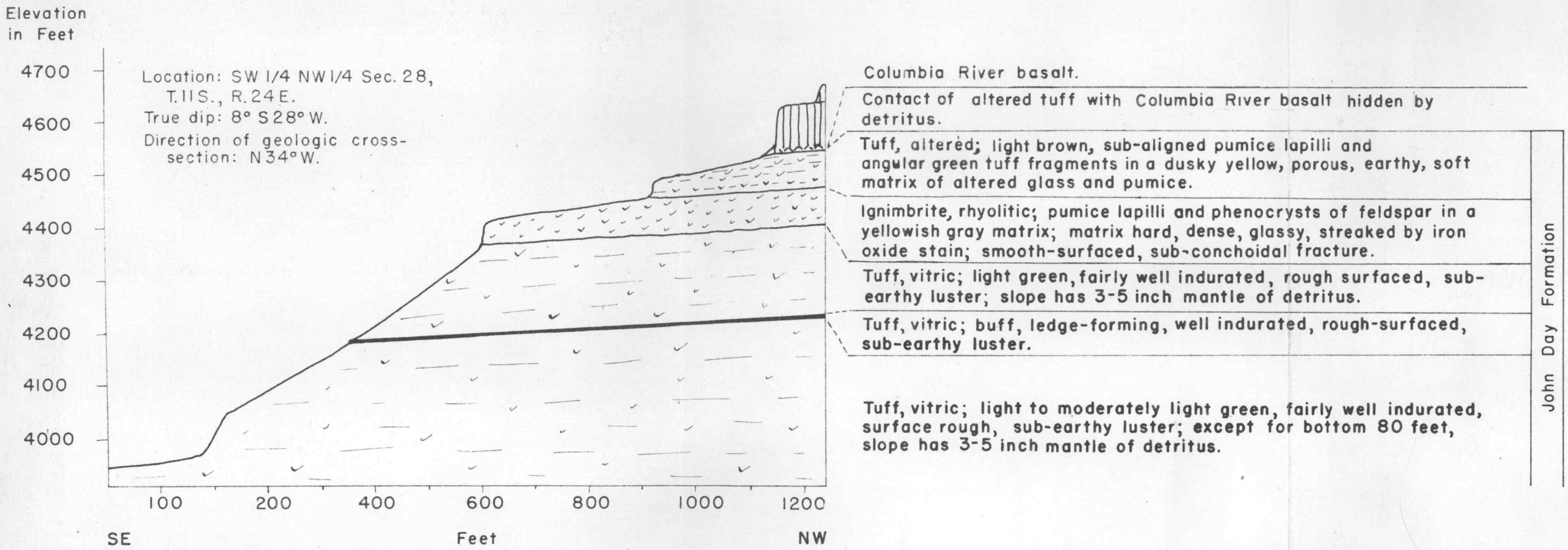


Plate II Geologic cross-section and description of the John Day formation west of Tubb Creek.

The middle green unit, a lower rim rock of ignimbrite, and an upper rim rock of altered tuff are the only units of the John Day formation exposed in the Juniper Butte area.

A section was measured in order to determine the thicknesses and stratigraphic relations of the ignimbrite and altered tuff. Most of the slope of green tuff below the rim rocks is covered by rubble, but the bottom 80 feet is eroded into prominent "badland" forms.

The point of origin of the section is about 1.3 miles north of the Ochoco highway, on the west side of a dirt road that connects with the highway exactly five highway miles east of the intersection of the Antone road with the highway.

Plate II is a geologic cross-section of the measured section site; figure 2 is a photograph of this site.

-Middle John Day Formation-

Megascopic

The middle unit of the John Day formation is a fine-grained vitric tuff that is colored pastel shades of green and buff. The rock is fairly well consolidated; the surface is coarse and has an earthy luster.

Microscopic

Essentially, the rock consists of devitrified pumice and glass. Andesine, augite, magnetite, and secondary quartz are also present. Calkins (5, p. 143) states that the tuff is andesitic.

A slightly birefringent, pale green mineral, or mineraloid,

Figure 2. View northwestward to the John Day measured section site in the left-center background.

impregnates the vitric constituents but has not invaded the crystals. Coleman (8, p. 96) suggests that the substance is a ferro-ferric compound. The range of colors from buff to dark pastel green is proportional to the amount of this green compound present in the rock.

-Ignimbrite-

Megascopic

The ignimbrite is hard, glassy, and dense. The subconchoidal fracture produces sharp edges. According to Calkins (5, p. 143), this yellowish gray (5Y 7/2) welded tuff is rhyolitic.

A few small phenocrysts of feldspar and a few flattened pumice lapilli are the only recognizable constituents in the hand specimen. Near the top of the flow, thin iron oxide stains streak the rock.

Microscopic

Devitrified glass and pumice, and spherulites of feldspar and quartz surround crystals of acid plagioclase, sanidine, quartz, and pyroxene. A few rounded fragments of basalt are present also. The vitric constituents compose about 85% of the rock; the spherulites constitute about 10% of the rock.

Sub-alignment of the pumice shards can be detected in some specimens.

-Altered Tuff-

Megascopic

The tuff is punk-like, earthy, and decidedly the most altered John Day tuff in the Juniper Butte area. The light brown (5YR 5/6) pumice lapilli, some of which are 1.5 inches by 0.5 inches, are sub-aligned but not collapsed. The dusky yellow (5Y 6/4) matrix is porous and relatively soft; it does not form as prominent a rim as other tuffs in the area. Fragments of green tuff resembling the tuff of the middle John Day are imbedded in the groundmass.

Microscopic

Ninety-five percent of the tuff consists of devitrified glass, pumice, and ash. Pumice lapilli, and phenocrysts of anhedral quartz and feldspar are imbedded in the matrix.

The vitric constituents are highly altered but the crystalline material is relatively fresh. The ash, pumice, and glass are impregnated by chlorite (?) and altered to montmorillonite and limonite.

Thickness

The ignimbrite and altered tuff rim rocks are each about 70 feet thick, by direct measurement. Estimates made at various points about the area agree with this figure.

At least 600 feet of the middle John Day tuff is exposed; the true thickness is probably much greater.

Paleontology

Two teeth from the jaw of an Oreodon sp. were found by Mr. Robert Collins, who graciously loaned the specimen to the writer. The fossil jaw was identified by Mr. Harold Boyd, Oregon State College paleontologist. Fortunately Mr. Collins remembered the exact site at which he had collected the fossil; this site is recorded on the map in the NE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 25, T. 11 S., R. 23 E.

Figure 3 is a photograph of this fossil.

Origin and Conditions of Deposition

Marsh (19, p. 52) was impressed by the close resemblance of the John Day tuff beds to lake deposits in Wyoming; he therefore postulated a similar origin for the central Oregon tuffs.

Merriam (22, p. 302) disputed the lacustrine hypothesis. He noted that "while organic remains are abundant, aquatic forms are rare." Merriam therefore suggested an aeolian origin.

Calkins (5, p. 143) pointed out that light and heavy material, such as the pumice and augite found in the John Day beds, would be sorted if strewn into a lake; however, the tuffs do not show lamination by such sorting. Further, he noted that the peroxidation of iron in the lower John Day red beds would not likely have taken place under water.

Coleman (8, pp. 126-129) summarized the evidence for both hypotheses and, substantiating his argument by further evidence, concluded that ash was ejected from early Cascade volcanoes and wind-blown eastward to be deposited upon the land and into whatever lakes

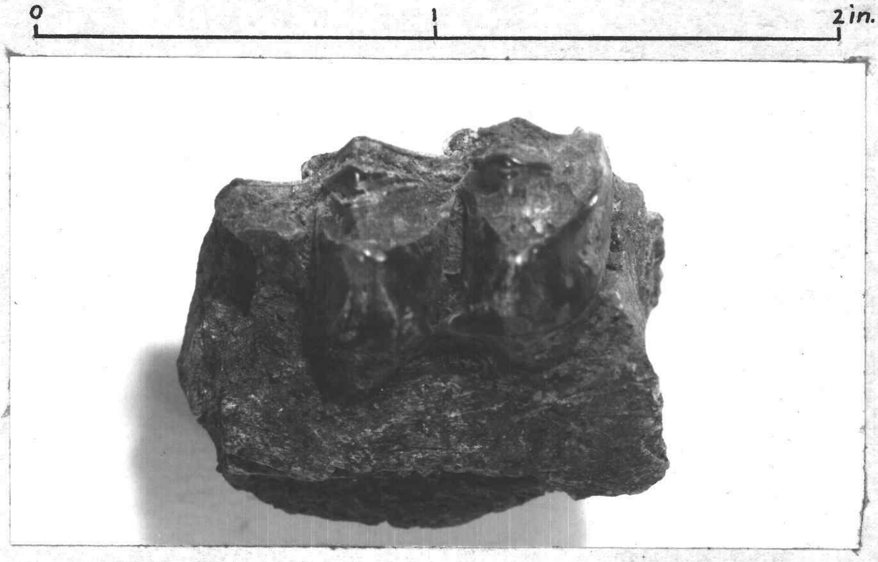


Figure 3. Fragment of a fossil <u>Oreodont</u> sp. jaw, which was collected from near the top of the middle John Day, in the NE$\frac{1}{4}$ sec. 25, T. 11 S., R. 23 E.

and streams existed.

To Coleman's summary, a clarification should be added: transportation in part by streams. Rain washed much of the easily eroded ash from the hills into the already clogged valleys, where streams probably were incapable of removing the material as quickly as it accumulated, or were able only to wash the ash from one local basin into another local basin at a lower level.

The ignimbrite rim rock, although topographically prominent, represents a deposition time of only a few hours, or at most a few days. Although Mansfield and Ross (19, p. 312) explain similar deposits in Idaho by the deposition of finely comminuted particles after transportation through the air over a long distance, the nuee ardentes theory seems more nearly able to explain the properties of this welded tuff.

It seems very improbable that, after traveling through the air for miles, the ash and lapilli would still retain sufficient heat to produce the intense welding displayed by this rock. The great surface area exposed by any large volume of such small particles would allow rapid dissipation of heat.

Sub-alignment of the collapsed pumice may indicate flow as in a glowing cloud; the collapse and welding indicate intense heat and probably pressure, which would be supplied by the weight of the still-cooling overlying mass; and the lack of fracturing of the enclosed crystals indicates that the material was viscous while being deposited. The numerous spherulites suggest that volatiles were abundant.

From local vents (whether volcanoes or fissures is not known) a hot mass, highly charged with super-heated gas, was ejected. This material flowed rapidly away from the vent and stopped only when blocked by a hill too steep or too high for it to mount or when the material had cooled enough to become too viscous to flow further.

The uppermost rim rock of the John Day formation in the Juniper Butte area is an altered tuff. This tuff directly overlies the ignimbrite rim rock. Numerous expanded pumice lapilli, undistorted glass shards, only slight welding, and the lack of accommodation of shards for crystals indicate that the tuff was not deposited as a "glowing cloud;" instead, the material probably was wind-deposited.

Chlorite (?) impregnates the vitric constituents, and weathering has yielded montmorillonite and limonite. The reason for such an advanced stage of alteration has not been established.

Age

The age of the middle and upper John Day formation has been established recently as lower Miocene. Green (13, pp. 1538-1539) found that mammal remains collected in the middle and upper tuffs indicate a lower Miocene age. Schlultz and Falkenbach (26, p. 92) substantiated this age. Oreodont specimens that they collected from the middle and upper John Day formation indicate an age approximating that of the upper Miocene Harrison formation of Nebraska and Wyoming.

Columbia River Basalt

Name

Prior to the work of Lindgren in the Blue Mountains, many Tertiary volcanics had been lumped together as Columbia lava, a term proposed by I. C. Russell (25, p. 21) in 1893. Lindgren (17, p. 592) suggested the name Columbia River basalt and proposed that the name be restricted to the Miocene basic lavas. This now is the accepted usage.

A type section for Columbia River basalt never has been established. Some of the earliest observed and most striking outcrops of this formation occur along both the north and south banks of the Columbia River where it forms the boundary between Oregon and Washington. The name logically followed.

Distribution and Topographic Expression

With the exception of the rounded hills in the northwest corner of the area, all the ridges in the Juniper Butte area are capped by Columbia River basalt.

The ridges are rounded on top but many have a steep escarpment, particularly on the side opposite to the direction of dip of the flows.

Canyons in the basalt are steep-walled, show little side erosion, and have narrow, relatively gravel-free bottoms.

Thickness

The Columbia River basalt thickens appreciably from west to east, and at the end of the time of extrusion, the lava probably covered the entire area except the northwest corner, where peaks of Clarno lava may have escaped such submergence.

Basalt on the east-west ridges in the west-central part of the area has an exposed thickness of about 350 feet. The exposed thickness in the northeast corner is about 1800 feet, the maximum in the area.

The thicknesses were scaled from the geologic map.

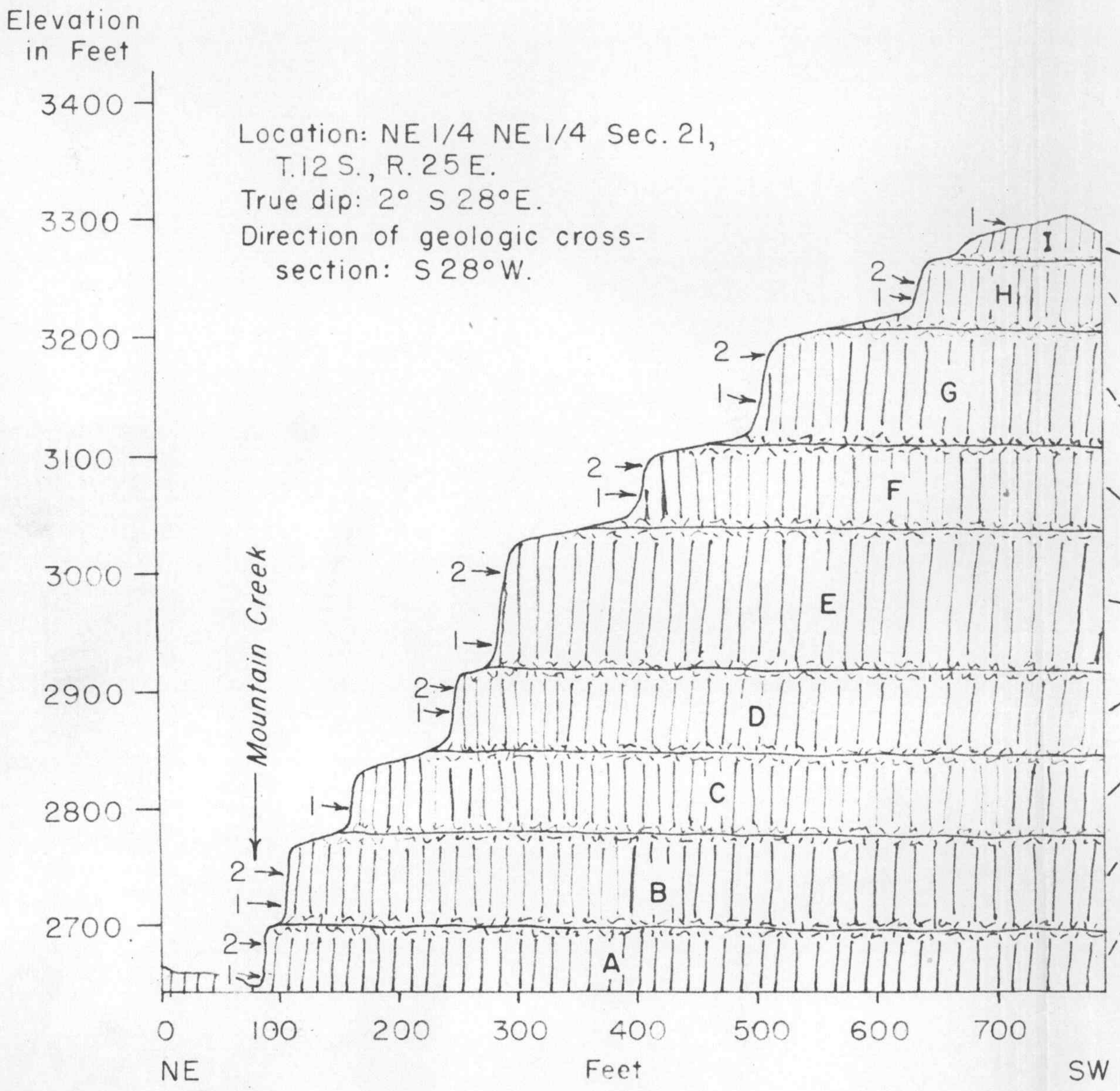
Lithology

A section of Columbia River basalt was measured in order to obtain a series of stratigraphically related specimens for petrographic study. The section measured is located in the NE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 21, T. 12 S., R. 25 E. Accessibility and exposure were the two principal factors governing the choice of the section site.

The block from which the samples were taken is slightly dislocated by slumping but as sampling was restricted to this block the slumping is no detriment to the petrographic investigation.

The sheet of Miocene basalt at this point is comparatively thin, but is nearly complete for this small part of the Juniper Butte area. The underlying John Day formation is exposed within a half-mile to the northwest, west, and southwest.

Sixteen samples from nine flows, with a total thickness of about 650 feet, were studied. The results are tabulated in plate III, which also shows a geologic cross-section of the measured section.



Flow	Sect.	Texture: Crystallinity	Texture: Granularity	Texture: Fabric	Modal Analysis in Percent: Clinopyroxene	Olivine	Magnetite	[a] Plagioclase	Chlorophaeite	[g] Carbonate	% Phenocrysts
I	1	Holocrystalline	microporphyritic	[b] intergranular	33	--	12	52	3	---	4
H	2	Holocrystalline	porphyritic	subophitic	43	2	3	42	[e] 7	3	1
H	1	Holocrystalline	porphyritic	subophitic	37	2	5	44	[e] 4	3	1
G	2	Holocrystalline	Microporphyritic	intersertal	25	1	37	35	3	--	17
G	1	Holocrystalline	Microporphyritic	intersertal	26	1	38	33	3	--	19
F	2	Holocrystalline	Microporphyritic	intersertal	21	2	55	19	3	--	21
F	1	Holocrystalline	Microporphyritic	[b] Intergranular	29	4	14	49	4	--	18
E	2	Holocrystalline	Microporphyritic	Intergranular	29	[d] 2	13	52	4	--	12
E	1	Holocrystalline	Microporphyritic	Intergranular	30	[d] 3	9	54	4	--	9
D	2	Holocrystalline	Microporphyritic	Intergranular	37	--	9	48	[f] 6	--	6
D	1	Holocrystalline	Microporphyritic	Intergranular	30	--	12	52	6	--	6
C	1	Holocrystalline	Microporphyritic	Intergranular	36	3	7	53	1	--	3
B	2	Holocrystalline	Microporphyritic	Intergranular	26	3	12	53	6	--	5
B	1	Holocrystalline	Microporphyritic	Intergranular	25	4	13	51	7	--	7
A	2	Holocrystalline	Microporphyritic	Intergranular	[c] 45	1	11	38	5	--	3
A	1	Holocrystalline	Microporphyritic	Intergranular	34	1	8	48	9	--	7

a. Plagioclase in the groundmass is usually normal labradorite. Phenocrysts are calcic labradorite.

b. Labradorite microlites are sub-parallel.

c. Flow 'A' has pigeonite. All other flows have augite.

d. Pseudomorphs of chlorophaeite and chlorite.

e. Chlorophaeite birefringent because of inclusions of chlorite fibers.

f. Chlorophaeite occurs as filling in pellet-shaped cavities.

g. Carbonate is secondary.

Plate III Geologic cross-section and petrographic description of Columbia River basalt west of the intersection of Mountain and Rock Creeks.

-General Rock Description-

Columbia River basalt commonly exhibits well-formed polygonal columns that may be wide and relatively straight, or thin and wavy. These columns develop normal to the surface of the flow. Secondary jointing normal to the columns causes platiness in some flows.

Non-columnar basalt is massive to irregularly jointed, and usually blocky. The corners of the blocks are rounded by weathering, and the weathered surface is stained light to dark brown by limonite.

The detritus is usually subangular; the more fine-grained material has a crude conchoidal fracture. Locally the basalt talus consists of broken columns that retain most of their form; these columns are so well-formed that they might easily be mistaken for carved artifacts.

Megascopically, the basalt is fine-grained to moderately fine-grained, dark gray to black, and occasionally vesicular, depending upon its position in the flow. Most commonly the rock is microporphyritic but porphyritic forms are found. Weathering has affected the rock only slightly.

Microscopically, the basalt shows only slight variation in texture and even less variation in composition.

Plagioclase, clinopyroxene, olivine, and magnetite occur as phenocrysts. The plagioclase is a calcic labradorite, which is anhedral to euhedral, generally twinned but not commonly zoned, and occasionally poikilitic with inclusions of subhedral magnetite. The clinopyroxene, either augite or pigeonite, is pale brown, non-pleochroic, occasionally twinned, and is slightly larger and less altered than olivine phenocrysts. Olivine is anhedral and usually corroded; also, olivine is the mineral most altered to chlorophaeite and chlorite. Magnetite is subhedral and constitutes the smallest phenocrysts in the rock.

The groundmass is composed predominantly of normal labradorite laths that are subhedral to euhedral, twinned, and generally closely packed. Small crystals of anhedral clinopyroxene and subhedral magnetite, and amorphous chlorophaeite fill the interstices. In a few of the specimens the chlorophaeite is filled with magnetite dust; in others, inclusions of chlorite impart birefringence to the otherwise isotropic chlorophaeite.

Origin and Conditions of Deposition

Columbia River basalt in the Juniper Butte area is confined to lava flows; no dikes were discovered. In other parts of Oregon and Washington both dikes and craters have been found and interpreted as vents for the Miocene lavas.

Russell (25, p. 21), Merriam (22, p. 304), and Collier (9, p. 13) report Columbia River basalt dikes cutting older formations. Waters (30, p. 13) reports basalt dikes exposed vertically through 4000 feet. Each dike fed from one to six flows.

Fuller (12, p. 74), after studying the Asotin craters of west-central Idaho, suggested at least part of the basalt issued from craters, but he also stated that "the Asotin craters are relatively late and cut most of the adjacent flows."

LeConte (16, p. 470), one of the first to consider the problem of origin, made this comment:

> "Over this immense area [about 250,000 square miles] are scattered a dozen or more extinct volcanoes . . . . It is simply incredible that all this lava has flowed from these volcanoes. There is no proportion between the cause and effect. . . . such great masses of lava . . . have come, not from crater eruptions, but from fissure eruptions."

During the middle Miocene the surface of the ground was breached by numerous dikes that poured streams of lava into basins and valleys. Soil layers, gravel, and petrified wood between some of the flows indicate that the outpourings were intermittent; enough time elapsed between flows to permit a moderate amount of weathering, erosion, and the growth of trees.

Eventually the early Miocene valleys were filled and the lava inundated all but the highest points in the area. The Clarno hills in the northwest corner of the Juniper Butte area may have been the only places not covered.

Evidence of an early Miocene valley-and-hill topography can be found in the Juniper Butte area. South of the Ochoco highway in the east-central valley, the contact at the base of an escarpment between the John Day formation and the Columbia River basalt, at the west end of the valley, has an elevation of about 4000 feet. The contact of the Clarno volcanics with the Miocene flows, also at the base of the escarpment but at the eastern end of the valley, has an elevation of about 3800 feet. About a mile to the south a narrow valley has been cut into the Columbia River basalt parallel to the escarpment to an elevation of about 3400 feet without passing through the basalt. This elevation difference of 400-600 feet cannot be explained solely by the $5\frac{1}{2}$ degree dip of the basalt.

Age and Stratigraphic Relations

In some places Columbia River basalt overlies the John Day formation; in other places the basalt overlies Clarno volcanics.

Columbia River basalt lies with an erosional unconformity on the John Day tuffs but the presence of an angular unconformity, as postulated by Merriam (22, p. 299), cannot be proved in the Juniper Butte area, for the contact is everywhere obscured by basalt detritus and grass. Any small difference in dip can be explained by slumping.

Columbia River basalt lies both erosionally and angularly unconformable upon the Clarno formation. The regional dip of the Clarno formation is about 13 degrees to the southeast; the regional dip of the Columbia River basalt is about 5-8 degrees to the southeast.

The overlying Mascall formation lies unconformably on Columbia River basalt. Post upper Pliocene faulting, in the southeast corner of the area, has produced dips in Columbia River basalt as high as 25 degrees; but the dips of the Mascall tuffs do not exceed 17 degrees.

Although Beck (1, pp. 462-464) reports logs and the mold and fragments of a leg bone of a rhinoceros in basalt in Washington, the age of Columbia River basalt is defined best by the ages of the underlying lower Miocene John Day formation and the overlying upper Miocene Mascall formation.

Sufficient time elapsed following the deposition of the John Day tuffs to allow considerable erosion. The basalt rests upon middle John Day tuff in some areas, on ignimbrite in other areas, and on the tuff in still other areas. In some areas, the tuff beds are missing entirely, and the basalt rests on Clarno volcanics. The upper John Day formation is missing; the tuffs may not have been deposited, or, if they were, they have been eroded away.

Merriam and Sinclair (24, p. 175) report the intercalation of thin basalt flows with lower Mascall beds.

The age of the Columbia River basalt is established therefore as middle Miocene.

Mascall Formation

Name

Owing to various inadequacies of the names previously applied to the interbedded tuffs, shales, and conglomerates found between the Columbia River basalt and the Rattlesnake formation, Merriam (22, p. 306) "proposed to designate these beds as the Mascall formation. The typical exposure is near the Mascall Ranch, four miles below Dayville," in north-central Dayville quadrangle.

Distribution and Topographic Expression

The Mascall formation crops out in four small patches in the step-faulted southeast corner of the Juniper Butte area. The four exposures are located in parts of five sections—15, 20, 21, 22, and 23—in T. 12 S., R. 25 E.

Mounds and rounded hills dissected by deep gullies and eroded into recesses, thin ledges, and narrow shelves, are the characteristic residual forms of the Mascall formation. The rounded tops of these hills are partly grass-covered, but the side slopes, usually steep and coated by a thin layer of mud, are nearly barren.

Thickness

The Mascall formation in the Juniper Butte area is thin, for the area lay at the margin of a rather extensive basin. The formation thickens southward in the Dayville quadrangle.

The exposed thickness, as measured from the geologic map, is about 320 feet; Coleman (8, p. 41) has measured 435 feet at the type section. In some places the Mascall tuffs are absent.

Lithology

Megascopically, the tuffs are either white (N9), light gray (N7), pale greenish yellow (10Y, 8/2) or light brownish gray (5YR 5/1). They are earthy, very light weight, friable, and usually gritty. All the constituents are too minute to be identified accurately in the hand specimen.

Microscopically, the tuff is found to be predominantly volcanic glass and clay. The glass is angular and very finely comminuted.

Some quartz and feldspar were observed but generally crystal fragments are too small to be identified.

The refractive index of the glass of one sample was 1.504-1.506. Glass in other samples was a mixture of fragments of a number of chemical varieties whose refractive indices varied from 1.496 to 1.543.

Calkins (5, p. 167) states that the tuff is rhyolitic.

Origin and Conditions of Deposition

After observing lenses of gravel, and fossil fish and leaves in the tuff, Merriam (22, p. 309) concluded that the Mascall formation is a lacustrine deposit.

Following the extrusion of the middle Miocene lavas, many lakes must have developed, for the old drainage system would have been eradicated and the new drainage system would have been extremely youthful. The discharge of streams would have been trapped in local basins formed by undulations in the lava or by the gaps between flows. Until the basin overflowed and an outlet was cut, the lake would have remained to capture pyroclastic material falling directly into the water or washed in by streams, along with silt and other products of erosion.

The location of the vent, or vents, from which the pyroclastics were ejected has not been found. The tuffs are not widespread enough in the Juniper Butte area to permit a size analysis that might indicate the direction from which the tuffs were blown. The fine division of the material may indicate a distant source or it may indicate re-working.

Age and Stratigraphic Relations

The Mascall formation is distinctly unconformable upon the Columbia River basalt; the discordance is as much as 9 degrees, but this can be attributed to initial dips because the tuffs in the Juniper Butte area were deposited at the margin of a basin. In turn, the Mascall tuffs are overlain by the Rattlesnake gravels with an even more pronounced angular discordance; the difference between the dips of the two formations is as much as 13 degrees. This discordance was caused by pre-Rattlesnake deformation.

Erosion of the Columbia River basalt prior to the deposition of the tuffs was very limited; the time was short between the final extrusion of lava and the first ash fall. Merriam and Sinclair (24, p. 193) presented evidence to show that the ash falls began before the final cessation of the lava flows. Therefore, the angular discordance may be partly the result of initial dips of tuff deposited at the sloping margin of a basin.

Plant remains were collected from the Mascall formation by Merriam and Sinclair (23, p. 95) and by Knowlton (15, p. 108); the flora in both collections were dated upper Miocene.

Rattlesnake Formation

Name

The Rattlesnake formation, mainly a gravel deposit stratigraphically divided into two parts by a flow of ignimbrite, was named by Merriam (23, p. 310). This terrestrial deposit is typically exposed along Rattlesnake Creek one mile west of Cottonwood Creek in north-central Dayville quadrangle.

Distribution and Topographic Expression

North of the Ochoco highway in the southwest corner of the area, the Rattlesnake ignimbrite, lying between thin gravel deposits, is quite prominent as a rim rock. The underlying gravel has been undermined by meandering Mountain Creek; consequently, the rim rock and the overlying gravel are slightly slumped, except at the extreme western end of the area.

South of the highway, a gentle, northward-dipping, slightly dissected fanglomerate slope is fairly continuous between the eastern edge of Keeton Creek valley and the Antone road. Wide, rounded divides are separated by northward-flowing intermittent streams that have not cut deeply into the gravel.

In the southeast corner of the Juniper Butte area, thick gravel deposits stand out as the terminal ends of four finger-like prongs entering from the Dayville Quadrangle. The prongs, formed by the dissection of a formerly continuous fanglomerate plain by northward-flowing intermittent streams, are steep-sided hills with lower slopes of gravel protected by a cliff-forming layer of ignimbrite. A relatively thin veneer of gravel gives the top a rounded profile.

Thickness

The gravel beneath the ignimbrite has an exposed thickness of about 350 feet in the southeast corner of the area.

Small isolated patches of ignimbrite in the northwest corner of the area are only about ten feet thick but the prominent rims in the southeast corner of the area are about 55 feet thick.

In the southwest corner, the extensive fanglomerate above the rim rock is at least 240 feet thick but the fanglomerate in the southeast corner is relatively thin; it does not exceed 100 feet there.

In the Juniper Butte area, the exposed thickness of the Rattlesnake formation is about 450-500 feet. The true thickness probably is much greater.

Lithology

The gravel is composed of rounded, unsorted, and loosely consolidated granules, pebbles, and cobbles in a matrix of silt that is locally tuffaceous. Most of the gravel is Columbia River basalt detritus but some of the gravel came from Clarno volcanics and still older meta-sediments. Stratification is not apparent.

The composition of the fanglomerate in the southwest corner of the area particularly is influenced by its proximity to the source area because the basin of deposition in this area is not very wide. Near Keeton Creek, where Clarno volcanics crop out, the fanglomerate is composed mostly of Clarno andesite and basalt detritus. Farther west, as Columbia River basalt begins to crop out in the hills to the south, the fanglomerate has increasing amounts of the younger basalt.

The ignimbrite has a matrix of glass and pumice shards with inclusions of pumice lapilli as much as three inches long and one inch wide. The fresh surface is light gray (N8) to light olive gray (5Y 6/1). The weathered surface is moderate brown (5YR 4/4). Where exposed to weathering, the top is pitted and very irregular; the effects of weathering are accentuated by the platiness of the top part of the ignimbrite. The basal part, which is slightly more glassy than the punk-like upper part in the thicker flows, has numerous inclusions of rounded basalt pebbles.

Vertical polygonal columns are striking features in some areas (see fig. 4), but the thicker flows have wide-spaced vertical joints.

A 3-8 inch layer of ash separates the flow from the underlying gravels.

The thin section shows glass and pumice shards surrounding large pumice lapilli, quartz, acid feldspar, and rock fragments. The groundmass has a vitroclastic texture. The vitric constituents are compressed, distorted, and aligned.

Calkins (5, p. 169) discovered by chemical analysis that the rock is rhyolitic. A determination of the refractive index of the glass of four samples agrees with this analysis. A value of 1.498 consistently was obtained.

Origin and Conditions of Deposition

An elongate, generally east-west synclinal valley had formed to the south of the Juniper Butte area in the late upper Miocene or early lower Pliocene. Middle Pliocene pluvial sediments and an ignimbrite flow crop out, along the southern boundary of the Juniper

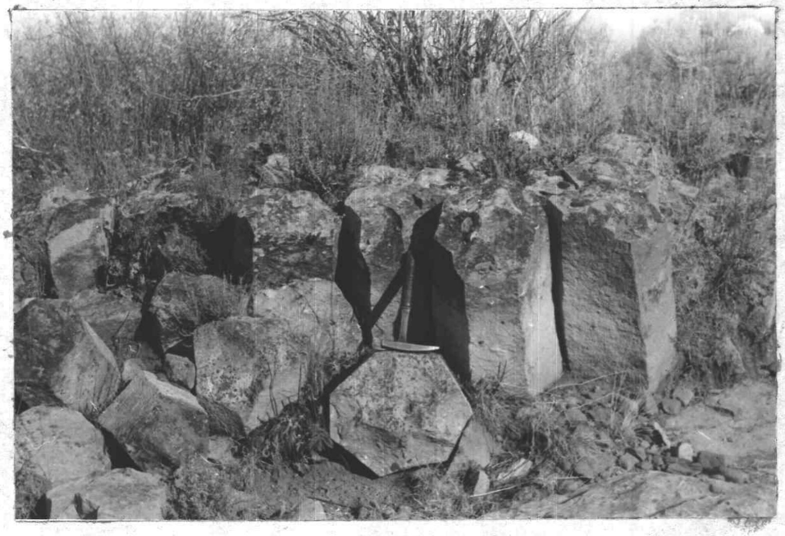


Figure 4. Outcrop of Rattlesnake ignimbrite, showing polygonal columns, south of the Ochoco highway in the NW$\frac{1}{4}$ sec. 22, T. 12 S., R. 23 W.

Butte area, as abutments against middle Miocene basalt flows and John Day tuffs that form the northern boundary of the basin.

Gravel, sand, and silt were carried by streams and slope wash into the basin. These sediments were derived principally from uplands to the south in the Dayville quadrangle, but also came from the anticlinal hill slope to the north in the Juniper Butte area.

After a considerable thickness of sediments had accumulated, pyroclastics were extruded across the surface of the basin. A <u>nuee ardente</u> origin has been suggested by most recent authors, hence the name ignimbrite. The inclusion of numerous pebbles in the basal part of the ignimbrite suggest flow on the ground rather than ash settling from the air.

Dense clouds of volcanic glass, viscous and charged with superheated gas, would have been funneled along the valley between the highlands on the north and south. The high fluidity would allow the avalanche to invade small tributary valleys, where erosional remnants, scattered and seemingly unrelated, now are found.

After the avalanche had ceased to move, residual heat and heat of the gases rising through the mass would cause welding of the pumice and would keep the mass sufficiently fluid to allow compression, distortion, and alignment of the vitric material in the groundmass without consequent breaking of either the lapilli or the crystals.

Compression and alignment may be due to the weight of the overlying pyroclastic material or to the inability of the pumice, if still viscous, to hold its expanded shape after the gas had departed.

The deposition of the welded tuff as an ignimbrite was completed in a short time. Consolidation by cooling required a few months at most. Therefore, although the unit is quite prominent topographically, it represents an insignificant part of geologic time.

The ignimbrite thickens from west to east and is more highly welded and glassy at the southeastern end of the Juniper Butte area, so as to suggest that the vents were probably located east or southeast of the Juniper Butte area.

The deposition of the overlying gravels was a continuation of the deposition of the basal gravels and perhaps should not be considered separately, for the welded tuff is an intervener in an otherwise unbroken sequence of gravel deposition.

Age and Stratigraphic Relations

The Rattlesnake gravels lie with a distinct angular unconformity on older beds. The gravels lie on truncated Mascall and John Day tuffs and abut against Columbia River basalt. In the southwest corner of the area, the gravels lie on Clarno volcanics.

A small, local flow of basalt conformably overlies the fanglomerates in the SW$\frac{1}{4}$ sec. 24, T. 12 S., R. 23 E.

Fossil plants, collected from the Rattlesnake formation by Wilkinson and his students during the summer of 1947, enabled Chaney (7, p. 1367) to date the formation as middle Pliocene. As the underlying Mascall formation is upper Miocene, lower Pliocene was a time of erosion in the Juniper Butte area.

Although some deposition of the gravels has continued to the present, erosion has been the dominant process since late upper Pliocene or early Pleistocene.

Basalt Intrusives

Olivine basalt intrudes the Rattlesnake formation as a small plug and an arcuate dike, from which extends a thin local flow; the dike and plug were emplaced presumably about the same time. The dike and flow are located in the SW$\frac{1}{4}$ sec. 24, T. 12 S., R. 23 E.; the small plug is in the SE$\frac{1}{4}$ sec. 23, T. 12 S., R. 23 E.

Outcropping at the top of a large conical hill, the arcuate dike is about 35 feet wide; its sides are vertical. The outer, or south-facing, side of the basalt arc stands about 45 feet above the gravel that forms the south slope of the hill.

In the middle of the arc, fractured John Day ignimbrite crops out, at an elevation of about 4200 feet. Similar, undisturbed ignimbrite crops out along the western edge of the valley of Fort Creek at an elevation of about 3920 feet. Therefore, the arcuate dike has carried a large fragment of ignimbrite a vertical distance of about 290 feet. On the slope below, small angular fragments of the light yellow ignimbrite that have weathered from the outcrop at the top of the hill are quite conspicuous against a background of black basalt detritus.

The basalt flow, which is about 25 feet thick, was extruded upon a gravel surface slightly domed by the intrusion of the basalt dike. For this reason the initial dip of the basalt flow is 10-15 degrees. The flow has coarse columnar jointing; the joints are spaced about 3-6 feet apart.

The basalt plug crops out at the top of a small hill. The plug, roughly circular in plan, is steep-walled but slopes of gravel around the plug make the hill conical in shape. The basalt is cut by a cross-thatch of vertical joints; the blocks which have resulted from the jointing have slumped apart, leaving spaces of three to four feet between adjacent blocks. The dark reddish brown rock has numerous small, rounded pebble inclusions that probably were plucked from the Rattlesnake gravel. The inclusions are resistant to weathering so have been etched into relief.

The basalt must have reached the surface as a viscous, gas-charged mass because the rock is very vesicular, the groundmass is very fine-grained, and no evidence of a flow was found.

The magma forced its way through the gravel and reached the surface, but had cooled sufficiently to be able to maintain its mass; that is, unlike the arcuate dike which was fluid enough to pour out a flow after breaching the surface, the plug breached the surface as a plastic blob. Release of pressure as the magma neared the surface allowed juvenile gases to expand as indicated by the vesicular texture of the rock.

A fault about three-fourths of a mile to the east has displaced Rattlesnake ignimbrite and gravel. If extended westward, the fault intersects both the arcuate dike and the plug. Although the fault may not extend so far to the west, a zone of weakness may have served to localize the intruding magma. However, the alignment of the intrusives with the fault seems too nearly perfect to be coincidence.

Lithology

Basalt specimens from the dike, flow and small plug will be described. Although presumably related genetically, the basalts exhibit textural and structural differences. The mineral assemblages are the same.

-Dike Basalt-

Megascopic

The dike consists of a medium light gray (N6), fine-grained, compact, finely porphyritic olivine-augite basalt. The surface of the sub-conchoidal fracture is slightly rough.

Microscopic

The essential minerals are plagioclase (64%), augite (19%), and olivine (10%). Magnetite (6%) is an accessory mineral. These minerals occur in two generations. Iddingsite and hematite are the only prominent alteration products.

Randomly oriented subhedral laths and slightly larger anhedral crystals of labradorite with interstitial subhedral magnetite, anhedral augite, and anhedral olivine constitute the groundmass. The texture is sub-granitoid because of the larger idiomorphic plagioclase crystals in the groundmass.

The olivine phenocrysts are the largest crystals in the rock; some are 1.2 mm but most are 0.3-0.7 mm wide. Along margins and cracks the mineral is altered to iddingsite. Some of the olivine in the groundmass has been almost completely altered. A part of the iddingsite has migrated from the olivine and lies as a film on the plagioclase.

Augite is light brown, non-pleochroic, and occasionally twinned. Some phenocrysts are 1 mm wide but the average size is about 0.5 mm. Augite is decidedly more abundant in the groundmass than in the first generation.

Phenocrysts constitute 7 percent of the rock.

-Flow Basalt-

Megascopic

The basalt is dark gray (N3), fine-grained, and slightly vesicular.

Microscopic

The flow, also an olivine-augite basalt, differs from the dike rock only slightly. The groundmass has smaller crystals and many more microlites of labradorite. The larger anhedral labradorite crystals are numerically unimportant. Microlites show incipient alignment.

The groundmass is holocrystalline, microporphyritic, and has an intergranular texture. Phenocrysts constituted about 9 percent of the rock.

The essential minerals, labradorite (61%), augite (22%), and olivine (9%), occur in two generations. Magnetite (8%), an accessory mineral, is limited to the second generation. Hydrothermal alteration of olivine to iddingsite has not progressed as far as in the dike rock.

-Basalt of the Plug-

Megascopic

The basalt is dark reddish brown (10R 3/4), very vesicular, and slightly porphyritic. Small phenocrysts of olivine and plagioclase can be seen. The fracture surface is very rough and uneven.

Microscopic

The olivine-augite basalt has an extremely fine-grained, magnetite-charged groundmass. Much of the magnetite has subsequently altered to hematite thereby coloring the rock. Olivine also is altered to hematite, rather than to iddingsite.

The hypocrystalline groundmass has an intersertal texture. A small amount of light brown glass provides the only variation in composition. Phenocrysts constitute only about 4 percent of the rock.

<u>Age</u>

The date of this volcanic activity can be stated reliably only as post middle Pliocene, but the lithology and stratigraphic position suggest that the rock may be related to the Ochoco basalt described by Wilkinson (31) and Brogan (4, pp. 117-120). The Ochoco basalt is dated upper Pliocene by Wilkinson, but Pleistocene by Brogan.

Quaternary Alluvium

Although the floors of most creek valleys are covered by gravel, only the larger areas of alluvium were mapped.

The alluvium consists of unstratified and unsorted sub-angular to sub-rounded boulders, cobbles, and pebbles loosely consolidated by a matrix of tuffaceous sand and silt. Most of the gravel is Columbia River basalt detritus but other formation also contributed.

Pockets of light colored andesitic ash are found in the gravel and on the hillsides. Nearly all the material is unconsolidated and probably has been re-worked. The ash fell uniformly upon the ground and was washed off the slopes into local depressions.

The ash consists of sub-angular to sub-rounded pumice fragments, glass, calcic andesine, and hornblende. The pumice, which constitutes about 85 percent of the material, has a refractive index of 1.510-1.512. Andesine crystals, which constitute about 10 percent of the ash, are broken but are very fresh. The dark green hornblende crystals are sub-rounded but have a low sphericity.

STRUCTURE

All pre-Pliocene formations in the Juniper Butte area are affected by regional folding. Faulting and slumping locally complicate the structure.

Folding

The Clarno formation was gently folded before the John Day tuffs were deposited. This folding may have formed a regional dome or a series of parallel folds similar to the present regional structure.

The area may have been folded again after the deposition of the John Day formation but confirming evidence is lacking. If the strata were folded at that time, deformation was slight.

Pre-Pliocene formations in the Juniper Butte form part of the southeastern flank of a broad, slightly assymmetrical anticline. The anticlinal axis, which trends northeast, is known from reconnaissance to be 5-8 miles north of the Juniper Butte area. This anticline is one of a series of swell-like, sub-parallel folds that dominate the structure of north-central Oregon. The fold, which developed after the deposition of the Mascall tuffs but before the deposition of the Rattlesnake gravels, probably was caused by compression.

On the southern flank of the anticline in the Juniper Butte area, Columbia River basalt has a regional dip of 5-8 degrees to the southeast. The Mascall tuffs are everywhere displaced by faulting that is younger than the folding; therefore, the dips of the tuff do not show the regional structure.

Undisturbed Rattlesnake gravels and ignimbrite abut against the flank of the anticline.

Faulting

Although a lower age limit for the faulting can be established, the upper age limit rarely can be defined stratigraphically. To facilitate description, three phases of faulting are recognized: post middle Pliocene, post middle Miocene, and post middle Miocene-pre upper Pliocene. Three separate faults and an area of step-faulting will be described.

Step Faults

In the extreme southeast corner of the Juniper Butte area, four high-angle, sub-parallel normal faults developed sometime after the middle Pliocene. The faults are recognized by repetition of beds, by scarps, and by displacement of the Rattlesnake ignimbrite rim rock.

The faults, which trend N. 50-65° W., are down-thrown on the northeast side. The acute angle between the strike of the faults and the strike of the anticlinal axis is about 65 degrees. The estimated displacement is about 500 feet, but subsequent erosion and the lack of a satisfactory marker stratum, except beside the two southern-most faults, make estimation uncertain.

Slickensides on a slumped block in the gorge west of the intersection of Mountain and Rock creeks indicate that Mountain Creek has followed a fault along this part of its course.

The faults may be the result of crustal adjustment required by the extrusion of great quantities of lava during the middle Miocene, but the length of time between the extrusion and the faulting argues against such a relationship. If the faulting were related to the extrusion, it should have followed the extrusion more closely.

Extensive slumping in this area has complicated the structure further.

Indian Creek Fault

Coleman (8, pp. 54-55) has traced an east-west trending normal gravity fault to the eastern margin of the Juniper Butte area. It seems likely that the fault continues along the course of Indian Creek, but an intensive search failed to yield confirming evidence. A dip of fifty-two degrees due north on the fault was measured by Coleman. He estimated a displacement of 700 feet.

The fault definitely can be traced to the east side of Hog Ridge but it is lost on the west side. The fault may die out at this point, but Indian Creek lines up well with a theoretical extension of the fault.

The Columbia River basalt is the youngest formation displaced; therefore, the date of the inferred fault can be assigned only to post middle Miocene.

Fort Creek Fault

A short, high-angle normal fault strikes N. 80° W. across Fort Creek about a mile west of the Antone road. The block on the north side of the fault has been down-thrown about 75 feet. Rattlesnake ignimbrite here serves as an excellent marker stratum.

As the youngest beds affected by the fault are the gravels of the Rattlesnake formation, the fault is post middle Pliocene. The short distance between the fault and the arcuate dike suggests a possible relationship of the intrusion to the faulting.

Fopiano Creek Fault

A high-angle, north-south trending fault enters the Juniper Butte area near the center of section 25, T. 11 S., R. 23 E., crosses Fopiano Creek, and continues southward along an intermittent stream valley for an additional mile and a half. The total length of the fault in the Juniper Butte area is about 2½ miles, but the fault continues an unknown distance northward.

Movement along the fault was probably rotational. The John Day formation, which has a regional dip of 7-8 degrees to the south, dips 13-15 degrees to the northeast in the area west of the fault. The west block has sunk more at the north end of the fault than at the south; consequently, the dip of the strata has been shifted from south to east.

The fault is known only to be post middle Miocene, for Columbia River basalt is the youngest formation affected by the faulting. The associated Rattlesnake ignimbrite dips five degrees N. 78° E., but this is probably an initial dip.

GEOLOGIC HISTORY

The geologic history of the formations exposed in the Juniper Butte area is essentially one of Tertiary volcanism. The history of the presumably marine sediments must be extrapolated from more extensive exposures in the Dayville and Mitchell quadrangles.

The recession of the Cretaceous sea marked the final appearance of a marine environment in north-central Oregon. Sediments laid in this sea were subjected to folding and erosion during the lower Eocene; by the time that middle Eocene vents breached the surface, the land had developed hilly topography, drainage courses had been established, and, except for the flora, the area may have looked much like it does now.

The extravasation of Clarno flows and the ejection of volcanic breccia during the middle Eocene initiated Tertiary extrusive volcanism in the Juniper Butte area. The lavas, extruded from time to time, eventually inundated the lower Eocene topography.

Even without uplift, the volcanics would have raised the surface of the ground sufficiently to rejuvenate erosion. However, regional folding is suggested by the angular discordance between the Clarno and John Day formations. This folding, combined with the great thickness of lava and pyroclastics, induced streams again to carve deeply into the land. For a second time in the Tertiary period, a mature topography developed.

The lower John Day formation does not crop out in the Juniper

Butte area. If the lower John Day formation was never deposited here, the upper Eocene and the entire Oligocene were erosional intervals.

During the lower Miocene, middle John Day tuffs were strewn across the Clarno volcanic hills and valleys. Rain washed the loosely consolidated pyroclastics from the hills into the valleys and basins, where thick deposits accumulated. Probably, the expulsion of the ash was intermittent and perhaps no one particular explosion yielded engulfing quantities, but the total volume, combined with re-working, produced very thick local accumulations of the tuff.

Deposition of the ignimbrite flow that caps the middle John Day required only a short time. Its expulsion must have been spectacular.

The second or upper-most rim rock, the altered tuff, probably was deposited in a very short time also. It may have been deposited as a unit, for it shows no trace of bedding or of an erosion surface within itself.

Upon a subdued surface produced by the filling of Oligocene valleys by lower Miocene ash, middle Miocene lava was extruded. This revival of extrusion resulted in one of the world's most extensive deposits of lava: the Columbia River basalt.

Baked soil layers between many of the flows indicate that some flows were subjected to weathering for extended periods of time before the next outpouring of lava.

The Juniper Butte area has a relatively thin sheet of Columbia River basalt; surrounding areas commonly have as much as 2500 feet of basalt, but the average thickness of the basalt in the Juniper Butte area is only about 1000 feet. The area was a highland during much of the lower and middle Miocene, but eventually most of the higher hills were flooded by the basalt. Perhaps only the hills in the northwest corner escaped inundation.

Cessation of lava extrusion was followed closely by a recrudescence of ash falls during the upper Miocene. The ash, along with silt and clay, collected in local depressions on the Columbia River basalt.

Although the Mascall tuffs lie with an angular discordance on Columbia River basalt, much of the discordance can be attributed to initial dips because the tuffs were deposited at the margin of a basin. In nearby areas the Mascall formation is conformable on the basalt.

The basal gravels of the Rattlesnake formation lie on beveled Mascall tuffs and abut against the southward-dipping Columbia River basalt. Such a contact indicates that erosion and regional folding preceded the deposition of the gravels. The Fopiano Creek fault may have developed concurrently with the folding.

Lower Pliocene folding not only produced the anticline that dominates the structure, but also a syncline to the south. Streams swept gravels, most of which came from highlands to the south, into this structural basin.

Upon this gravel much of the Rattlesnake ignimbrite was extruded.

The *nuee ardentes* was channeled into the structural basin; the cloud also invaded tributary valleys where thin, less welded outliers of welded tuff now are found. Gravel continued to accumulate on this new surface.

Like its predecessor in the John Day formation, the Rattlesnake ignimbrite represents only a minute part of geologic time.

The arcuate dike and plug were emplaced and most of the faults developed probably during the upper Pliocene. Deposition of the Rattlesnake fanglomerate very likely continued until the Pleistocene epoch. Then streams began to dissect the gravels.

During the Quaternary, the Juniper Butte area was showered by intermittent falls of andesitic ash. This ash was washed into pockets in stream channels and into local depressions on the hillsides. An alluvial veneer was deposited along parts of Rock and Mountain creeks (see plate IV), but erosion rather than deposition has been dominant during the Quaternary.

Pg. 69 attached separately

BIBLIOGRAPHY

1. Beck, George F. Fossil bearing basalts. Mineralogist 9:462-464. 1941.

2. Bedford, John W. Geology of the Horse Mountain area, Mitchell quadrangle, Oregon. Master's thesis. Corvallis, Oregon state college, 1954. 90 numb. leaves.

3. Bowers, Howard E. Geology of the Tony Butte area and vicinity, Mitchell quadrangle, Oregon. Master's thesis. Corvallis, Oregon state college, 1953. 152 numb. leaves.

4. Brogan, John P. Geology of the Suplee area, Dayville quadrangle, Oregon. Master's thesis. Corvallis, Oregon state college, 1952. 139 numb. leaves.

5. Calkins, Frank C. A contribution to the petrography of the John Day basin. University of California publications in geological sciences 3:109-172. 1902.

6. Chaney, Ralph W. Age of the Clarno formation. Proceedings of the Geological society of America for 1935. p.358. 1936.

7. ______________. Pliocene flora from the Rattlesnake formation of Oregon. Bulletin of the Geological society of America 59:1367-1368. 1948.

8. Coleman, Robert G. The John Day formation in the Picture Gorge quadrangle, Oregon. Master's thesis. Corvallis, Oregon state college, 1949. 211 numb. leaves.

9. Collier, Arthur J. The geology and mineral resources of the John Day region. Mineral resources of Oregon 1:3. 47p. 1914.

10. Dawson, John W. Geology of the Birch Creek area, Dayville quadrangle, Oregon. Master's thesis. Corvallis, Oregon state college, 1951. 98 numb. leaves.

11. Dobell, Joseph P. Geology of the Antone district of Wheeler county, Oregon. Master's thesis. Corvallis, Oregon state college, 1949. 98 numb. leaves.

12. Fuller, Richard E. The Asotin craters of the Columbia River basalt. Journal of geology 36:56-74. 1928.

13. Green, Morton. Review of the stratigraphy of the John Day formation in Oregon. Bulletin of the Geological society of America 61:1538-1539. 1950.

14. Jensen, J. Granville. Climate types. In Atlas of the Pacific Northwest resources and development. Ed. R. M. Highsmith, Jr. Corvallis, Oregon state college. 1953. pp.11-15.

15. Knowlton, Frank Hall. Fossil flora of the John Day basin, Oregon. Washington, U.S. Government printing office, 1902. 153p. (U.S. Geological survey. Bulletin 204)

16. LeConte, Joseph. The theory of the formation of the great features of the earth's surface. American journal of science and arts 4:360-372. 1872.

17. Lindgren, Waldemar. The gold belt of the Blue Mountains of Oregon. U.S. Geological survey, 22nd annual report, part 2:551-576. 1902.

18. Mansfield, G. R., C. S. Ross. Welded rhyolitic tuffs in southeastern Idaho. Transactions of the American geophysical union 16:308-321. 1935.

19. Marsh, O. C. Ancient lake basins of the Rocky Mountain region. American journal of science 109:49-52. 1875.

20. McIntyre, Loren B. Geology of the Marshall Butte area and vicinity, Mitchell quadrangle, Oregon. Master's thesis. Corvallis, Oregon state college, 1953. 96 numb. leaves.

21. Merriam, John C. A geologic section through the John Day basin. Journal of geology 9:71-72. January-February 1901.

22. ______________. A contribution to the geology of the John Day basin. University of California publications in geological sciences 2:269-314. 1901.

23. ______________., and William J. Sinclair. The correlation of the John Day and the Mascall. Journal of geology 11: 95-96. January-February 1903.

24. ______________., and ________________. Tertiary fauna of the John Day basin. University of California publications in geological sciences 5:171-205. 1908.

25. Russell, Israel Cook. A geological reconnaissance in central Washington. Washington, U.S. Government printing office, 1893. pp.13-108. (U.S. Geological survey. Bulletin 108)

26. Schultz, C. Bertrand, Charles H. Falkenbach. Promerycochoerinae, a new subfamily of Oreodonts. Bulletin of the American museum of natural history 93:73-197. 1949.

27. Stirton R. A. A rhinoceros tooth from the Clarno Eocene of Oregon. Journal of paleontology 18: 265-267. May 1944.

28. Swarbrick, James C. Geology of the Sheep Mountain area and vicinity, Mitchell quadrangle, Oregon. Master's thesis. Corvallis, Oregon state college, 1953. 102 numb. leaves.

29. Taubeneck, William H. Geology of the northeast corner of the Dayville quadrangle, Oregon. Master's thesis. Corvallis, Oregon state college, 1950. 155 numb. leaves.

30. Waters, Aaron C. Multiple dike feeders of the Columbia River basalt. Bulletin of the Geological society of America 61:1533. 1950.

31. Wilkinson, W. D. Geology of the Round Mountain quadrangle, Oregon. Oregon, State department of geology and mineral industries, 1940. 1 folded page. (A geological map with text, tables, and bibliography)